Australian Fish Farmer

SECOND EDITION




A PRACTICAL GUIDE TO AQUACULTURE

John Mosig and Ric Fallu

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Also available from Landlinks Press: *The Australian Yabby Farmer* by John Mosig

Dedication

The authors would like to dedicate this edition of the *Australian Fish Farmer* to the memory of Richard Carson. Richard's passion for fish was legendary. His knowledge of water chemistry and its mysterious behaviour when combined with growing aquatic organisms was unsurpassed. This gift of his knowledge was passed on freely to anyone who was wise enough to listen.

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Introduction

This book is about taking the first steps in aquaculture. You've already taken the first step. You've bought this book.

This is the second, and revised, edition of *The Australian Fish Farmer*. The authors would like to thank anyone who is buying it for the second time and would like to assure them that they won't be disappointed. Much has happened in Australian aquaculture over the intervening years and the text revision has been major. New species are being cultured, new diets developed and new husbandry methods proven.

For new readers, could we suggest you read the whole book through first to get an overview of the subject. The chapters have been based on years of developing practical training programs. They will take the reader through the overall thrust of aquaculture, the nuts and bolts of the industry and how they are put together to create a commercial operation. They outline the different phases, from the highly technical hatchery phase to the daily routine of the production phase to the high excitement of marketing.

First of all, aquaculture is not rocket science, although it is based in science. The rules of genetics, water chemistry, nutrition and biology are the parameters within which we, as practicing fish and crayfish farmers, have to operate. How we, as farm and business managers, work within those boundaries will determine how successful our enterprise becomes.

The views and methods expressed in these pages are based on our own experience, observations and accepted industry practices. We have put this information into book form to help steer prospective and practicing aquaculturists in the right direction.

Aquaculture is multi-faceted and anyone who thinks they can push aquaculture in the direction they want it go is kidding themselves. We see, too often, people coming into aquaculture trying to make it what they want it to be, rather than what it is. One thing this book should leave you with is the knowledge of what aquaculture is.

To call the book 'Fish farming made easy' wouldn't be honest, because like all things in life worth doing, it's not. What we have tried to do is simplify fish farming. We feel that we have achieved this. We hope you feel the same after having read it.

The three tenets of **The Australian Fish Farmer** are to:

- expose the reader to the many opportunities that exist in aquaculture;
- alert them to the many pitfalls; and
- develop enough confidence in the reader's aquaculture judgement to make their own informed aquaculture and commercial decisions.

If this book does nothing more than this, it will have succeeded.

Good luck and good fish farming.

John Mosig and Ric Fallu

Acknowledgments

The Authors don't claim to have all the answers, but between them they pride themselves that they know where to get them. In compiling this book they have called on the accumulated knowledge of a wide range of industry personnel and would like to thank and acknowledge their contribution to this compilation.

Bill Wiadrowski of Natural Balance Pet Foods made a major contribution. His knowledge of animal nutrition and how it works is unsurpassed in this country and the authors were honoured to be able to borrow extensively from his Warmwater Aquaculture Course nutrition talk.

Dr Alistair Brown is one of that small but tireless army of fish vets easing the mind of worried fish and crayfish growers. Alistair read the fish health pages and offered constructive criticism, all of which was gladly incorporated.

Dr Stuart Rowland of the NSW Fisheries Service allowed us to draw on his knowledge and publications. His contribution to the aquaculture industry cannot be overestimated.

Fish vets are thin on the ground and two worthy of mention; John Humphrey, fish vet extraordinaire, now sadly lost to more lucrative occupations healing small animals in the UK; and Dr Grant Rawlin, another selfless fish vet, have offered their help and advice over the years.

Industry personnel offered their experience and accumulated knowledge without question, among them:

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Bill Keast of the Queensland Crayfish Farmers' Association
Bruce McInnes of Wartook Native Fish Hatcheries
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Cris Phillips of Barramundi Waters
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Nick Ruello of Nick Ruello & Associates
Peter Van Lierop of Australian Aquaculture Systems
Rick Datodi of Aquarium Industries
Rod Missen of RAD Aqua

But there are more who have contributed in so many ways over the last quarter century who shall remain unrecognised in this Acknowledgment. The authors would like to thank those unsung pioneers of Australian aquaculture who by their efforts, successful or otherwise, coloured the message contained in these pages.

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Contents

1

What makes aquaculture work?

This chapter is about the key components that drive aquaculture and make it work. Topics covered include:

- the importance of control over the whole system
- the influence and need to identify limiting factors
- how to maximise your production outcomes
- genetics
- water quality
- the environment
- husbandry
- nutrition.

Before we discuss what makes aquaculture work we should define aquaculture. *Aquaculture is the production of aquatic organisms under controlled conditions.*

The commercially minded might like to add: 'the purpose of aquaculture is to produce aquatic organisms in an efficient manner so that the operator can make a profit'.

Sure, the fish are important, but the water quality and the matters that influence the stability and balance of the system are what you are managing. The fish are what you are growing. In other words, the reason you are managing those inputs is to achieve an outcome of having market-quality fish to sell. For management purposes, it is sometimes helpful to separate the two in your mind. You can't achieve the latter without paying complete attention to the former.

In its purest form, aquaculture is intensive animal production, not far removed from intensive pig and poultry production, and in that sense a lot of the groundwork has already been done over the last 30 years by those food-producing sectors.

The key to aquaculture is *water quality management*. Get that right and many of the potential problems are minimised. The degree of control an operator has over water quality will determine the degree of control he or she has over the production from any given body of water.

Strictly speaking, rice growing is aquaculture, but this book will deal with the options offered by farming what is loosely called 'seafood': finfish, crayfish (crustaceans) and shellfish.

Aquaculture can range from a laid-back managed fishery to a full-on intensive animal production unit. The aquaculturist determines the level of the intensity. This book will cover the practical aspects of aquaculture production.

Once the practicalities are under control, the farmer has to look at the marketing side of aquaculture. Part of the art of farming is balancing the risks against the odds and the costs, and the more ways of monitoring the production trends the grower has at their disposal, the more accurate the predicted results will be. And from a marketing point of view, this is what it's all about: knowing what you've got to sell at a given time in the future.

One point we would like to make though is that this book is a textbook, not a manual. Our purpose is to help you develop sufficient confidence in your own aquaculture judgement to be able to write your own manual for your own circumstances and your own management style.

What is a fish farmer?

Aquaculture is the art of culturing aquatic organisms. However, running a fish farm is a business and should be structured and operated as one. We cover all the elements of fish farming from setting up the business plan, through construction of the ponds, administration, post-harvest handling and preparation for sale to the actual marketing of the product.

We've included a description of a fish farmer so you'll be able to grasp how many people you'll have to be during this phase of your life. The following has been borrowed from the training notes of the *Introductory Course in Commercial Warmwater Aquaculture* (Aquaculture Services Australia Pty Ltd 1995). It later appeared in a column that appeared in *Austasia Aquaculture*, the national trade periodical, and takes a humorous look at 'What is an Aquaculturist?' by comparing the skills required by one person or family with the skills expected of a team of cricketers. The purpose was to highlight the range of attributes needed for the operation of a successful fish farm.

> If you were in charge of the local cricket team you'd look to recruit players with natural ball skills and the ability to play in a position in which the team is weak. So, let's look at recruiting an aquaculture team. Just like a cricket team, an aquaculture team has specialist positions that serve to make up team balance.
>
> Aquaculture is about growing things in water so the first people we would pick for our champion aquaculture team would be the water experts: a plumber, a sewerage plant manager and an irrigation farmer. This group can be likened to the bowlers in a cricket team: if you can't bowl the opposition out twice you can't win. If your water quality can't be maintained the game's over: you lose.
>
> The sewerage plant manager would have the skills to maintain water quality under the most overloaded conditions imaginable. He's our strike bowler. Holding the water quality at a level that would maximise natural food production yet still maintain the water at a quality in which fish will thrive would be a piece of cake for someone with the training and experience of a sewerage plant manager.
>
> The plumber would rig and maintain the plumbing in the purging/holding room and the hatchery, should one be part of the operation. The fish are at their most vulnerable when handled in high densities. It is important that the water management here is first class and is supported by back-up systems in case of breakdowns. Oxygen supply to the tanks is also critical and the plumber could take this on. Naturally, this team member would be invaluable should you be growing fish in a re-circulation system.

The irrigation farmer would be experienced in moving large volumes of water without which the grow-out ponds are inefficient. The plumber and the irrigation farmer would probably overlap in a few areas, which is what team play is all about really.

When it comes to system design, you may need some skills coaching from the earth-moving contractor, the re-circulation system designer or a surveyor for farm layout, or all three.

Fish farming is intensive animal production so we would select someone from the pig or poultry industries, as they would have the experience in this field. We are running a fish production unit so there should be an emphasis on production. This person is our opener. It is from here that the foundation of the innings is laid.

To play alongside the production manager we would select an inland angler: one who gets a feed whenever he goes out, one way or the other. This left-hand, right-hand combination would complement each other: the orthodox production manager would have the understanding that fish have to eat a balanced ration to grow and the more they can be made to eat, the more they will grow. The angler, on the other hand, would know that they may need a little coaxing and a little pampering to get them to eat as well as having a good feeling for the preferred comfort zone of the various species and their natural feed preferences. The team would rely on these two to produce the bulk of the early runs.

Nutrition is a specialist skill so we turn again to the specialist coaching skills department if we feel that we're not up to scratch in that area. The feed industry has, or should have, nutritionists on the staff to help us with our run scoring technique.

Then there's the heavy work: someone to bowl uphill into the wind all day to tie up an end; someone to hold off a hostile pace attack while the last recognised batsman secures the innings; someone to belt a quick 35 at the end of the innings. Somewhere on the team there will have to be players who can lift full tubs of water and fish while slogging through deep mud and up slippery banks. Some of the bullocking work can be removed from the system by innovative engineering but at any given time the work can be back breaking. Hauling nets will wrench your body out of shape in next to no time.

The erection of predator control netting requires the skills of a good fencing contractor at worst, an engineer at best, so we've got the talent scouts out for either of those, although a skills coach can be hired for this specialist short-term position.

Regular maintenance of motors, vehicles and equipment demand the attitude and knowledge of a mechanical engineer: the keeper. There's nothing more time consuming than having to run into town every time something breaks down; like chasing a ball down to the fence every time it gets past the bat. And the little bits and pieces of off-the-shelf equipment that make life easy in other farming pursuits aren't always available for aquaculture, so there would be a place in the team for an all-rounder: an innovative engineer; part bush mechanic, part bush carpenter, part Thomas Edison. In fact, ingenuity in all aspects of fish farming is something the coach should be instilling in the members of the team.

And speaking of the coach, this aquaculture cricket team of ours will also need a captain, a coach and a manager. Someone has to be in control of the day-to-day play, someone has to have an overview to plan strategy and someone has to hold it all together and make sure the players get to bed early and that all the gear is aboard the bus in the morning. The day-to-day problem solving and the development of the planning phases of the project will fall to this group. Without it the team is a bloody shambles.

The on-field team is only as good as the club it represents, so we'll need to have in place a sound club administration so that the club is also financially successful. Someone to run the fund raisers, take care of the catering, sell the tickets to the games and market the image of the club in order to increase membership. This is the aquaculture equivalent of the growers' association.

You may not be particularly gifted in each of these skills, but as long as you are aware of their importance you can learn the basics required to get you out of trouble; or more to the point to keep you out of trouble in the first place. Ask yourself how many of the places in the team you can fill off your own bat, and then consider who you would pick for the vacant positions.

Why would you go into aquaculture?

Basically there are no other species on this planet that will produce protein for human consumption more efficiently than fish. Nor, as nutritionists are discovering, is there a healthier form of protein. Omega-3 fatty acids, found in seafood, are claimed as a cure for everything from arthritis to mental wellbeing.

As cold-blooded animals, fish don't require energy to maintain body temperature.

Being suspended by flotation bladders they burn up very little energy maintaining their vertical position compared with, say, a cow or a sheep; nor do they burn a lot of energy moving about in search of food and water.

This energy efficiency means that they are able to devote a good deal of the energy they consume to building body tissue and muscle. Food efficiency is measured in terms of food conversion ratio (FCR). The FCR quantifies the amount of food used to produce a unit of weight, usually a kilogram. It is expressed as a ratio to one. So a fish that eats 1.5 kg of food to produce 1 kg of weight gain would have an FCR of 1.5:1.

To provide some idea of how efficient fish are at converting food to saleable product, compare their FCR with that of other intensively farmed animals. In a feedlot, a steer converting at 10:1 will lose the grower money; 8:1 is considered the industry benchmark and 6:1 very good. Well-managed pigs in a temperature-controlled environment will convert a properly designed diet at the rate of 2:1 and chooks at 1.6:1. Fish under commercial conditions are considered efficient at 1:1 to 1.2:1. Anything above 1.5:1 in an intensive operation is regarded as borderline and anything above 2:1 as sub-economic. In efficient re-circulation systems under good management, some species have recorded better than 0.8:1 and a feed conversion efficiency of 1:1 would be considered the norm.

There is a downside to this. Fish diets are generally more than double and sometimes triple the price of those designed to feed monogastric animals or ruminants. However, this is compensated for by the value the market places on seafood.

Because of their natural tendency to school, fish can be produced at high densities thus enabling the fish farmer to produce a large volume of product from a small area.

As we touched on previously, fish have a very high acceptance in the market place. In fact some of the species cultured are amongst the luxury items on the dinner table. This is not necessarily a good thing as it tends to give a false impression of the realities of aquaculture and it can build up people's hope of a new rural boom. Make no mistake – aquaculture is hard work. It's farming in water, nothing more, nothing less. As long as we remember that, we can't go far wrong.

It is only fair to ask the opposing question: 'Why not aquaculture?' The answer should be obvious: if it were easy, we'd all be doing it. Aquaculture is a high-risk occupation. As we shall discover, water is a dynamic and volatile environment in which to farm. The aim of this book is to provide an awareness of the risks involved and develop in the reader knowledge of how to minimise their impact.

How do you make aquaculture profitable?

The only proven way to culture aquatic organisms for profit is by following the basic principles of aquaculture and applying them to the business of running a fish farm.

The principles of aquaculture are based in science. Therefore the fish or yabby farmer has to operate within the boundaries imposed by the lores of biology, water chemistry and nutrition. The aquaculturist will have to know the scientific limitations these lores impose on his operation.

The product being grown is a live animal and as temperamental as any living organism. In some cases the aquaculturist has to keep more than one species thriving at the one time. In the case of a species dependent on live food, such as raising silver perch larvae or yabby juveniles, the grower will be managing a plankton bloom at the same time as a growing crop. The operator of a re-circulation unit will also be keeping two groups of organisms going: the fish in the tanks and the bacteria driving the nitrification cycle in a bio-filter. This can take some doing and demands hands-on management.

Then there's the running of a business. While the commercial influences on the farm are dynamic and require adaptable management, recording and analysis entails painstaking care in recording and reviewing the day-to-day inputs of farm and stock management. This calls for flexibility, practicality and thoroughness. The marriage of those three qualities underwrites the success of the aquaculture enterprise.

What are the areas that influence production?

An area of influence is any point of the production process where a variation of conditions will influence the level of efficiency of the production unit.

As you will find, it is important to our management that we keep the areas of influence separate in our thinking. These areas of influence can be divided into five components:

Genetics: A fish can only perform to the maximum level of its genetic capability.

Water quality: Nothing stresses fish quicker than poor quality water. The maintenance of water quality is critical to the success of your fish farm.

Environment: The environment or climatic conditions: being cold-blooded animals, fish activity is governed by the ambient temperature.

Husbandry: Husbandry is the art of keeping your charges within the confines of their preferred comfort zone. This includes keeping them apart from predators and monitoring their health. It can also be described as the removal of stress from your production system. This is the area in which farming ability has the most influence. It is the area in which you will find most of your limiting factors, and is the area in which the farmer must take total responsibility.

Nutrition: The growth and wellbeing of any animal is greatly determined by their diet, and fish farming is no different. Diets must be designed to suit, as closely as possible, the nutritional profile of the animal being raised.

These five areas of influence are interdependent and an element that has a direct influence on one area is likely to have an indirect effect on one or more other areas. For instance deteriorating water quality will stress the fish, which in turn will reduce their appetite; a poor appetite will leave food uneaten in the system, thus further negatively influencing the quality of the water.

To further confuse the issue, the deteriorating water quality may be caused by feeding an inappropriate ration in the first place. This will create a situation in which some of the feed will be staying in the fish but a large percentage will be passed through the fish into the water as nutrient. This in turn will feed a plankton bloom that the grower has to manage or face deteriorating water quality.

A change of diet, a sudden weather shift, or the presence of predators could have the same effect on the fishes' appetite and, ultimately, water quality, so you can see how important it is to recognise any change in pond behaviour and be able to identify the direct cause.

What are the factors that limit production?

A limiting factor is an element negatively influencing the performance of the systems, thereby limiting their output. The effect of a limiting factor may be found in more than one of the areas of influence but it will have a primary point of influence.

The most limiting factor in the chain of production will determine the level of efficiency of the whole unit.

For instance: if the genetic potential of the fish, through selective breeding, has been improved to 85% of what it could be; water quality management is spot-on at 95% of pure; the season is favourable with an early spring warm-up, a steady summer without too many heat waves and thunderstorms, followed by a beautiful long calm autumn, let's say 80% of optimum; and the husbandry has the fish thinking that they're in piscatorial heaven at 90% of what they would regard as ideal; but the nutrition is El Cheapo and only 50% of the nutritional value of the feed stays in the fish, the output of the whole operation would be 50%; and all the effort to bring the other areas of influence up to best-practice level will count for naught.

In fact the outcome would be less than 50% efficient, because the downward pressure the poor quality feed would place on water quality would, at some stage, make water quality the lowest common denominator overriding the influence of the poor quality feed.

As mentioned in the Introduction, aquaculture is complex, and keeping all the balls in the air at the one time is a challenging task on its own, without trying to hop on one leg blindfolded. Stick to the rules established over time and concentrate on removing limiting factors from your production system. Experimentation may be exciting, cutting-edge stuff, but it's a gamble, and while it could be said that you don't get anywhere without taking risks, consolidate the farm first.

What is the production manager's role?

The role of the production manager can be defined as the art of getting the charges in his or her care to grow into healthy, marketable specimens as economically as possible.

The production manager is one of the most important people on the farm. It is their responsibility to produce the stock, the sale of which provides the reason for the farm existing in the first place.

What does the production manager do?

The daily routine of the production manager is made up of problems: problem prevention; problem identification; problem solving, and (as your expertise and confidence grow) problem anticipation.

Problem prevention

Problem prevention is based in planning and depends on sound knowledge of the areas that can present problems. The two things that will most concern the production manager are loss of production and loss of stock. The source of these headaches is usually poor water quality, poor nutrition and stress. Discounting predation, which is due to poor planning, and inefficient feed, which is due to poor understanding of nutrition, most problems can be prevented if the possible source of poor water quality and stress are considered in the planning and operational stages.

Problem identification

This is the art of husbandry. In most cases what you can best identify are the symptoms, but with experience you will become competent in identifying specific problems.

Symptoms can be related to any number of causes but an easy way to isolate the cause is to trace it back to its area of influence. Look systematically at each area of influence. To give an example:

Symptom: slowing of the growth rate although the fish appear healthy and vigorous.
Possible causes:

Genetics? Could be the case if seedstock of the same species, but from different broodstock, are performing better under similar circumstances. If the slowing growth rate is due to normal slowing due to the fish moving into a more mature stage of their development within the normal production cycle then the cause is unlikely to be genetic.

Climatic? If the temperature moved outside the species' preferred range, this is likely to be a contributing factor, if not the only reason. Unless water temperatures have moved above or below the stress levels, fish will appear normal although their metabolism will not be functioning as efficiently as it would if temperatures were closer to their optimum ranges. That their feeding rate has fallen away somewhat would be an indicator of a thermal influence on the fishes' activity level. Sudden shifts in climatic conditions, such as a severe frost or a summer cold spell, can also have an adverse effect on appetite. Fish love stability.

Water quality? Fish will lose their appetite in poor quality water and usually show signs of stress as the conditions deteriorate. The circumstances under investigation could be an early warning sign to an impending critical water quality problem. Dissolved oxygen levels may be low, thus depriving the fish of a key ingredient for growth.

Husbandry? Crowding beyond the preferred social density of the fish is a common cause of uneven growth rates and stunting. A given number of small fish in a given space may not be overcrowded, whereas the same number of larger fish in the same space is. Take a closer look at the fish. Put some scrapings from the scales under the microscope; there could be a health problem looming. The gills may be damaged by bacterial outbreak. The fish generally know before you when they're feeling under the weather and go off their feed before they show symptoms of deteriorating health. This is not unlike the sore throat that heralds an oncoming cold in humans. Our health doesn't take a nosedive until the cold hits properly, but we can feel the onset and dread the outcome. Then again it could be the presence of predators putting the fish off their feed as they're usually skittish if predators are about. As we said before, this is the area in which you will find most of your limiting factors.

Nutrition? A slowing in growth rate without signs of stress could be attributed to a falling off in the nutrient value of the food, due to poor storage or a change in manufacturer. The fish may not be getting enough food, or, if relying on natural food, there may be a reduction in the available nutrition.

Problem solving

Problem solving is self-explanatory. If you can't solve it yourself, don't be afraid to seek expert advice. You could ask another, more experienced fish farmer, a government Extension Office or Fisheries scientist, a veterinarian or perhaps an animal nutritionist.

Problem anticipation

Problem anticipation is also self-explanatory. It is the single most cost-effective procedure on the farm. Recording the results of daily monitoring procedures, such as pH and dissolved oxygen trends, and observations, such as signs of the presence of predators, will go a long way towards enabling the production manager to stay on top of things.

As an example of observation: the discovery of a leaky pipe would allow the problem to be corrected before the whole bank collapses or a tank drains out overnight.

As an example of monitoring: in the case of water quality breakdown, there are signs of progressive deterioration and we'll talk about them later in great detail.

The importance of water quality management

It would not be possible to talk about aquaculture without mentioning water quality management. *Water quality underwrites the success of everything we do in fish farming* and we'll be referring to it constantly.

How are the fish managed so that they grow?

Nutrition is the key to growth.

The first tool the production manager must have in this phase of the operation is an understanding of what makes animals grow. The only way to make fish grow is to get them to take in more nutrition than they require for daily activities and body maintenance. The surplus nutrition is thus translated into growth. Achieving this with the least possible fuss and the least possible cost without compromising water quality is critical to the success of the operation.

The other aspect of nutrition is that it must be made up of, as close as possible within the confines of the knowledge of the time, the nutrient profile of the species being cultivated. We'll be looking more closely at this and other aspects of feeding and nutrition in chapter 9.

A stress-free environment is essential for fish growth. A happy fish is a feeding fish; and a feeding fish is a growing fish. The numerous and varied factors relating to stress in your fish-growing systems will form an undercurrent throughout these chapters.

What are the tools of a successful production manager?

A production manager will use tools that are simple and relatively inexpensive. We'll talk about these in more detail later but we want to touch on them now so you aren't tempted to rush into any rash purchases.

- The first and most valuable artificial aid to aquaculture production is a pen and notebook. Record everything that you observe and monitor. The data can be transferred to a computer program later.
- Plankton net. This can be of the cast and haul variety or the hand-held shrimp net you will get from an aquarium shop. This will give you a cross-section of what's living in your production system apart from fish.
- Maximum–minimum thermometer to record periodic temperature movements.
- A pH meter to record changes in pH.
- A dissolved oxygen (DO) meter to measure the amount of oxygen available in the water for the fish.
- General and carbonate hardness, phosphorus, ammonia, nitrite and nitrate test kits to measure the amount of these parameters in the water.
- A 20 to 40 power microscope will prove to be more than useful when examining fish and crustacean's gills, skin and organ tissues, and when viewing other pond life such as plankton. However, being able to magnify up to 400 magnification would provide a much better view of many of the items you'll find in aquaculture.

Doubling – the power of prediction

Doubling is one of the handiest tools in the fish farmer's kit. It will enable the grower to monitor growth performance in a meaningful way as well as project target dates.

'Doubling time' is the term used to describe the time it takes for a fish to double its size. For instance, if a silver perch is 100 g at the beginning of the month and 200 g

47 days later, it has been growing at the rate of 1.5% per day. This is called the Specific Growth Rate (SGR).

A 1 g fish will undergo nine doublings to reach 512 g. At a constant growth rate of 1.5% daily it would take 423 days. But it doesn't quite work like that. Fish naturally grower quicker when they are younger and may well be increasing at an SGR of 5%, from 1 g to say 32 g. This would give them a doubling time of 14 days for the first five doublings, or, in terms of days, it would reduce the growing time over those first five doublings by 165 days.

The calculations in simple terms go like this.

- From 1 g to 32 g is five doublings
- At an SGR of 1.5% the fish would take 47 days to double their weight. Therefore they would take 235 days to reach 32 g from 1 g.
- At an SGR of 5% the fish would take 14 days to double their weight. Therefore they would take 70 days to reach 32 g from 1 g.
- Saving in grow-out time = 165 days.
- From this example it can be seen what a valuable tool doubling is as a yardstick of the crop's progress. This of course assumes optimum conditions during the entire growing season. This rarely occurs, except in the case of fish grown in environmentally controlled re-circulation systems.

By knowing potential growth rates and being able to monitor actual growth rates, the fish farmer is able to determine how far behind or ahead of schedule his stock are. This is crucial information in relation to assessing the status of the business at any given time or projecting it into the future.

Time lost by not maximising production opportunities is never recovered; and the most expensive time lost is when the fish are at their maximum SGR potential.

Table 1.1. Days of growth required to double the size of fish at a given daily weight gain.

Percentage of body weight	Doubling period in days
5%	14
4.5%	16
4%	18
3.5%	21
3.0%	24
2.75%	28
2.25%	32
2%	35
1.75%	41
1.5%	47
1.25%	53
1%	72
0.75%	93
0.5%	139

This chart can be used to calculate the average SGR over the period in which it takes to double its size. For example: a fish that takes 35 days to double its weight will have a daily weight gain of 2% of bodyweight.

It can also be used to estimate the time it will take to bring a fish to a certain size if the SGR is known. For example: if a grower has a pond of 250 g fish growing at an SGR of 1.25% it will take him or her 106 days to get them up to 1 kg.

The time taken to double in size can be seen to increase dramatically as growth rates slow. This is why monitoring these parameters of nutritional uptake and growth is so important in a production-based industry.

SGR calculations

To calculate the specific growth rate (SGR) as a percentage of body weight gained on a daily basis from measurements taken over any given time, the following formula can be employed. For practical purposes, the SGR would be calculated as a series of short-term calculations, such as weekly, because the plotted results would graph as an exponential decay curve.

A general formula for calculating SGR is:

SGR = (W2 ÷ W1) to the power of (1 ÷ n) –1 x 100

where: W2 is the end weight in grams
W1 is the starting weight in grams
n is the time in days

For example: if a fish weighing 5 g weighed 10 g in 30 days, the gain in weight as a percentage of body weight as an average gain over the period would be calculated as follows.

SGR = (W2 ÷ W1) to the power of (1 ÷ n) – 1 × 100
= (10 ÷ 5) to the power of (1 ÷ n) – 1 × 100
= 2 to the power of (1 ÷ 30) – 1 × 100
= 2 to the power of 0.03333 – 1 × 100
= 1.0233 – 1 × 100
= 0.0233 × 100
= 2.33%

You can always simplify matters by just multiplying the difference in weights over the given period by 100 and dividing the answer by the starting weight, but this will only provide the percentage gain over the given period, be it a week or a month, which is not quite the same as daily average weight gain.

Food Conversion Ratio

Food Conversion Ratios or FCRs are another important tool in the kit. It refers to the weight of food required to produce a single unit of fish. The most common unit used around the world is the kilogram. So if a fish consumes 1.5 kg of food to produce 1 kg of muscle and bone the FCR is 1.5:1. An FCR of 1.5:1 is regarded as an industry benchmark. If you aren't approaching or bettering that mark there's something wrong somewhere, either with the food, with the production system, with the fish or with the husbandry. To give you some idea of what can be achieved, commercial FCR values of less than 1:1 are being achieved on salmonid farms and in re-circulation systems.

As food costs should make up more than 50% of the farmer's outlay on production costs, it is important that this input be closely monitored.

Aquaculture is simple

It's been mentioned before: aquaculture is not rocket science. The authors have seen many people go into fish farming who insist on making it difficult for themselves by trying to invent an industry and not focusing on the simple things. The five limiting factors for instance. If you take the first letter of each section they spell GWQEHN.

One school of thought has accepted a translation of an old scripture found in an excavated Welsh Druid temple site to identify GWQEHN (pronounced 'Gwen') as the goddess of aquaculture to the ancients of that region. Hieroglyphic evidence from the Jordan Valley eerily also translates to GWQEHN suggesting a more ancient link with the Phoenicians who traded throughout the Mediterranean and beyond. Not wishing to enter a theological argument, the authors welcome both sources and would like to suggest you make GWQEHN your guiding star in aquaculture. By applying the GWQEHN test to any farming problem you should be able to come up with its source. Once you know the source of a problem you're more than half way to the solution.

Throughout the book GWQEHN's wisdom will be highlighted to prompt you to remember key aspects of the art of aquaculture.

Aquaculture is all about balance, stability and control. Fish love a balanced environment and they love a stable environment. But you can't have stability and balance without control. We'd like to leave you at the end of this section with this thought.

Before you incorporate any management procedure or add any infrastructure to your production system ask yourself: 'How much more control is this going to give me over the stability and balance of my farm?' Then quantify the value of the extra control in dollars terms before making the final decision.

GWQEHN says:
'The key words in aquaculture are BALANCE and STABILITY. Balance and stability cannot be achieved without CONTROL.'

2

Aquaculture production systems

This chapter briefly describes the structure and workings of each of the options available to the Australian aquaculturist and examine their advantages and disadvantages. Topics covered include:

- finfish mariculture – floating cages
- shellfish mariculture – subtidal
- shellfish mariculture – inter-tidal
- ranching
- feedlotting
- land-based mariculture
- freshwater flow-through systems
- freshwater static pond systems
- freshwater re-circulation systems
- freshwater cage culture.

It should be noted that, while the systems vary widely in design and application, the basic principles of aquaculture still apply in their management and GWQEHN remains the aquaculturist's guiding star.

The production systems used to produce aquatic organisms are only part of the story. The aquaculture industry is also divided up into a number of geographic and climatic sectors. Australia ranges climatically from the tropics to cold temperate, from oceanic coastal environments to inland continental regions.

Seafood can be produced in inland waterways and purpose-built ponds, brackish estuarine areas or in full oceanic seawater. Farming in seawater is sometimes referred to as marine farming or mariculture.

In addition the range of species grown commercially falls into different categories again. Broadly speaking they are finfish, crustaceans, shellfish and plants. In actual fact Australia's largest aquaculture industry is in the last sector: plants. It is also the world's largest aquaculture sector. Rice is an aquatic organism and fits the definition as an aquaculture product, but it's not seafood so we'll leave it where it probably belongs – in the grain sector. Seaweed production in China is enormous; on a tonnage basis it dwarfs the production of animal flesh of all other aquaculture around the world. Even those categories don't cover it all. Species like trochus and abalone are gastropod molluscs (snails). Trepang are holothurians (sea cucumbers).

Finfish mariculture – floating cages

The idea of a floating cage is simple: a net is hung from a flotation structure around its periphery. Fish are farmed inside the net.

Figure 2.1. Floating cages come in all sizes and shapes, from these large salmon cages to small fresh-water-based production cages of <10m³. Shown here are the cages of a shore-connected salmonid farm on the Tamar River in Tasmania. Note the easy vehicular access and automated food delivery conduits to each pen.

The production of fish in floating offshore cages is relatively new. In Australia it was primarily associated with the production of Atlantic salmon and ocean trout although snapper, yellowtail kingfish, tuna, barramundi and mulloway are now being grown in ever-increasing numbers. It is a cheap and efficient way to produce fish. The under-writing factor in farming in an open environment in floating cages is often summed up with the catchphrase 'dilution is the solution to pollution'. The ocean is so vast that the nutrient wastes of the metabolic process of growing fish are dispersed by the tides and currents and naturally neutralised by the biochemical organisms present in the sea. Depending on water movement and other conditions, biological wastes can be quickly dispersed and naturally processed. While it is common for there to be some effect directly under cages from falling faeces and uneaten food, impact is rarely detected a few tens of metres from the cages. By moving the cages to new sites on a regular basis, the farmer allows the natural environment to neutralise any adverse impact that may have occurred because of continuous occupancy.

Cages have increased in size over the years as the industry has been developed and more efficient engineering has emerged. It is conceivable that in the future submerged sea cages will be operating in open ocean conditions and ships that bring the food and supplies for the crews on the factory ship will return to shore loaded with processed seafood.

The disadvantages of this method to the average fish farmer are the establishment costs. Most of the world's salmon production is carried out by corporations or very solid family companies.

The Tasmanian salmon and ocean industry was established in the early 1980s when the technology was being developed around the world. Private investors and government shared a vision of building a sustainable industry to grow seafood and create wealth and jobs for Tasmanians. Working together they identified the steps that would be necessary to achieve success and planned how these steps would be taken. The accomplishment of this project is now part of history and Tasmania is one of Australia's premier seafood-producing regions.

As a sign of the vigour and energy in the aquaculture industry, production technology has moved ahead dramatically over the last couple of decades and some of the older salmon production operations have found themselves locked into high production costs while the world markets for salmon are soft as part of the global re-structuring and adaptation of new technology.

Access to sites is a problem as farmers prefer sheltered water, which brings them into conflict with other stakeholders in the natural resource such as professional and recreational fishers, boat users and conservationists.

Shellfish mariculture – subtidal

Shellfish can be grown subtidally, below the water's surface. In Australia, species farmed subtidally include scallops, mussels, native flat oysters and pearl oysters. They are grown in baskets or on ropes suspended from longlines. Being filter feeders they grow by extracting nutrition from the plankton that comes to them on the tides and currents.

Demanding less capital than sea cage farming, this kind of farming nevertheless has a downside. Growers are dependent on natural food production over which they have no control and their operation is subject to the vagaries of the weather. They also have to compete with other stakeholders for access to suitable sites, such as recreational anglers, boat users and conservationists, but as with finfish farmers, more robust gear and new technologies will enable them to move their farms to more remote regions. However, this is likely to make the industry more expensive to enter.

Pearl farming is a specialist area as the marketing is far more sophisticated than normal seafood marketing, but scallop and mussel farming are relatively straightforward and the methodology required has as much to do with seamanship as technology.

It can be argued that filter-feeding bivalves present no threat to the environment. These animals are in fact are cleaning the algae created by shore-based pollution washed into the marine environment from domestic and agricultural activities. It can therefore follow that shellfish farming is part of the natural cycle, so access to water should be easier to attain.

Figure 2.2. Mussels are grown on ropes suspended from longlines. The bivalve molluscs filter feed on the nutrients available in the water column and present a very inexpensive way of producing seafood for the market.

Shellfish mariculture – inter-tidal

The best-known example of inter-tidal shellfish farming is the Sydney rock oyster. This world-class shellfish is grown on racks, on sticks or in baskets that are exposed by the outgoing tide and covered by the incoming tide. Like mussels and scallops, they are filter feeders. Farms are situated in estuaries to gain as much tidally exposed water as possible and to prevent their growing systems from being battered by high seas.

Appropriate technology keeps them in their comfort zone. Species such as oysters normally live attached to hard surfaces (something not always that common in estuaries where there are often high natural silt loadings). In the distant past, rocks were used. Later in NSW, spat was caught by letting it settle on sticks, and the sticks were placed on stakes in the inter-tidal zone. This technology is being replaced by 'single seed' where hatchery-bred stock are settled onto a small chip of shell or something similar. They grow free of any underlying surface. Single seedstock are grown in cages or trays, which keep predators out, and facilitates handling. If the trays are moved periodically (for example with the rise and fall of the tide) the stock is continually sorted and resorted, so that no particular individual is deprived of nutrition, or forced to grow slower than their peers.

See chapter 23 for more information on oysters.

Figure 2.3. **Oyster farming is one of the oldest forms of aquaculture in Australia. The oysters feed when the tide is in and the exposure time helps harden the shells. This is what makes them such a good product for long-distance travel to lucrative markets in Asia, Europe and North America.**

Ranching

Ranching takes its name from the American word for grazing; and in principle it is very similar to the land-based operation. The essence of ranching is that the farmer assists the production of new stock (in aquaculture, this may well be in a hatchery or a nursery) then releases the young into the wild. After the appropriate amount of time, the stock are harvested and taken to market.

There are issues common to all ranching. How do you tell who owns the stock? In cattle ranching, brands were effectively used and in more recent times ear tags have been introduced. In aquaculture, solutions vary. Who owns the wild stock in the ranching? In cattle ranching, cleanskins belonged to whoever took them first. However, in many marine areas, commercial fishermen have paid good money to purchase a licence that gave them a property right, and they are understandably reluctant to cede that right.

Back in the 1970s, it was proposed in the US to ranch salmonids. A hatchery released the stock into the wild. At the end of the growing period, the urge to reproduce took the now grown-up fish back to the site of their hatching. They would swim right into a catching bay. No problems about determining who owned those fish! The idea was attractive, but never got off the ground (or into the water). One problem might have been that the farmers had no control over who caught the fish, even if the fishers were immediately outside the farm.

In more recent times, some members of the abalone sector have used ranching. There are different approaches practiced in different parts of the world but, in principle, growers breed their stock and put them out on an artificial reef. The artificial reef grows the weed (that before the creation of the artificial reef didn't have a surface upon which to establish itself). The ranchers manage their stock just like you'd manage a mob of sheep on a sheep station; moving them onto a better section of the reef if they haven't found it themselves, checking the health of the animals and so on. The farmers are only allowed to harvest hatchery-reared stock, which are easily identified from the different shell colouration due to the artificial diets they were raised on during their on-shore nursery stage.

Naturally the idea, being new, has everyone suspicious. The wild abalone dive sector has an enormous investment in their quotas and, at the time of writing, a 19 tonne Victorian quota was reputedly worth $8 million. You can build a lot of artificial reef for $8 million, and the industry understandably feels threatened. The conservation movement hasn't warmed to the idea although artificial reefs have been shown to increase fish habitat. The recreational fishing bodies don't seem to have allied themselves to the cause of the ranchers and the politicians have distanced themselves from the issue. However, the establishment of a network of distribution for illegally harvested abalone has increased the incidence of theft and ranching doesn't seem as attractive as it once was.

Ranching has been proposed for trepang (sea slugs) in tropical parts of Australia. Trepang are easily spawned in a hatchery. They are on-grown in a nursery and the kid's-finger-sized sluglets are placed out in the ocean. The idea is that the natural limit of production in the area is insufficient stock, and that placing lots of young there will increase production. It might make a difference, it might not, but the idea has its appeal.

By their very nature, it is impossible to mark trepang, so it is impossible to distinguish hatchery-produced stock from wild fish.

Another issue is that the areas that will be good for ranching trepang are the ones currently good for trepang fishing and commercial fishers don't want to lose their livelihood. If aquaculture technologies are to be applied, the commercial fishers want to be the ones to apply it. The situation has a lot of parallels with the dispute about abalone ranching at the southern edge of the continent.

Feedlotting and conditioning

The practice of feedlotting is to take grown fish and to feed them up. By having stock in the best possible condition, the grower can command the best possible price from the market. If you have enough control, you can also have goods for sale when prices are at their best. The practice has been well established for beef, and can be applied to finfish.

Another aspect of feedlotting is that market entry can be timed to coincide with peak market values.

Yabbies, especially under the multiple waters licencing arrangement that apply in some states, can be held and fed in captivity until they moult. The old stained shell is discarded and replaced with a clean new shell lifting its market appeal dramatically.

Probably the most well-known seafood feedlotting operation is with tuna at South Australia's remote Port Lincoln. Here bluefin tuna caught in the wild are held in sea cages, for all intents identical to the cages described earlier. They are fed, gain condition and are ready for shipment to Japan at the peak market times. Similar operations have been planned for yellow fin tuna and kingfish. See chapter 23 for more information.

Another form of feedlotting is being carried out with abalone and is based on growing abalone in cages set on the seafloor. The farmer grows the type of seaweed that abalone enjoy and feeds it to the abalone on the cages. The design of the cage ensures good tidal water exchange and that predators are kept out.

Feedlot operations can be expensive to establish and operate. There may be an opportunity to feedlot other commercial species but the value would need to be high to warrant the risk and the outlay. One group that would fall into this category would be rock lobster, and trials are under way in some states.

Fattening eels has been shown to be viable. This species reponds to feedlotting and the extra condition they put on enables the grower to sell them at a premium. This is a bonus on top of the weight gained through the feedlotting process.

Mariculture – land-based

A recent development in commercial aquaculture has been the land-based marine farm. Farms, under plastic houses or sheds, are established within pipeline and pumping distance of the sea. Seawater is pumped through a series of land-based tanks before being returned to the sea. The method underwrites the emergent abalone farming sector.

Land-based mariculture is very expensive. The systems are expensive to build. The water required is enormous and the pumping systems are huge. Everybody wants coastal real estate, so obtaining access to suitable sites can take time. An exorbitant outlay is required to deal with the application processes and also because of the need for expensive Environmental Impact Statements (EIS) required to address the concerns of local stakeholders. It is doubtful whether anything other than premium products, such as abalone and sea dragons, would fit the economic model.

Underneath a lot of Australia there is fossil seawater. If this comes to the surface, as is the case in many places where poor land management has raised the water table, the saline water is a pollutant and kills plants. However, a lot of the water (but not all) has the same ion profile as seawater, and some even is diluted to the same degree. It has been suggested that this water could be used for mariculture. The idea of taking a problem, and turning it around to create an asset, is very exciting and has caught the imagination of more than one research body. However, at this time it still remains in the realm of imagination. A few pilot projects have shown that some species, such as Atlantic salmon and rainbow trout, can survive in this water, but it is a far cry from a proven and risk-free form of aquaculture.

Limited water exchange brackish pond systems

Some species prefer an environment with salinity less than seawater but far from fresh. These species are raised in brackish water systems. Most prawn species fall into this category. An appropriate site will allow growers to control the salinity of their system by having good and secure access to both fresh and saline water, and, if necessary, will have the correct topography to build growing and freshwater holding dams. Often, these sites are found adjacent to estuaries.

Static ponds are ponds in which the production water is held and evaporation is replaced. The fish or crustaceans are raised in the pond and water quality is maintained by mechanical aeration and the application of water quality management protocols. One of those protocols may be to exchange some of the pond water to maintain water quality stability, and as a result some ponds may get more water exchange than others.

Because of evaporation and the need to constantly mix fresh and seawater to maintain the correct salinity levels, brackish water ponds tend to receive more water exchange than their freshwater counterparts.

Freshwater flow-through systems

Flow-through aquaculture systems are one of the oldest methods of fish farming in the world. The fish traps found in the lake beds of the Anabranch lakes system in far western NSW would have been a hunter–gatherer prototype for the earliest fish farms. The principle is simple. Divert the water from a permanent stream through a series of raceways in which the fish are held and fed. The incoming water brings oxygen to the fish and the outgoing water removes the by-products of metabolism.

Most trout farms operate on this basis and freshwater farming of trout has proven itself to be one of the most economic ways to produce fish.

Figure 2.4. One of the most successful forms of aquaculture around the world has been the flow-through system. This picture shows a grow-out raceway being stocked with fingerlings from nursery raceways.

Access to suitable sites is a problem in Australia, as we are not blessed with the bountiful river systems of other continents. The upper reaches of the rivers rising in the Great Dividing Range support some trout farms but even then they are vulnerable to El Niño events. It is feasible to incorporate flow-through systems in the many irrigation schemes around the country but to date nobody seems to have given it much thought.

Limited water exchange freshwater pond systems

Freshwater ponds with limited water exchange are operated in much the same way as their brackish water counterparts. The exchange rate may often not be as high as in the brackish ponds but the grower will have water exchange as an option for problem management. Should he or she be having a bad trot, the exchange rate will be higher than normal.

The catfish aquaculture of the Mississippi delta is based on this kind of pond culture.

Freshwater ponds are relatively inexpensive to build and can be incorporated into a diversified farm development program. They are of course subject to the vagaries of the weather, as is any outdoor system.

Most of the inland fish ponds in Australia utilise limited water exchange. In the southern half of the continent, they are generally referred to as 'warm water' ponds, because their water is warmer than that used to grow fish like trout. Warm water ponds are successfully used to grow silver perch, Murray cod, jade perch and barramundi.

Figure 2.5. An aerial shot of a typical inland pond system. This one is situated in the New England Tablelands of New South Wales.

Freshwater re-circulation systems

It is possible to continue to use the same water again and again, but the biological wastes from the growing process have to be removed. In the more extensive approaches to fish farming, natural biochemical processes work in the pond bed and water column; but in intensive re-circulation systems, the natural processes are facilitated by technology. The application of the technology enables the grower to carry stocking densities unimaginable in an open system.

The principles of re-circulation technology have been known for years and form the basis of any sewerage treatment plant. Over the last three decades the technology has been applied in aquaculture. Appropriately designed and engineered systems capable of dealing with the high loads placed on them have been able to produce commercial quantities of fish.

Re-circulation systems have a distinct advantage over other systems in that they can be adjusted so the fish are grown in their optimum conditions: 24 hours a day, seven days a week, 52 weeks a year. The operator has maximum control over the stability and balance of the environment and water quality in which the fish are living. This eliminates some of the major instabilities in an aquaculture production system, allowing the operator to maximise the full growth potential of the stock being raised.

The downside is that re-circulation systems are expensive to build and expensive to operate. To date they have only been used to economic advantage to produce high value species such as Murray cod. Once the price of a species comes down, as it did in the mid-1990s for shortfin eels, the operator has to find another high priced species to grow. This option may not always be forthcoming.

There is a definite role for re-circulation systems in the hatchery and nursery stage where water quality is at a premium (the hatchery stage) or the growth of the fish is fast enough to warrant the outlay (the nursery stage).

Juvenile fish don't take up a lot of room and their growth rates are inherently greater than more mature fish. For instance a 1 g fry might be growing at a specific growth rate (SGR) of 5% of its body weight a day, in which case it will be doubling its weight every 14 days. On the other hand, a more mature fish of around 500 g might only be growing at 1% of its body weight, in which case it would be taking 72 days to double its body weight. That is five times slower.

To look at it another way, if the grower has 1 tonne of 1 g fry in his or her system and wants to grow them to 32 g the fry will have to double their size five times. Presuming the SGR over the period averages 3%, it will take the grower 120 days to achieve this. In that time they will have produced 32 tonnes of fish. The sums are simple:

Fish gaining 3% of their body weight a day will double in weight every 24 days.

Therefore they will take 120 days to reach 32 g

$$1\,000\,000 \times 1 \text{ g fish} = 1000 \text{ kg}$$
$$1\,000\,000 \times 32 \text{ g fish} = 32\,000 \text{ kg}$$

The grower with a tonne of 500 g fish growing at 1% a day will produce a 1.666 tonne of fish in the same time.

Figure 2.6. Indoor fish farms, like the one pictured here, have become popular because of the control they provide over key factors such as predation, water temperature and quality.

Fish gaining 1% of their body weight a day will double in weight every 72 days. Therefore in 120 days they will have doubled their weight 1.666 times

$$2000 \times 500 \text{ g fish} = 1000 \text{ kg}$$
$$2000 \times 1666 \text{ g fish} = 3332 \text{ kg}$$

This gives an advantage to the person raising the nursery stage fish of ten to one but the fish are only growing on an average of three times faster.

Intensive re-circulation farms are compact and should be enclosed. They are easy to heat. Juveniles can be grown faster in temperature-controlled conditions than they would in an outdoor situation. Atlantic salmon farmers in Scotland and Norway are more than halving their smolt growing time by avoiding the bitter winter in nursery cages in the lochs and fiords. The Tasmanian industry has adopted the same techniques.

Freshwater cage culture

Floating fish cages can be used to rear fish in freshwater, using much the same technology as used in the sea. While Australia doesn't have a lot of natural deep-water lakes such as are found in other parts of the world it does have reservoirs built to conserve water for irrigation.

Figure 2.7. A popular way to rear fish in freshwater ponds is to moor a floating cage to a jetty.

In WA, barramundi are produced in large floating cages in Lake Argyle behind the Ord River Dam in the Kimberley. The West Australian Government has plans to promote cage farming of barramundi in Lake Argyle, with a proposed annual production of many hundreds of tonnes.

Queensland barramundi farm cages tend to be much smaller and are often set up attached to a jetty in ponds. The water is kept moving through the cages and around the pond by running aerators 24 hours a day. The management is much the same as it would be in a static water pond. In fact this kind of system could be considered a primitive re-circulation system, as natural processes in the rest of the pond treat the waste from the fish-growing cages. The water is pushed around to where nitrifying bacteria in the pond deal with the ammonia build-up and the water is re-charged with oxygen before being pushed back to the fish in the cages.

3

The five stages of a fish's life

This chapter looks at the five stages in the aquacultural life of fish, crustaceans and shellfish:

- the hatchery stage
- the nursery stage
- the grow-out stage
- the processing stage
- the marketing stage.

Each stage has its own special requirements. Some growers will take on all five stages in the operation and others will concentrate on one particular stage. Trout growers tend to be active in all stages, running the hatchery, nursery, grow-out, processing and marketing stages, while ornamental breeders tend to be active in just the hatchery stage and nursery stages.

The hatchery stage

Almost all aquaculture species have an egg as part of their life cycle. To start the growing process, eggs have to hatch. Aquaculture seedstock are produced in a hatchery, hence the term 'hatchery stage'. Hatcheries supply the aquaculture industry with the vital seed-stock, without which it cannot exist.

Depending on the species, the technology for conditioning broodstock and inducing breeding can be quite complex, and full details are outside the scope of this book. Suffice to say that if you don't take the trouble to ensure your bloodstock is in the best of health, then the resulting young, at best, will have poor survival, and at worst will not result at all. In many cases the technology is readily understood and applicable, but like all farming pursuits, some farmers are better at breeding than others. The actual breeding may not require a lot of infrastructure support but the broodstock holding facilities may take up quite a large area and require an investment in water and pondage.

Many hatcheries are intensive and indoors, using flow-through or re-circulation technologies (as described in chapters 2 and 11). Theoretically, at least this provides the greatest level of control and the most reliable production. However, high overheads have to be passed on in the form of higher prices for the produce.

Where larvae are produced in open ponds, the infrastructure requirement will be relatively extensive, even though the pond management itself will be intensive.

A profitable fish farm doesn't have to include a hatchery stage. While freshwater species such as golden and silver perch are relatively easy to breed, marine species are

Figure 3.1. Trout fry being raised in a government hatchery for restocking purposes.

notoriously difficult to breed. The beginner just setting out on his or her aquaculture journey may find it to be more practical and less costly if, in the learning phase of their fish farming career, they purchase seedstock from an established hatchery.

In some cases, such as yabbies, the breeding cycle and rearing is straightforward. Under these circumstances it is possible to set up a yabby hatchery to provide seedstock but you still may find it more economical to buy in your juveniles.

It is at the hatchery stage that the longest lever in the aquaculturist's hand nestles, as it is here that genetic strains can be determined. Poultry farmers will tell you that genetic improvement accounts for more than 80% of the lean meat deposition in the poultry industry and fish farmers will find similar improvement when they start fine-tuning their various species for commercial efficiencies. This means that the hatchery operator will be able to develop a better food-converting, faster-growing fish to sell, and attract clients to his farm gate. Competition will ensure that the hatchery with the better performing fish will be the one that corners the market. This means that in the end there will be only one or two hatcheries supplying that particular strain to the market.

Genetic development doesn't come cheaply or quickly. First, the method of production has to be standardised to ensure the species is being farmed in the most efficient way possible. Then the diet that gives the best results under these efficient farming methods can be identified. Once that has been achieved, and only then, can the breeder start isolating the genotype that performs best under this regime. Talking with geneticists it would seem that their role alone in the development of a better farming subspecies could take 10 years and millions of dollars to get the kind of efficiencies that drive the pig and poultry industry. Of course, when dealing with a wild species, as most aquaculture species are, any improvement towards developing a domesticated line would be an advantage and worth pursuing.

Hatcheries can have a very fast turnaround time, that is, breeding can be induced quickly (and with some species in some climates, frequently) and once it has been, it is only a matter of days before the produce can be sold as larvae; or a few weeks before they can be sold as fry. This provides good cash flow.

When looking to sell hatchery produce, one consideration is the market for seedstock. If the sector isn't exactly booming and there are already several hatcheries operating in the field, there may not be enough customers to go around. This shouldn't be a problem if your seedstock is the best available on the market.

Breeding fish for the recreational angling market is an option that could present an upside. There may well be some work involved in attending angling club meetings and holding hatchery open days but the financial reward is likely to be there for anyone willing to put in the work. Selling to government departments that purchase fry and fingerlings for re-stocking waterways is likely to be less time consuming but the market is more competitive so you may not be able to hold your margin. Of course, in most cases, government orders are for large volumes.

The nursery stage

Once hatched, very young fish or shellfish (larvae) have a particular set of problems in the first growing stages of their lives. In the wild, this is normally a time of massive mortality. In aquaculture, the larvae are nurtured to reduce mortality to minimal levels. This cycle is termed the 'nursery stage'.

Aquaculturists are often idiosyncratic individualists (sometimes even rugged idiosyncratic individualists); they do things their own way! Terminology varies from sector to sector. Oyster growers often use the word 'nursery' to include hatchery as well.

Nursery technology can vary from species to species, and even vary in farms producing the same species according to commercial and environmental constraints or management approach.

Many nurseries utilise intensive flow-through or, increasingly, re-circulation technologies. These are capital intensive but usually operate with a high degree of reliability, an important factor for purchasers requiring seedstock on time to fit their own production schedules. Larvae are fed specially grown algae or formulated foods.

There are other approaches that can be employed. Some fish, like barramundi or silver perch, may be placed in a plankton-rich pond cultivated by the farmer, given time to grow, then some weeks or months later, the pond is drained and the now grown fingerlings harvested. On a dollar-per-dollar basis this is usually the cheapest approach to the nursery stage. By monitoring the stock and culturing the natural food supply in the plankton pond the grower is able to keep track of the production outcome.

What makes nursery stage growth important and how do you make money from it? Fish, like all animals, have a very fast early growing stage. For example, a child at two years of age has already attained half its full height, which probably won't be reached until the age of 16 or so. Under the right conditions and dietary regime the fish are able to achieve growth rates far in excess of the grow-out stage of their lives. This is when the farmer can really stack on some growth and make some money.

The dietary regime, whether natural or artificial, is a crucial factor in maximising growth in the nursery stage. The fish will feed more constantly and, although mechanical feeders can lighten the labour of this task, the animals still should be monitored for health and growth.

The rapid growth of finfish in intensive nurseries means they will need to be graded. Carnivorous species will eat each other if sizes are not kept relatively equal. It's a general rule with carnivorous finfish that if you can get your mouth around it, and it sits still for long enough, you eat it. Grading in the early stages also sorts out the fish predisposed to a particular growth rate under culture conditions into size cohorts and will reduce the need for grading at a later stage. In short, the stock requires more managerial input and cost than would be needed to grow the stock during the grow-out stage.

The turnaround time in a nursery is substantially longer than that for a hatchery, but, by the standards of some other stages in aquaculture, the time is relatively short. Usually the nursery stage lasts some weeks or a few months, and then the stock can be sold. A few months is not long by fish farming standards and nurseries potentially have good cash flow.

The markets again present a narrow field. The main market would be for farmers wanting advanced fish that they can grow out in their ponds during the ideal growing times in their district. Secondary markets could be found in the pet industry and people wanting to stock recreational waters already stocked with fish large enough to eat fry.

The grow-out stage

This stage is when young, post-nursery stage stock are grown to the size at which they will be harvested for the market.

The grow-out stage can be carried out in any of the production systems discussed in chapter 2.

Management input is less technically demanding during the grow-out stage and the procedures more mundane. However, the time associated with grow-out is longer and the workload and management demands consistent – as in seven days a week all year round.

All the issues that impact on the previous two stages also apply to the grow-out stage but the sheer volume of management has increased dramatically. 100 000 fry averaging 1 g weigh 100 kg. By the time they have passed through the nursery stage they will have increased in size 50 to 250 times depending on the species. For instance, it is generally accepted that the growth of silver perch starts to slow down at 50 g. In that case, our 100 000 fry would weigh 5 tonnes. One hundred thousand Murray cod may weigh 25 tonnes at the same stage.

By the time they have reached market size of, say, 800 g for silver perch and 1.5 kg for Murray cod, the grower would be handling (presuming no losses for the sake of the exercise) 80 tonnes and 150 tonnes of fish respectively. The crop of course would be worth considerably more at this point and, it could be argued, so would the risk.

The market at this stage is for finished product and there is the whole seafood-consuming population to sell to, providing of course that you have chosen the right species and done a good job with them.

The processing stage

Most seafood is sold in a processed form of some sort or another. Most of the fish consumed in Australia is in the form of boneless, skinless fillets. A very small proportion is sold as a live product. That means the product presented to the consumer is most likely going to have to be processed in some way.

Processing is a specialised area and complying with food safety regulations can be quite costly and, in this litigious age, onerous. It may well be more cost effective and safer to form a strategic alliance with someone already well established in this field. The person or organisation may turn out to have a well-oiled network that could help you place your product, as a bonus.

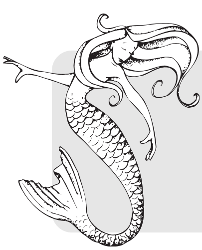
The marketing stage

The final stage in a fish's life is the marketing stage. This is the most crucial stage as far as the farmer is concerned. If he or she doesn't get maximum value at this point they are undoing all the work that's gone into bringing the fish through to this stage. Quality is paramount when it comes to achieving top dollar for anything, and seafood is certainly no exception.

Again we have to accept there are marketing professionals, just as there are processing professionals. When it comes to seafood, those professionals know their sector like nobody else and they have established networks all over the country.

We'll discuss marketing in greater depth in chapter 19 but at this point the smart fish farmer may have already worked out that it might be more convenient for him or her to be sending their fish to someone who knows more about selling them than they do.

One of the authors remembers talking to a chap who farmed jade perch for the live fish market, only an hour's drive from the heart of a state capital. He thought he had someone lined up to take the lot off his hands as they reached market size.



GWQEHN says:
Look at the Hatchery Stage as the pumping of seedstock into the ponds; look at the Marketing Stage as the pumping of dollars into the industry. Neither succeeds without the other.

Unfortunately this arrangement fell through and he had to do his own marketing. All of a sudden he found himself sitting behind the steering wheel of his delivery lorry unloading live fish two days a week. That was two days a week he had to find from the five and a half he was going to spend growing the fish. He couldn't find them so he had to give up his weekends to catch up on the grading and other management jobs that had to be done. After two years he had put the farm on the market.

The point of this story is – don't take on more than you can handle. Your fish will have to pass through those five stages to reach their final destination. Sooner or later you'll have to decide which one or ones you're going to be involved in or it will be decided for you.

Then there's the chap who wanted to go yabby farming. He looked around at the industry as it was in those days and decided that the climate at his place wasn't nearly as good for growing them as the farms he visited. But in his travels he noticed that the industry really didn't have much idea of marketing and growers, on average, were price-takers. He promptly set up a marketing outlet. Very soon he had developed such a market interest that he was buying freshwater crayfish from all over Australia to satisfy the enthusiasm he was generating in the product through the energy he was able to devote to developing product awareness. He was handling yabbies from wherever he could get them, as well as marron from WA and redclaw from Queensland. His efforts put a floor in the market from which the growers benefited. Sadly, irregular supplies of quality stock drove him out of the industry.

The moral of this story? Do what you're best at, or what the resources you have on hand limit you to.

Some people regard 'proper' aquaculture to involve all the stages mentioned in this chapter, but that's not so. In fact, unless you have the financial resources and Wisdom of Solomon, it shouldn't be the case. A fish farmer should concentrate on what he or she does well, and if that involves only one stage, so be it.

A final word: whilst the stages outlined above apply to all fish farming species, sometimes they get a little blurred. For example, some growers may translocate yabbies with eggs into grow-out ponds: the hatching and nursery stages all may occur in the grow-out pond. As mentioned above, oyster farmers often refer to two stages only: 'nursery' and 'fattening'. Regardless of the names and the farming practices, the principles remain the same.

4

Aquaculture categories

Broadly speaking, there are four main categories in aquaculture and they are mainly based on climatic conditions:

- cold water species
- temperate water species
- warm water species
- tropical species.

The most common categories in aquaculture relate to temperature tolerances (although there are others such as 'finfish', 'crayfish', 'shellfish', 'filter feeders' and 'snails'). It's helpful to know what general climatic range the stock prefer and what their biology is. The upper critical limit (UCL) and lower critical limit (LCL) for a given species will be the same, regardless of whether the animal is in the wild or on the farm. Fish in the wild have habitat options unavailable to farmed fish. If it gets too hot, the grower will have to stop feeding, as the fish won't be interested in food under these stressed conditions. This probably won't worry the fish too much, but the farmer is losing production. In effect, the UCL and LCL relate to the farmer as much as they do to the fish.

To grow aquatic organisms successfully as a commercial venture, the water temperature will have to be within the chosen species' optimum temperature band for at least six months of the year. More detailed information is given in chapter 7 dealing with site selection, but for the moment we're going to examine the options open to us as far as species groups are concerned.

Cold water species

Cold water species are comfortable in conditions such as those found in waters off Tasmania. Atlantic salmon and rainbow trout are cold water species. Generally speaking, the optimum temperature range for maximum production is between 10°C and 18°C. Particular species may have a preference within that band. For instance, rainbow trout will tolerate and perform more efficiently than Atlantic salmon at the higher end of the range (although, selective breeding for a genotype that displays upper or lower critical tolerance should enable growers to farm the species in regions that would otherwise be marginal). The UCL for cold water species would be something like 21°C and the LCL would be 3°C.

Although parts of Australia fall into the cold water category, there aren't many native species cultured commercially within this climatic range and, under the various state fauna and flora protection acts and the *Commonwealth Environmental Protection* *and Biodiversity Conservation Act 1999*, it is unlikely that any new cold water farming species will be allowed in the country. However, as we grow as an aquaculture nation it is likely that the economic worth of many native species may well be discovered and farming methods developed, particularly in the marine environment.

Cool temperate water species

Cool temperate water species fall in between cold water species and warm water species. Estuary perch are an example of a temperate water species. The optimum temperature range for culture is 15°C to 23°C with the UCL around 28°C and the LCL at around 4°C.

There are many areas in southern Australia, particularly those along the coastal plain, which may experience some really scorching hot days during the summer but actually, due to the tempering influence of the ocean and the watery environment, fit this climatic profile. Growers considering farming in these areas should look at the water temperature profile over the whole year before selecting a species to grow.

Warm temperate water species

More commonly called warm water species, warm temperate water species' optimum temperature range lies between 20°C and 28°C, with an ULC of 31°C and a LCL of 5°C. This is the temperature range suited for the commercial cultivation of the species native to the Murray–Darling Basin and is the widest geographic area suitable for fish farming in Australia. Along the east coast the range would extend from east Gippsland to the Sunshine Coast.

Warm temperate water species also provide the widest range of freshwater species available for culture. Inland species already being raised commercially in this range include Murray cod, silver perch, catfish and golden perch (yellowbelly or callop).

Eels are an interesting species in that they appear in a wide range of climatic conditions. For instance: longfin eels are found in the tropics and in the Furneaux Group in eastern Bass Strait. Their shortfin cousins are found from subtropical Queensland to the icy reaches of Tasmania's eastern river system. Where do they fit? As a general category they cover the eastern seaboard of the continent.

In farming terms, it's better to be in the warmer reaches of a species' tolerance zone, if you don't have the luxury of temperature control. Often, it is not the warm part of the year that beats you – it's the winter months that bring the water temperatures down (see chapter 10 where we look at site selection).

Subtropical species

As the name implies, these species are suitable for culture in subtropical climates. Subtropical Australia covers the country along the coast where there is the moderating influence of the oceans buffering the extreme low temperatures of an inland winter but doesn't have the extreme high temperatures of the country that sits north of the Tropic of Capricorn. As is the case with warm water and temperate species, there's some overlap and species that can be grown in subtropical regions generally can also be

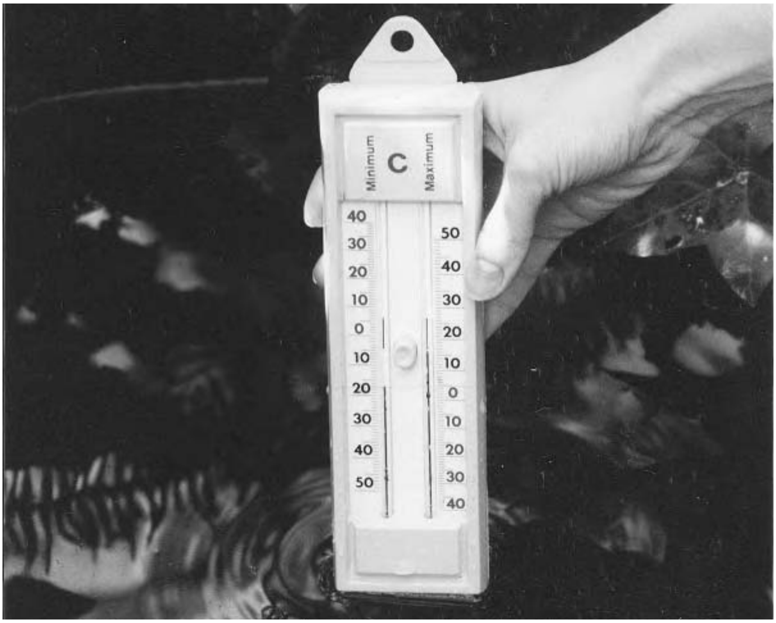


Figure 4.1. Monitoring water temperature is a regular part of fish farming.

cultured in tropical climates. For instance, black tiger prawns can be cultured in northern NSW as well as in Queensland's far north.

The optimum temperature range for subtropical species is 23°C to 31°C with an UCL of 34°C and a LCL of 10°C. Jade perch (Barcoo grunter) are an example of a finfish cultured commercially in the subtropics.

Tropical species

Tropical species are those that are found in the tropical areas of Australia. Barramundi are probably the best known of them. The temperature band ranges from 26°C to 33°C with an UCL of 36°C and a LCL of 15°C.

Tropical Australia, with its abundant water and ample space, is probably one of the major untapped aquaculture resources in the country, although there are issues with the environment and native title. However, with a bit of common sense and some data as to the real environmental impact, these issues should be able to be resolved. This of course applies to all regions.

We will now look at the types of aquaculture that can be practiced within the climatic zones.

Filter feeders

Filter feeders are bivalve shellfish species such as mussels, scallops and oysters and clams. They comprise one of the major aquaculture sectors around the world, and shellfish production makes up a significant part of Australian aquaculture.

Mussels and oysters, apart from a pelagic larval stage at the very start of their lives, are sedentary animals and lend themselves to aquaculture as they passively sit on their trays, sticks or ropes waiting for the tide to bring them natural food. In the wild, scallops and clams are able to move about the seabed in a limited manner but for farming they are held in baskets or cages.

Generally speaking, filter feeders are cultured in sheltered waters, although modern technology and stronger (albeit more expensive) gear allows more exposed waters to be farmed.

While there is no food cost for filter feeders, the labour component of production costs is commensurately high. Unlike technologies such as rearing finfish in a re-circulation unit, where all the concern is about food conversion efficiency, a key skill required for mussel farming is seamanship.

Finfish

Finfish have requirements of their own. Production options range from sea cages and inland static ponds to flow-through systems and re-circulation units. Finfish species are more susceptible to undesirable climate and water quality variations and tend to have more health problems than shellfish, and consequently require more management.

Finfish generally have to be fed a supplementary ration. In fact there aren't any examples of commercial finfish grow-out for the market that come to mind that aren't based on feeding a manufactured diet, in the grow-out stages at least. It would be safe to say that feed will be a major cost in finfish production and food conversion efficiency a major factor in the cost of production.

Crustaceans

Australia is blessed with a wide range of freshwater and marine crayfish species, as well as crabs and prawns. Strictly speaking, marine crayfish species should be referred to as 'lobster' and Australia's rock lobsters are regarded as being as good as any in the world. Our freshwater crayfish also have an international reputation and the Western Australian marron is regarded as the prince of freshwater crayfish.

The breeding technology has yet to be developed for rock lobsters. However, CSIRO and others have been on the job for many years now and could develop the technology that will lead to the successful commercial culture of this premier marine crustacean. Prawns are grown around the world and Australian prawn farmers can boast of having developed a world-class sustainable prawn farming industry. The breeding protocols for mud crabs have been established and mud crab farms are now a reality. Freshwater crayfish have been produced commercially since the 1980s.

Farming crustaceans is different from growing finfish. To start with, the production cycle for freshwater crayfish and prawns is only six months and more natural food can be used, especially during the nursery stage. Ponds for crayfish and prawns are also shallower than those required for finfish so system construction costs tend to be less.

Crustaceans, however, still require constant monitoring. Harvesting, especially for the live product market, as is the case with freshwater crayfish, such as marron, redclaw and yabbies, takes more care and time than that required of the finfish or shellfish farmer.

5

The first step – the acquisition of knowledge

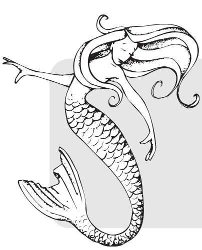
This chapter deals with such items as:

- setting a goal
- taking stock of the resources available
- obtaining the basic skills
- obtaining the necessary technical knowledge.

You've already taken the first step towards acquiring knowledge – you're reading this book.

Too many people barge into aquaculture waving their chequebooks, while just as many poke around the edges for ages before they, too, blow their budget on some of the instant aquaculture that is freely on offer. The first step should be the acquisition of knowledge, real hard data giving the true facts about aquaculture.

If to some people the words, 'I'm from the government and I'm here to help you,' send chills down the spine, the authors' blood runs cold when they hear, 'There's got to be money in it'; 'She'll be apples mate'; or 'I'll pick it up as I go along'. There seems to be a determination in this country to discredit the role of knowledge. (We all know Dad and Dave finally made it down on Our Selection with a mixture of perseverance, hard work and Mum's cooking, but I'll bet Dad would be the first to admit that he could have done better with a bit of knowledge about soil structure, animal health and world markets.)



GWQEHN says:
There are no short cuts in aquaculture; it is totally unforgiving.

Setting a goal

The first thing to do in aquaculture is determine what you want out of it. Do you want a stand-alone income or do you want to integrate your aquaculture activities with your existing farming enterprise? Do you want to build an aquaculture empire or will you be satisfied with growing a few yabbies for the local market down on your weekender? Or are you looking at aquaculture as a career that will bring you enjoyment, fulfilment and a livelihood for the whole of your working life?

Responsibilities have their impact too. A person who has a house to pay off and kids to educate needs to be a lot more careful with their assets, and to get a much larger return than somebody without these obligations.

Whatever the chosen entry point to aquaculture happens to be, the starting point will be the same: find out what you're getting yourself into first. If you're unsure of your goals at this stage, the more you know about the industry the easier it will be to chose the right path for you.

Taking stock of the resources at hand

A good first step would be to take stock of the resources available. If you're on an irrigation farm with plenty of water, you've got an essential resource. That's a good start. It's most likely you'll have some of the farming equipment such as a tractor, fencing equipment, welder etc. You'll also have the skills to match the equipment. By assessing the climate you'll have an idea of the species options open to you. This will give you a goal to target the next step in the acquisition of knowledge.

On the other hand, you may be still studying and are considering a career in aquaculture. Your resources would be youth and energy and, most importantly, time. You have time to take aboard knowledge of a wide range of aquaculture options before deciding on the path you'll follow. If you like the sea, you may find yourself looking at mariculture as the road to the future. If you love a sunburnt country, your aquaculture path will take you inland to the freshwater regions of this wide brown land.

Then you might be somewhere in the middle with a desire to get out of what you're doing and re-invent yourself as a fish farmer. Your resources may just be your savings and your vision. The whole world of aquaculture is your oyster.

Whatever the circumstances, the major limitation to the extent and direction of your goal will be the resources you have, but the most important of those will be technical knowledge and an understanding of what really drives aquaculture from the production and commercial points of view. This book sets out to:

- expose you to the opportunities;
- alert you to the pitfalls; and
- give you enough confidence in your aquaculture judgement to enable you to make your own aquaculture decisions based on scientific and commercial reality.

Working out the basics

Before you rush off and buy that 'you beaut' system advertised in the small farming magazine or put a deposit on a 10-hectare bush block with a natural spring, make sure you have the basic understanding not only of how to operate your fish farm but how to evaluate the opportunity's true potential, or lack of it.

Basic aquaculture skills are universal to all aquaculture sectors. While the biology of different species may vary, the chemistry of water quality and the science of nutrition and genetics are common to all forms of aquaculture. The authors hope they can impart some of this before the reader moves on to the next stage of his or her aquaculture journey.

The old-fashioned way to pick up the basic understanding was to do an apprenticeship with a master while learning the technical aspects at a tertiary institution at night school. Not that the master hasn't got the technology down pat, it's just that at a practical level the technology has become methodology: the method used to run his or her fish farming operation. For some reason the old apprenticeship system fell out of favour with educators, social engineers and governments but the option is now available again through the New Apprenticeship scheme. However, while it offers a tremendous opportunity to school-leavers it doesn't always suit those of us who have day jobs.

One way to acquire the basic skills, or at least a first-hand experience of them, is to set up your own system and set about murdering fish. There's a saying in some aquaculture circles that 'You're not a fish farmer until you've killed a dozen ponds of fish.' The obvious limitation to this method is that you may run out of fish before you've mastered the basic skills.

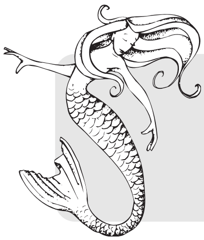
An easier and more effective way would be to kill someone else's fish. If you don't have time to embark on an apprenticeship, you could ask an established fish farmer to let you work on his or her farm for nothing so you can learn a few of the basics. Make sure you choose someone who knows what they are doing or you could pick up some bad habits. If you don't have time for this exercise, it may well be that you don't have time to run your own fish farm either.

Beware of YMD – Young Man's Disease. Don't rush into it until you're absolutely certain of what you're getting into and know how you're going to go about it.

Obtaining technical knowledge

Once you've decided that aquaculture is for you and the direction you'd like to take in it, it's time to get the necessary technical skills to make it all come about.

There are training courses available ranging from short course modules at TAFE institutes to post-graduate university courses. What technical skills you need to get will be determined by the direction you wish to take. For the school-leaver the choices are many. Anyone with a love of the sea can pursue a range of options from marine biology and resource management to any of the mariculture programs. For instance the University of Tasmania is regarded as Australia's key centre for aquaculture learning. The courses offered take the student through three years full-time study in both marine and freshwater systems. Hands-on training plays a major role throughout the program and there are weeks of each year devoted to work experience on some of the best aquaculture operations in the country. The students start off being introduced to aquaculture technology and engineering at a very general level. Once the students have an understanding of the nuts and bolts of aquaculture their second year takes them through such items as the design, operation and maintenance of re-circulation systems, cage culture systems, aeration options, grading machines and food processing. Food safety, occupational health and safety and Fisheries regulations are also part of the second-year program. Their third-year deals with more advanced technology such as disease diagnosis and genetic manipulation and modification. There are four separate units each semester dealing with nutrition, engineering, crustacean culture, finfish, mollusc and algal culture, zoology and ecology. There is also a business course unit that can be taken which prepares graduates to take upper management roles.



GWQEHN says:
If you don't know the role the nuts and bolts of aquaculture play in fish farming, you won't know how to put them together.

It can be seen from the above example that the university programs prepare graduates for anything they are likely to face in the outside world. However, the various diploma and TAFE courses around the country offer the industry entrant exposure to the commercial side of the industry and may not require the same amount of time. Some short courses will target specific sectors such as warm water species or tropical species. For instance, the course offered through the Grafton TAFE in northern NSW offers a range of electives that can be done by correspondence with some work experience required.

Beyond the formal training options there are plenty of textbooks available, but please remember that they are textbooks only. You'll still have to apply the information in them to your own circumstances to write your own operations manual.

If you just want to work for somebody on a fish farm, practical skills are at a premium. We have heard lots of existing fish farmers wish for staff who can fix small motors and pumps, and who have qualifications in electrical repairs.

Other growers are a great source of technical knowledge. They certainly should know what works and what doesn't under a range of circumstances. Networking is an essential part of the industry and, if you select a growers' association that suits your aquaculture profile, this will give you exposure to other farmers. Most associations have a newsletter and many have affiliation with other associations that become handy contact points when growers are travelling outside their own district. Some of them even have their own websites that will list field day, workshop and conference dates. For instance, the Aquaculture Association of Queensland has an annual conference right in the middle of the southern winter, which makes a compelling reason to travel north to meet some of the longest-standing warm water fish farmers in the country and hear a range of guest speakers from government research institutions and industry impart some of the latest technology.

Trade magazines and websites are another good source of information. We are blessed in Australia with a trade magazine that has served the industry for nearly 20 years. *Austasia Aquaculture* magazine is based in Hobart and would have covered just about every aquaculture story in the country over that period. It also has a website and puts out an annual trade directory that leads readers to the equipment and service providers who make life easier for the fish farmer.

International magazines can also provide leads to new technology and overseas trends. Some international websites are free but, to give you some idea of the value of the industry on a global basis, the market report services they provide may cost thousands of dollars.

Arguably the most important knowledge to acquire is market intelligence. That may entail visiting lots of high profile restaurants and talking to the executive chefs to find out what they look for in a product; visiting markets and talking to the buyers and distributors operating out of them; watching at seafood counters in retail outlets, supermarkets and food halls to see who's buying what and listening to the sorts of questions they ask the servers about the products they're buying. Read food magazines and watch/listen to food and cooking programs. Contact food writers and anyone you think can help you with information about the seafood products you're thinking of growing.

Data can be obtained from organisations such as the Australian Bureau of Agriculture Resource Economics (ABARE) that will tell you the volume of seafood produced by each state and territory, and even how much is imported into the country. Austrade is another government service that may be able to offer some useful information regarding what overseas buyers are looking for.

If, at the end of your quest for knowledge, you have spent say $5000, or even $10 000, buying books and magazines on aquaculture; attending courses, conferences

Figure 5.1. A seafood display in an up-market Hong Kong food hall featuring Australian seafood.

and workshops; visiting farmers and probing market opportunities; only to decide the aquaculture industry is not for you, think about the time and money this method has saved you compared to the person who dived straight in without doing the information search you undertook. Compare the outlays and the incomes of the two approaches. You won't get your money back, but you won't have spent as much nor will you be locked into an inappropriate system that is keeping you awake at night wondering how you're going to get out of it.

GWQEHN says:
Don't give up your day job until you're sure of what you're doing.

6

Water quality

Water quality management is the single most important aspect of aquaculture. This chapter deals with:

- the impact of aquaculture on water quality parameters
- the nitrification cycle
- the impact of photosynthesis on water quality parameters
- managing water quality parameters.

You wouldn't think of flying a plane without knowing anything about aerodynamics, and water chemistry and aquaculture share the same relationship. Unfortunately water chemistry can be confusing at first. It's the closest thing in the practical side of aquaculture to rocket science. The authors have tried to simplify it as much as possible, but don't worry too much if it doesn't come easily to you at first. We keep coming back to it throughout the book so a good deal of it should stick by the end of the first reading. The important thing is that the symptoms of deteriorating water quality are recognised and the corrective measures are understood.

It should be noted that the parameters discussed in this chapter are for freshwater systems only. Biochemistry in brackish or saline waters, although similar in dynamics, responds in a different, and slightly more complex manner. However, as most marine farming is carried out in sea cages or flow-through shore-based systems, the dynamics don't impact on the production system as dramatically as they do using static pond methods.

The importance of water quality

Water quality imposes the living standards under which the farm stock live. A low-living standard will give the farmer low production and a high number of problems to solve.

The dynamic and volatile nature of water quality

Water quality is dynamic. It can and will change in nature very quickly under certain influences. Cause and effect can have a complex connection and understanding these relationships, as well as being able to manage them, is the role of the pond manager.

The influence of photosynthesis on water quality

Photosynthesis

This is the formation of organic substances in plants. These substances are mainly sugars, and are made from carbon dioxide, nitrogen, phosphorus and trace elements.

The energy of the sun is the driving force of photosynthesis. The most prolific plant form found in productive fish ponds is phytoplankton. Under certain circumstances it can form a dense cloud of these microscopic organisms. This is called a plankton bloom.

Oxygen production

This is part of the process of photosynthesis. The phytoplankton extract carbon from the carbon dioxide (CO_2) in the water, leaving the oxygen molecules. This increases the amount of dissolved oxygen in the water. During the night the aquatic plants revert to normal respiration: using up oxygen and generating carbon dioxide. This process is called 'reverse photosynthesis'. What this means to the fish farmer is the greater the plankton bloom, the more extreme the output and uptake of oxygen.

pH

Put simply, pH is a measure of how acidic the water is. Photosynthesis, by breaking up the CO_2 in the water, raises the pH (less acid) during daylight hours; and reverses this process by respiration at night (more acid). It is the transpired CO_2 that increases the acidity of the water and the uptake of carbon to build phytoplankton cells that reduces the acidity. (N.B. In an indoor fish farm, devoid of sunlight, photosynthesis is not an issue.)

Plankton

What role does plankton play in the pond's food supply and what effect does it have on water quality?

Phytoplankton

Phytoplankton provides the foundation upon which the natural food web in a water body is anchored. Plants need light and nutrients to grow. The density of the phytoplankton in ponds is driven by the availability of these two inputs. The sun provides the light. Nutrients are compounds containing elements such as nitrogen, phosphorus and potassium (N-P-K). Nitrogen and phosphate are both natural by-products of fish and crustacean growth.

Zooplankton

Zooplankton are the micro and macroscopic crustaceans that feed on the phytoplankton and between them these two groups make up a large proportion of the natural food created in a pond.

Microbes and bacteria

Microbes and bacteria are an important part of the plankton and they have the role of breaking down the organic waste in the pond. This organic waste is called detritus and is made up of fish waste, dead plankton and rotting vegetable and material such as hay and dead fish. It forms an important habitat for the microbes. The bacteria that convert the potentially dangerous ammonia to relatively safe nitrate are also part of this group.

Microbes also make up the nutrient source of many crustaceans.

Invertebrates

Invertebrates consist of the aquatic insects and their larvae that inhabit the pond. Although often not regarded as plankton, they are part of the biota that makes up the plankton.

Plankton deaths

Plankton deaths are not uncommon. When plankton die in large numbers, the resulting changes may be contributing factors causing a water quality collapse.

The plankton crash

Plankton relies on sunlight for its energy. If a productive burst of warm weather, particularly in a nutrient-rich pond, is followed by a cold snap or overcast conditions due to thunderstorm activity, the recently booming phytoplankton is suddenly deprived of its energy source and it dies. When it dies, it deprives all those organisms depending on its life-giving properties for survival.

To have the pond's food supply stopped is one thing, but the real danger is that the dead plankton sinks to the bottom of the pond where it starts to rot. The process of degradation uses oxygen at an alarming rate, thus denying it to the rest of the pond life. This is called a plankton crash.

Plankton crashes are one of the nastiest things that can happen to a fish farmer. The irony is that when natural food production is at its best the ponds are at their most vulnerable. However, being caught by a plankton collapse is avoidable! If the farm is in a district subject to irregular conditions, during the height of the season the farmer should keep an eye on the weather map and ease off the nutrient input at the first sign of a low-pressure system and/or exchange the water in the pond. The pond may have to be flushed out to remove some of the phytoplankton. Water should be monitored for any unmanageable swings in water quality. We won't tell you that judging this is as easy as falling off a log, because it's not, but it is a skill that can be developed fairly quickly once you get down to it.

Sudden weather change is not the only cause of plankton crash. An imbalance in the pond's nutrient load can also cause the pond's biological mechanisms to fail.

It is impossible to operate a commercial fish farm in the open without creating a plankton bloom. Managing it is the secret and that's what we're going to look at once we've got the nuts and bolts sorted out.

Biota and biochemical oxygen demand

Biota or biomass

The biota or biomass is the total volume of the organisms in the pond ranging from the microbes and the plankton to the fish being produced.

These organisms all use oxygen and the amount of oxygen they use is called the *biochemical oxygen demand* or BOD. When the fish in the pond are small they place very

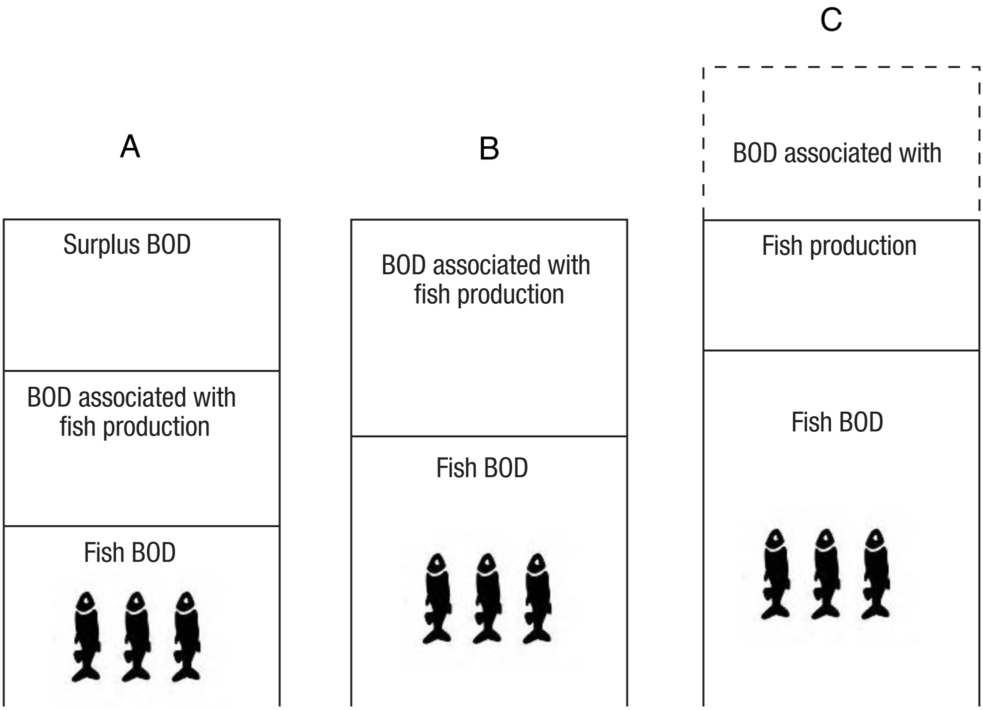


Figure 6.1. Biochemical oxygen demand (BOD).

In A the biomass has surplus oxygen in the system.
In B the activity of the system's biomass has utilising all the available oxygen.
In C the BOD had exceeded the system's oxygen supply.
One of the most important concepts of aquaculture is BOD. The capacity of the system is governed by the draw down of its oxygen supply by the organisms in it. Those organisms include those supporting fish metabolism. They include the bacteria that are turning the potentially lethal ammonia into relatively harmless nitrate as well as those breaking down the faeces and other organic solids associated with fish production.

little demand on the BOD. As they grow the percentage of the BOD that they occupy increases. At the same time, the pond's other biota are expanding and increasing their component of the pond's BOD. Awareness of the pond's BOD, or bio-space, is a key element in managing your system and is one of the factors determining stocking rates.

This also governs the production of natural food in the ponds. Phytoplankton (algae) will produce oxygen during the day but the same system will require supplementary aeration overnight.

Should the demand from the organisms in the system exceed the available oxygen then the activity of the organisms will shut down to varying degrees. The system will at best be compromised, at worst crash. The step from best-case scenario to worst-case scenario under these circumstances can be a very short one, especially in re-circulation systems. It sounds and looks simple enough, but you'd be surprised how many growers seem to ignore this concept when determining stocking density.

Oxygen

Oxygen is dissolved in the water at very low levels compared to atmospheric oxygen (about 33 000 times lower) and is referred to as *dissolved oxygen* or DO for short.

Oxygen is dissolved in the atmosphere at the rate of 21 parts per hundred but water will, on average, only dissolve 10 parts per million[1] (milligrams per litre) thus making it an extremely precious resource in a fish production system.

Because every organism in the water uses oxygen, it's the farmer's job to ensure that one group of organisms doesn't deprive another group of this life-giving element.

Dissolved oxygen

DO levels vary at different altitudes and different temperatures. Altitude should not be a problem in warm water farms in Australia but water temperature will. Colder water can hold higher levels of DO than warm water. Water at sea level will hold more DO than at the top of Mt Kosciuszko. Most fish farming in Australia is carried out at altitudes close to sea level or at elevations beyond any major influence on oxygen saturation levels.

The saturation level of dissolved oxygen

This is the point beyond which the water is unable to retain DO. Warm water species have generally evolved a capacity to handle lower DO levels than cold water species.

Supersaturated DO levels

These can be experienced in phytoplankton-rich ponds but only as long as the sun's energy is driving the photosynthetic process. Indoor production systems can also have water supersaturated with DO. Concentrating oxygen from the atmosphere, injecting it under pressure into water and introducing the water to the production tanks will lift the saturation level of the water available to the fish. In either case the supersaturation is only transient and the fish will avail themselves of the opportunity to use the extra oxygen to metabolise food and other everyday energy-using functions.

Signs of oxygen deficiency

Fish suffering oxygen deficiency can be seen gulping at the surface in a frantic effort, or sluggish manner, depending on the progress of the emergency. Fish that have died of oxygen starvation (anoxia) usually have their gills and mouths agape.

Aeration

To prevent oxygen deficiency, aeration of some sort will be necessary on a commercial fish or crustacean farm. In Nature this process is carried out by the agitation of wave action and water movement over rocks and logs. In aquaculture, mechanical devices are used. We'll discuss the options and outcomes from mechanical aeration in chapter 12.

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1 The authors have used the calibration of milligrams per litre, in most cases, written as mg/L. This value can also be read as parts per million (ppm).

Table 6.1. The saturation levels of oxygen in chloride-free water at sea level.

ºC	mg/L	ºC	mg/L	ºC	mg/L
0	14.6	12	10.8	24	8.5
1	14.2	13	10.6	25	8.4
2	13.8	14	10.4	26	8.2
3	13.5	15	10.2	27	8.1
4	13.1	16	9.9	28	7.9
5	12.8	17	9.7	29	7.8
6	12.5	18	9.5	30	7.7
7	12.2	19	9.3	31	7.5
8	11.9	20	9.2	32	7.4
9	11.6	21	9.0	33	7.3
10	11.3	22	8.8	34	7.2
11	11.1	23	8.7	35	7.1

Stratification of water

When pond water is warmed by sunlight, the water at the surface will become less dense than the cooler water at the bottom of the pond. Anyone who has dived into a farm dam to cool off in midsummer will vouch for that.

The water at the surface is called the 'epilimnion'. The water at the bottom of the pond is called the 'hypolimnion'. The layer of water that forms the demarcation between the two bodies of water is called the 'thermocline'.

Unless something is done to de-stratify it, the pond will actually be made up of two ponds, one sitting on top of the other. Until the weather changes, and the epilimnion becomes colder than the hypolimnion, the two will not mix of their own accord. Wind action is rarely enough to mix the two bodies of water; otherwise you wouldn't get such a shock when you dived through the warm surface water into the cold hypolimnion in the farm dam. De-stratification can only dependably be achieved by mechanical aeration.

On the farm, it is important that the thermocline be broken and the pond water well mixed to ensure an even temperature and good distribution of pond nutrients, natural foods and oxygen. This is particularly critical in crustacean ponds where the animals live mainly on the bottom of the pond.

In a re-circulation system, the water is continually on the move and is thoroughly mixed. In these systems, stratification should not be an issue.

How do fish breathe and what happens when they do?

Oxygen and fish

Fish pump water across their gills. The difference in the partial pressure of the oxygen in the water and in the fish's blood forces oxygen into the blood, where it diffuses into the haemoglobin. It is then transported and used around the body to drive the bodily functions, including digestion and metabolism. The gradient of partial pressure of oxygen is greatest when the water is nearest saturation level. It becomes harder for the fish to obtain oxygen as the DO levels fall below saturation level. As levels fall, farm stock respond by reducing their activity levels, primarily feeding, digestion and metabolism. When DO levels fall so low that oxygen becomes unavailable, the stock die.

Different species have different tolerance levels and our warm water native fish are amongst the best in the world at handling low oxygen levels. But this doesn't mean they thrive on them.

Smaller fish use more oxygen than larger fish because their metabolic rate is higher. For instance a 5 g fish may be growing at three times the rate of a 1 kg fish of the same species. Presuming the feed conversion rate is the same, the smaller fish will use three times the amount of feed and require, in simple terms, three times the amount of oxygen to metabolise that feed. Therefore a tank that can comfortably handle 300 kg of feeding fish of a kilogram each would only be able to grow around 100 kg of 5 g fingerlings at commercial feeding rates. The gain in weight on a daily basis within the system would be the same, as would the oxygen requirement.

Feeding fish also use more oxygen than fish that are not feeding. The oxygen requirement for fish that are feeding, digesting and metabolising feed can be twice that of fish that haven't been fed for half a day and are in the resting phase. Growers will sometimes increase the oxygen levels to cope with these high oxygen requirement periods in heavily stocked ponds or tanks when the biomass has increased beyond the particular system's normal oxygen output.

Other factors that impact on DO requirements are fish activity, the condition of the fish and water temperature. In some cases the increase can be considerable. For instance doubling the speed fish are forced to swim can double their oxygen uptake. If there are fluctuations in the system's oxygen uptake it will be necessary to monitor the DO levels. In re-circulating systems it will probably be done by a computerised monitoring system but most pond operators use a DO meter (see chapter 12). Of course there's always the el cheapo method of waiting for the fish to come to the surface gasping for air to tell you to turn on the aerators.

Ammonia

Another by-product of fish metabolism is the production of ammonia. This compound is produced as part of the respiration and will also be generated by the process of breaking down the fish's waste and uneaten food. We'll look at ammonia in more detail in a moment.

Carbon dioxide

Carbon dioxide (CO_2) is also expelled from the body via the fish's gills. This has a fluid relationship with the other elements in the surrounding water where it will be taken up by the phytoplankton, become part of the carbonic acid in the system, as well as building up the CO_2 levels in the water.

Excessive CO_2 in the water will make fish lethargic. It will also block the absorption of oxygen to the water. As CO_2 seeks equilibrium, this dissolved gas is easily removed by the same agitation that allows oxygen to be dissolved in the water. Re-circulation systems may sometimes include a de-gassing tower, where the water falling down over a series of obstacles, breaks the water's surface tension and allows any CO_2 to escape from the water. Some systems even have an exhaust fan drawing off the air from these de-gassing towers. There is a simple chart that allows the grower to measure CO_2 by reference to the measured carbonate hardness and the pH of the water that we'll look at later.

To keep stock breathing freely, and for maximum production, it is best to keep DO levels as close to saturation as possible. If the ponds are relying on high levels of plankton production for their nutrient supply, or high plankton levels are experienced from feeding programs, it would be unwise to operate without mechanical aeration of some kind.

Ammonia and the nitrification process

Ammonia not only comes from fish waste and metabolism, it is generated by the activities of the pond biota. The more active the pond, the more ammonia is produced. As the farmer is trying to keep his pond as active as possible to enhance production, ammonia is an ever-present threat and can often become a problem. Ammonia production is also associated with high protein loadings in the pond such as uneaten food or dead fish.

It is present in the water as gaseous ammonia (NH_3) and as the dissolved ion ammonium (NH_4^+). We measure its presence as Total Ammonia Nitrogen (TAN). It is mainly present in the aquatic environment as ammonium. Ammonium is only toxic to fish in very high concentrations. It is when it's in the gaseous or free form that it can be highly toxic to fish. This is one of the tests we carry out to ensure the fish are in a safe environment and we'll be looking at the management options in chapter 12.

The temperature and pH (acidity) of the water determine the proportion of un-ionised or toxic ammonia that is active in the water. The colder the water and the lower the pH (more acid), the lower the amount of toxic ammonia free in the water and the greater the amount of relatively harmless ammonium.

Yabby farmers use this bit of water chemistry to their advantage by lowering the water temperature of their yabby-holding systems to minimise the amount of toxic ammonia in the water, as well as keeping their yabbies calm. Growers raising fish in re-circulation systems, where they have almost total control over their water quality parameters, take advantage of it by keeping their pH low, by adding Epsom salts (magnesium sulphate), to achieve the same result in cases where they have high TAN readings.

Even though water temperature and pH might be keeping the toxic ammonia in check, the presence of total ammonia nitrogen of over 0.5 mg/L should be cause for review of the system's water quality, especially if the reading is constantly climbing. Although TAN readings are not necessarily dangerous in themselves, an increasing TAN is an indicator of a nutrient load build-up and will cause the fish some discomfort. Stress not only reduces production, it can undermine the fish's immune system thus contributing to disease.

The symptoms of ammonia toxicity are lethargy and depression as their nervous system starts to deteriorate. The final result is death and the progression of the condition is rapid.

The treatment is to aerate like mad and exchange water until the problem has been flushed from the system.

It may be difficult to keep ammonia levels down in a commercial pond. Levels of between 0.5 mg/L and 2 mg/L are not uncommon in warm water ponds. However, while some species may withstand ammonia levels as high as 2 mg/L in short bursts, prolonged exposure can be fatal. It will certainly damage sensitive parts of the fish's anatomy, especially the sensitive and crucial gill tissues, and compromise their immune system. Aquatic systems managers should aim to hold ammonia levels below 0.1 mg/L, either by keeping the pH levels in the system low or by operating at a low TAN level.

Constant short periods of exposure are a sign of poor pond management procedures. They will result in loss of production at best, and mortalities at worst. The most likely cause is overfeeding and/or overstocking. Management procedures should be reviewed as soon as the instability is noticed and every effort made to return the water to a balanced state.

Table 6.2 below shows the influence of pH and temperature on toxic ammonia in the water in relation to TAN. It can be seen how the increase in pH dramatically increases the percentage of NH_3 in the water. TAN levels must be monitored and managed if the grower is to maximise results from the pond. Keeping it at 'safe' levels is only one aspect of the management procedure. Keeping it at minimum and stable levels will reduce stress on the fish and give the grower better results.

Table 6.2 allows the grower to monitor several elements in the system's water and calculate what other values are. For instance: if the water temperature in the system is 24°C and the pH is 8 then 5% of the TAN will be present in the un-ionised toxic form. If the TAN is 2 mg/L, the ammonia is 0.1 mg/L. Should the temperature remain at 24°C

Table 6.2. Percentage of total ammonia nitrogen (TAN) in the toxic un-ionised form NH_3 at different temperature and pH values (from Boyd, 1982).

pH	Temperature (°C)						
	8	12	16	20	24	28	32
7.0	0.2	0.2	0.3	0.4	0.5	0.7	1.0
8.0	1.6	2.1	2.9	3.8	5.0	6.6	8.8
8.2	2.5	3.3	4.5	5.9	7.7	10.0	13.2
8.4	3.9	5.2	6.9	9.1	11.6	15.0	19.5
8.6	6.0	7.9	10.6	13.7	17.3	21.8	27.7
8.8	9.2	12.0	15.8	20.1	24.9	30.7	37.8
9.0	13.8	17.8	22.9	28.5	34.4	41.2	49.0
9.2	20.4	25.8	32.0	38.7	45.4	52.6	60.4
9.4	30.0	35.5	42.7	50.0	56.9	63.8	70.7
9.6	39.2	46.5	54.1	61.3	67.3	73.6	79.3
9.8	50.5	58.1	65.2	71.5	76.8	81.6	85.8
10.0	61.7	68.5	74.8	79.9	84.0	87.5	90.6
10.2	71.9	77.5	82.4	86.3	89.3	91.8	93.8

From *Silver Perch Culture* (Rowland and Bryant, 1994).

but pH then leaps to 9.2 (as it can), then 45.4% of the ammonia component of the TAN would be toxic. Without a change in the TAN levels of 2 mg/L, the ponds would literally become a time bomb by the movement of just one parameter as the ammonia content of the water reaches 0.9 mg/L.

pH and its effect on water quality

Without doubt pH is the most misunderstood element of water quality and its management. pH is the measurement of the hydrogen ions in a given situation and is calibrated on a scale of one to 14. A pH reading of 7 is neutral. Strictly speaking, this should be qualified by saying that at a temperature of 25°C, however, for our purposes we can accept that a pH of 7 is neutral. The lower the reading is below 7, the higher the acidity of the medium being measured. Conversely, the higher the reading above 7, the higher the alkalinity in the pond's water or substrata. We'll examine the options for this in chapter 12.

The pH reading in aquaculture systems is influenced to a large extent by the carbonate hardness level. In distilled water at sea level the pH of water with a carbonate hardness reading of 100 mg/L will be 8.17. It doesn't increase above that but it will fall away as the carbonate hardness reading drops. Aquaculturists use this factor to 'buffer' their water against radical downward pH swings by liming their ponds or adding bicarbonate to their re-circulation systems respectively.

The optimum range of pH for fish farming is between 6.5 and 9. Fish can tolerate short bursts of extreme pH down to 5 but it is highly inefficient to keep them at that range. Commercial species will not survive below a pH of 4.

Ponds carrying high phytoplankton loads – and let's face it, most of us will have to deal with the situation at some point during the season – may climb to a pH of 10 or more as photosynthesis dissembles the carbonic acid in the water to build plant cells. In saline situations higher extremes, up to 12 pH, have been experienced in phytoplankton-rich situations. It is in this kind of situation that large numbers of oxygen molecules are released from the CO_2 chain and the water becomes supersaturated with dissolved oxygen. Fish can tolerate high pH in short bursts but prolonged exposure will be stressful and sometimes lethal; pH levels of 11 will certainly prove to be so for most species we'll encounter on a commercial fish farm.

pH will move up and down during the production of phytoplankton. A high pH will present a problem with toxic ammonia when TAN levels are high so it is imperative that the pond manager regularly monitors the pH for signs of wild swings.

Wild swings of pH are also a good indication that the pond is producing large amounts of plankton with consequentially high oxygen output and CO_2 uptake during the day, with the reverse high oxygen uptake and CO_2 output during the night.

Fish love stability and pH swings place unnecessary stress on them. Further to that, excessively high or low pH can damage the gill membranes. The damaged gills open the path to bacterial infection, which will compound an already grave situation, and lead to mortalities.

pH is also influenced by the biological activity occurring in the water. Growing fish or crustaceans will produce acids that eat into the carbonate hardness buffer. The action of the nitrification process, whether in an open pond system or a re-circulation system, will eat into the carbonate reserves in the system as part that process. pH is a fluid element within the system and will have to be monitored and managed. Remember, the role of a fish farmer is to maintain control over the balance and stability of his or her system.

Biological balance

With all this ammonia build-up and biological activity going on in the water we should be getting pretty worried. But nature comes to our aid. Chemoautotropic bacteria change the ammonia nitrogen in a two-stage process called nitrification. Using oxygen as a source of energy, *Nitrosomonas* bacteria make use of the ammonia to form nitrite (NO_2). *Nitrobacter* bacteria, using carbon dioxide as a source of carbon and oxygen as a source of energy, turn the potentially toxic nitrite into relative harmless nitrate (NO_3). It has been found that nitrification is most efficient at pH ranges between 7 and 8 when the temperatures are between 25°C and 35°C.

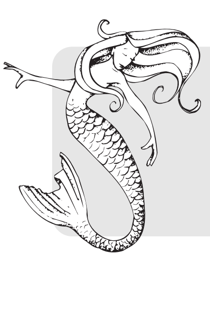
If nitrite is toxic to fish, why doesn't the nitrification process kill them? It is because the two nitrifying bacteria act in unison. As the *Nitrosomonas* convert the ammonia to nitrite, the *Nitrobacter* convert it to nitrate. In poorly managed or designed systems, the nitrate finds itself trapped in a pocket of oxygen-depleted water. In some circumstances oxygen will be 'robbed' from the nitrate (NO_3) in order to drive a chemical or biological function of some other element or organism. The relatively harmless nitrate loses an oxygen molecule and becomes nitrite (NO_2) again. Under these oxygen-depleted circumstances the nitrite will remain in that form and become a lethal factor in the system.

To say that oxygen drives the nitrification process is an understatement. As we will explore later, oxygen is one of the most critical components in a successful aquaculture system.

The nitrification process will eat away at the carbonate levels in the system and, unless managed, the pH will go into free-fall. In re-circulation systems the process is managed by adding bicarbonate to maintain a reading of 100 mg/L or higher. In active systems, managers will find themselves doing this on a daily basis.

Some re-circulation operators take the view that the fish will live with high TAN readings as long as the pH is kept low. These operators may allow the pH to fall to around 6 and hold it there by dosing the water with magnesium sulphate.

There shouldn't be any need to exceed 150 mg/L, and 300 mg/L would be approaching the upper limit. In pond systems, the manager buffers against pH swings by liming the ponds between crops or even during the growing season should the need arise.



GWQEHN says:
Don't fall for the trap of loading up your re-circulation system with enough carbonate hardness on Monday to last the whole week. A little and often will give better results. Remember – stability and balance are the keys to aquaculture.

If you are farming in a flow-through system or in sea cages these rules also apply. However, there's little you can do, as you will have to take the water that the tides or the diversion brings you. That doesn't mean you don't measure the situation so you can monitor the conditions the stock are growing under. Farmers operating a static pond site or a re-circulation system will have to be very aware of this chemistry and how far it can be taken. Throughout this book we will discuss nitrification in its many forms and in different circumstances.

General hardness and carbonate hardness (alkalinity)

Carbonate hardness

There exists a complex chemical relationship between pH, carbon dioxide, hardness and carbonate hardness. Carbonate hardness is also called alkalinity. In this book we'll use carbonate hardness calibrated in milligrams per litre. There are several ways of measuring these values in the water (see chapter 12).

Carbonate hardness buffers water against the pH swings caused by the movement in and out of the water of CO_2 generated by the action of photosynthesis, metabolism, nitrification and respiration. Water with a moderate to high carbonate hardness does not react as wildly to an active plankton bloom.

General hardness

Hardness, or general hardness as it is sometimes called, measures the amount of calcium, magnesium, potassium and some other salts in the water. If the carbonate hardness is low it can be corrected by adding calcium carbonate (agricultural limestone) in a pond system or bicarbonate of soda in a re-circulation system. General hardness can be adjusted, but in most cases it's not considered to be necessary unless it is beyond the tolerance range of the fish.

Most surface water in Australia is what we would regard as soft – below 20 mg/L carbonate hardness. Adding agricultural ground limestone (calcium carbonate) to ponds will lift the general hardness levels as well as carbonate hardness and calcium levels. We'll look at this in more detail later.

Calcium has a beneficial contribution to the health of the fish and the quality of the water. Crustaceans absorb it during moult to harden their shells. Shellfish use it for shell building, finfish utilise it for bone formation. In addition, calcium is also necessary for efficient osmoregulation and it reduces the toxic effect of ammonia and metal ions.

Most textbooks will tell you to keep your fish ponds at a carbonate hardness of between 20 mg/L and 250 mg/L with the optimum at around 100 mg/L to 150 mg/L. In conversation with Michael Masser, when he was visiting Australia as head of the Alabama Fisheries Extension Service, he pointed out that channel catfish farmers in the USA try to keep their ponds up around the 100 mg/L carbonate hardness level and are uncomfortable should they fall below half that figure. The USA channel catfish aquaculture produced over 250 000 tonnes of fish a year, so we can only be guided by the experts.

The range for general hardness is in reality species-specific but a reading of between 50 mg/L and 200 mg/L would be fine. If it's any help, those long experienced fish keepers, the ornamental growers, favour 150 mg/L to 180 mg/L as an appropriate range for natives.

The relationship between carbonate hardness, pH and carbon dioxide

The relationship between carbonate hardness, pH and carbon dioxide is not too dissimilar to the previously described relationship between pH, ammonia and temperature. By accurately knowing the pH and carbonate hardness, it is possible to calculate the amount of carbon dioxide in the water. Carbon dioxide acts as a sedative on the fish and reduces their activity, which we don't want in an aquaculture production system. The following table and comments are courtesy of the late Richard Carson of Aquasonic, Ingleburn, NSW.

Table 6.3. The relationship of CO_2, pH and carbonate hardness.

Carbonate	pH								
(mg/L)	6.0	6.2	6.4	6.6	6.8	7.0	7.2	7.4	8.0
10	15	9.3	5.9	3.7	2.4	1.5	0.9	0.6	0.2
20	30	19	12	7	5	3	1.9	1.2	0.3
30	44	28	18	11	7	4	2.8	1.8	0.4
35	59	37	24	15	9	6	4	2.4	0.6
45	73	46	30	19	12	7	5	3	0.7
55	87	56	35	22	14	9	6	4	0.9
60	103	65	41	26	16	10	7	4	0 1
70	118	75	47	30	19	12	6	5	1.2
90	147	93	59	37	23	15	9	6	1.5
110	177	112	71	45	28	18	11	7	1.8
140	240	149	94	59	37	24	15	9	2.4
180	300	186	118	74	47	30	19	12	3.0
270	440	280	175	111	70	44	28	18	4.0

Where does carbonate hardness go?

Carbonate hardness is eaten away by acids in the water.

There are many sources of acid in a seafood production system:

- acids are constantly formed in an aquaculture production system by biological breakdown of waste products. This process also draws on the water's DO reserves;
- fish release acids into the water. In live seafood systems and large stock-holding facilities, the influence of such acids can be dramatic. When fish are handled, whether they are abalone, crustaceans or finfish, large amounts of lactic acids are produced and purged into the water;
- acids are produced by respiration; carbon dioxide forms carbonic acid; and
- as biological filters develop they produce nitrite (NO_2) which combines with water to form nitric acid.

As acids from these sources, and more, constantly eat away the carbonate hardness of the water, the pH falls. Once the buffering effect of carbonate hardness is gone the pH may fall uncontrollably. If the pH goes into free-fall, the stock in the system are in grave danger.

Turbidity

Turbidity can be defined as the distance you can see into the water. It can be caused in several ways: by inorganic clay particles being suspended in the water; and by organic particles including phytoplankton blooms.

Turbidity is measured by using a 'Secchi disc'. The Secchi disc is divided into quadrants of black and white and mounted on a calibrated rod. The depth at which the disc disappears from view is the Secchi disc reading. It is used to monitor plankton density. More on this later when we look at plankton production.

Colloidal clay particles can be particularly dense. A dam in an old goldfield region usually displays the characteristics of the typical cream to rusty-red of colloidal clay suspended in the water. Light penetration under these circumstances is practically zero. Turbidity caused by a plankton bloom will vary according to the state of the bloom and the density of the algae.

In the case of the colloidal clay particles it has been found that they tend to flocculate (fall out) of the water as a by-product of plankton production and/or as liming changes the nature of the substrate.

Turbidity will reduce the amount of the sun's energy the pond can absorb with the obvious reduction in plankton production. Once the sun's energy is reduced to 5% of the light striking the water surface, plankton production is minimal. At 1% it ceases altogether.

Heavy colloidal turbidity in particular, and to a lesser extent plankton production, will reflect the heat and also prevent the pond from warming up.

In ponds not protected by bird nets, turbidity makes it harder for the birds to locate your stock, but only a millionaire would rely on it to protect them entirely.

Hydrogen sulphide

Hydrogen sulphide, or rotten egg gas, is caused by the activity of anaerobic bacteria and is highly toxic to fish. Hydrogen sulphide (H_2S) is fatal to fish at concentrations as low as 0.01 mg/L to 0.05 mg/L. It is most dangerous at low pH levels.

Hydrogen sulphide is generally associated with high loadings of organic matter in the substrate, where the aerobic bacteria use available oxygen to break down the matter. Once the oxygen has been depleted, anaerobic bacteria take over and generate hydrogen sulphide, with the consequences rapidly becoming fatal. It is a condition to be avoided at all costs. Uneaten food, hay, dead fish and plankton all contribute to increased loadings of organic matter and these should not be allowed to accumulate in a situation with inadequate oxygenation. In finfish sea cages, the seabed under an overfed, or over-utilised cage, will turn black, indicating a build-up of organic matter and a shift to anaerobic conditions if the cages aren't managed in a responsible manner.

How does the practical farmer tell when things are going bad? The sludge on the bottom of the pond will be black and have a strong 'rotten egg' gas smell to it. In really bad cases, when you walk through the ponds your footsteps will squelch out foul-smelling bubbles from the anaerobic mud. This is not a bad thing in itself as the anaerobic zone is trapped in the substrate, but it is a warning to make sure you keep the substrate well aerated.

The short-term cure is aeration and water exchange. The effects of the aeration must reach the bottom of the pond otherwise it won't cure the problem; so using the right method is essential.

If the condition becomes established, a review of management practices, particularly the feeding and aeration regimes would be in order. In unmanageable cases, more radical action will need to be taken, such as draining, drying and removal of the build-up of organic waste material. Black, foul-smelling sludge on the bottom of the pond is an indication of the presence of anaerobic bacteria. In most cases the sludge is contained under a thin layer of aerobic silt. As long as that thin layer of aerobic bacteria has plenty of oxygen it will be the dominant microbe. However, should a situation arise in which a sudden demand on the aerobic bacteria causes a depletion of the available oxygen in that zone, the anaerobic bacteria will become the dominant microbial force with the consequential hydrogen sulphide event. A poorly managed plankton crash is a common cause of such an event.

There are proprietary brands of 'algae eaters' available and it has been claimed they may assist, and they're certainly worth a try, but they tend to be expensive and personal experience with them has not been encouraging. They are made up of enzymes that attack the 'bad algae'. In this case, the cause of the problem lies at the bottom of the pond and can only really be corrected at its source.

Oxidation-reduction potential (ORP)

Oxidation-reduction potential (ORP) is a straightforward process controlling chemical reactions. As Professor Claude Boyd describes it in his book, *Water Quality in Ponds for Aquaculture*: 'a substance is oxidised if it loses electrons and reduced if it gains electrons. Every oxidisation requires a corresponding reduction to balance electrons. The substance gaining electrons is an oxidizing agent and the one losing electrons is a reducing agent' (p. 90).

What this means in aquaculture is that when oxygen is depleted in a place that can't or isn't being re-oxygenated, some elements there will draw oxygen from other elements thus changing their nature. It is the oxidation-reduction potential (ORP) that drives the formation of hydrogen sulphide in anaerobic pond mud, and when nitrate is reduced to nitrite.

ORP can be measured. ORP readings can be used to evaluate the potential of the system to handle any pressure placed on it by an adverse chain of events (usually instigated by an ill-judged management procedure) and the system's ability to maintain the balance and hold a stable water quality. In a nutshell, ORP readings measure your system's readiness to absorb a load, either intended or not.

Dealing with water quality problems

Fish farmers, as you can see from the above sections, can be faced with a multitude of problems from water quality. Fortunately warnings are there for the grower, through certain parameters that should be closely monitored. Picking up a particular trend, before it becomes a problem, can save your crop. In the longer term there are other steps that growers can take to make their systems a safer place for fish and crustaceans.

Monitoring

Monitoring certain water quality parameters forewarns the aquaculturist of impending disasters. Monitoring should be undertaken daily when high stocking and production rates are used.

In open ponds, taking a reading before the sun has risen and another at midday will allow plotting of the daily movement in the water quality values driven by photosynthesis. The rule of thumb is that the upward movement of the values during the day will be a mirror image of the values as the sun ceases to drive photosynthesis. An alternative method is to take a reading at noon followed by another at dusk and extrapolate the decline of the graph to estimate the amount of oxygen in the pond at a given time after photosynthesis has ceased and the algae and other organisms in the pond become net users of the oxygen reserves.

The pH will follow a similar pattern in ponds driven by photosynthesis. It will rise during the day, alarmingly so in poorly buffered ponds, and fall during the night. Midday pH readings as high as 10 can be recorded. Ponds with a TAN level of any consequence, say over 0.5 ppm, would be of concern under these conditions.

For example, if the DO at early dawn is 4 mg/L and at midday it is supersaturated, at say 15 mg/L, it will have a corresponding decline during the night reaching its nadir as the sun starts to get the next day's photosynthesis under way.

Of course, if you have the aerators running through the night, the dawn reading will be distorted. In that case you'd get a better idea of the shape of the graph by doing it in reverse. Take a noon reading and a dusk reading and plot the angle of the decline in DO values along that line.

The reality of the situation is that with just a little experience you will be able to confidently estimate when you will need to aerate. Most growers will set their aerators to cut in at 11 pm when the off-peak electricity rates kick-in and to switch off at 7 am when the day rates start again because they know their ponds are loaded with phytoplankton and will need aeration anyway.

This doesn't mean you don't take the readings. Remember the oxygen drives the pond's biochemical oxygen processes. You should know how much you've got in the tank. However, you can have a day off for cricket or tennis once a week without endangering your ponds as long as you're sure they're stable.

At this point, the new chum should be warned that identical ponds don't seem to behave in an identical way, and this variation can be very confusing at first. Of course the variation may be due to instrument error (and we'll deal with this later) but concentrate on the trends for each pond and you won't get into too much trouble. (We seem to cope with our kids being different from each other even though they're from the same mould, so just use the same rationale.)

In re-circulation systems the story is vastly different. The biological load on the water quality is much higher, sometimes as much as 200 times higher. The fickleness of the weather won't have an impact on your system (unless you have built the system in an uninsulated shed and not made provision for temperature control) but the effect of photosynthesis shouldn't be an issue. In fact, one of the huge advantages of re-circulation technology is that the water quality parameters should remain more or less constant. If there is any continuing shift in water quality values, there is cause for concern.

For instance, should the DO values fall over three consecutive readings, an explanation should be sought immediately; likewise, any continuing rise in TAN readings.

The values that should be monitored on a daily basis in an open pond system at either dawn and midday or midday and dusk are:

- *dissolved oxygen levels* will tell you how much fuel you have in the tank to drive all the processes such as respiration, metabolism, nitrification, degradation and just about anything else that's good for the system.
- *pH levels* will tell you how stable your system is and alert you to times when it could be entering danger zones in relation to upper and lower critical pH circumstances and how much of the TAN is present as toxic ammonia.
- *maximum and minimum temperatures* will tell you what gear your system is in. As fish are cold blooded they operate more efficiently at certain temperature bands. Their metabolic rate will respond to water temperature and the amount of food they can metabolise. Anything fed over their capacity to metabolise will be passed into the water and load your system with unwanted nutrients that will have to be neutralised, using precious oxygen. Temperature also has an influence on the amount of ammonia in the water.
- *total ammonia nitrogen, or TAN*, will tell you how your bio-filtration system is working and how much risk you're running should the temperature or, more particularly, the pH level rise.
- *ammonia (NH_3)* – calculated from Table 6.2 after measuring the temperature, pH and TAN.
- *nitrate readings* will tell you what the build-up of nitrate is in the system. Upper critical levels are high and factors contributing to a dangerously high reading are more likely to be a threat than the actual nitrate value. In a pond system, nitrate is taken up by photosynthesis, and in a re-circulation system the continual water exchange associated with flushing organic solids from the system should ensure that it doesn't reach lethal levels.
- *nitrite values* will tell you how efficiently your system's bio-filtration processes are working, and whether or not you are getting any reduction in the nitrate the system will be building up.
- *Secchi disc readings* will tell you the density of your phytoplankton bloom. Should the disc disappear from view at a depth of 20 cm, or less, the pond is carrying a volatile density of phytoplankton and it will have to be dealt with. If the ponds are producing natural feed and the reading falls to 50 cm it would indicate that the ponds are getting low in nutrient and fertiliser will have to be added to boost production. The Secchi disc reading will give you a profile of the condition of the system's environment.

Interpret your readings

The measurements should be recorded in the production book and interpreted. Using a computer program that can plot these values on a graph will help you appraise any movement in the condition of that particular parameter. When it comes to long-term reviews, graphs make comparisons so much easier.

Interpretation is important. Make it a part of your daily routine. It may sound silly but the authors have known people to record these parameters, especially in a situation where more than one person is taking the readings, and then overlook interpreting them, with disastrous results when they have missed a crucial trend.

The nitrification cycle titration tests are slow and the authors are going to trust you here. If you're absolutely certain that the ponds are stable, the nitrification cycle readings can be done once a week in open pond systems. However, if the fish are at all sluggish, check the ammonia levels immediately.

Once you get the hang of your open pond systems you may find yourself taking these readings less regularly, just to check your estimates. However, there is no such relief for growers in re-circulation systems. With the high stocking densities in these units the critical values will have to be established at least on a daily basis, if not more often. It shouldn't be too difficult as the water throughout the system would be pretty much the same. There are some growers who like to test each tank for DO levels in case the water flow to a particular tank needs to be boosted. Of course Secchi disc readings are not relevant in a system that isn't influenced by photosynthesis unless the operator finds that a particular turbidity produces colouration in the fish that is not acceptable to the market.

GWQEHN says:
Fish are livestock, and livestock can quickly become dead stock.

Pond maintenance

Good pond maintenance is an important step in preventing production problems. The most effective step is drying the pond between crops. If the organic sludge in the bottom of the pond warrants removal, it should be scraped out of the pond.

Drying also breaks the chain of aquatic pathogens and invertebrate predators and allows for the removal of any unwanted tenants such as tortoises and predacious fish.

Liming

There are two primary reasons you would lime the dry pond. One is to kill parasites and pathogens, in which case you would use quicklime (calcium oxide) or slaked lime (calcium hydroxide). Both these substances can be dangerous to humans and will react with water. If you find yourself in the position of having to disinfect a pond, seek expert advice on handling these materials before proceeding. However, it is more likely that you'll be using agricultural ground limestone (calcium carbonate or calcite – $CaCO_3$), which will:

- raise the carbonate hardness levels to stabilise the pH. This will buffer the pond against pH swings and increases the availability of carbon dioxide for phytoplankton production, thus reducing nitrate build-up by diverting it to plankton production;
- increase the productivity of the pond by releasing phosphorus that would otherwise be locked in the sediment;
- provide calcium to be used by biota, especially crustaceans, such as zooplankton, shrimps, prawns and crayfish;
- increase the microbial activity in the sub-strata of the flooded pond; and
- in addition to the general fertilisation program, flocculate the suspended inorganic material from the water over a period of time.

When to apply lime and the application rates

There are many factors involved in establishing the 'exact' amount of lime required in an aquaculture pond and these formulae along with sample calculations and qualifications can be found in Professor Claude Boyd's informative *Water Quality in Ponds for Aquaculture*. The purpose of this book is to simplify aquaculture and on that basis we quote from Boyd's publication: 'If one prefers to guess, ponds that need lime seldom need less than 2000 kg/ha' (p. 208). He also suggests a minimum of 20 mg/L of carbonate hardness for a fish pond and 50 mg/L for a crustacean pond as a starting point. Upper limits over 200 mg/L shouldn't be of concern and will provide a healthy reserve of carbonate hardness. However, hardness levels over 400 mg/L may indicate other mineral imbalances in the water or soil and careful consideration should be given to the advisability of the site. We'll look at this again when we look at site selection in chapter 10.

The International Centre for Aquaculture and Aquatic Environments based at the Alabama Agricultural Experiment Station, Auburn University, Alabama, suggests that a pond bottom soil of 6.5 to 7.5 is the optimum pH range for fish production (see p. 22 of *Water Quality for Pond Aquaculture*). At the same time they admit that little is known about the relationship between pond bottom soil properties and production of aquaculture species, but as their publications are used as a field guide for an aquaculture industry that produces over 250 000 tonnes of catfish and 60 000 tonnes of freshwater crayfish annually, it would be safe to say their advice is generally well accepted.

As stability is one of the contributing factors to successful aquaculture production, it would be fair to say that your goal should be to get the carbonate hardness to a level that enables your production system to maintain a relatively stable pH.

Application is easiest and most effective if carried out when the pond is being dried out between crops. The lime should be spread over the entire bottom of a dry pond, or if the application is to correct a dangerous acidic situation during the growing season, over the entire surface of the pond. Some growers lightly scarify the sediment when they've completed the liming.

If you're putting in an over-winter crop in the dry pond bed to provide a base for a later detrital food web, it could be sown at the same time as liming.

Application rates vary depending on the requirement of the soil and the water. Generally speaking, surface water in Australia is soft, i.e. less than 20 mg/L hardness. As a rule of thumb if you need to add lime you will need to add a healthy amount. A heavy first application may be required to lift the carbonate hardness up to or near the desired level. 2000 kg/ha on most Australian soils shouldn't be too much as a first application. After that only maintenance applications should be needed. If, after this treatment, the water is still not sufficiently buffered, it may be necessary to add another tonne or two. This can be done from a boat by spreading the lime across the pond.

The value of liming is an often overlooked element of pond maintenance and water quality stability. Lime is not expensive, especially in relation to the benefits it provides to the grower. Don't be timid. Small lots of a few hundred kilograms per hectare are not effective.

Mixing a liquid 50% lime and 50% water and pumping it around the pond is another way of getting the lime evenly into the water. Some growers mix the lime with the incoming water during a water exchange. Others will operate the aerators during application to ensure an even distribution.

A simple calculation used in other parts of the world is to add 500 kg of lime per hectare for every point of pH you wish to raise soil. On that basis, if the pH of the pond sediment is 6.3 and you wish to raise it to 7.3, then an application of five tonnes of lime per hectare would be required.

It is worth keeping in mind that a high water exchange program will also flush a good deal of carbonate hardness from the ponds.

For the scientifically minded: when one of the authors was speaking with the late Richard Carson of Aquasonic, who had decades of experience in this field, it became apparent that understanding and being able to control the absolutes in this aspect of water chemistry is essential to maintaining stability and balance in any form of aquaculture, be it a static pond or a highly sophisticated re-circulation system. Richard's comments on pH were as follows:

- the basis of the pH in any water system is the carbonate hardness level, which consists of all the carbonates and bicarbonates;
- carbonate in water forms bicarbonates by taking on CO_2 from the water. If there is not enough $CO_2$for the carbonates to form bicarbonates they will stay as carbonates and the pH will be higher. That is because the pH of bicarbonate is 8.15 and the pH of carbonate is 9.2;
- if there isn't sufficient carbonate in the water for the CO_2 to act on after reaching equilibrium with the atmospheric CO_2, it becomes carbonic acid that will have the effect of lowering the pH. In fact, without a carbonate buffer in the water the pH in ponds subject to a high level of photosynthetic activity, or a re-circulation system under high metabolic loadings, will go into free fall;
- the pH level reached depends on the quantity of bicarbonates or carbonates in the water. If there are a lot of bicarbonates the pH will be 8.15, if not the pH will be less. The same applies to the level of carbonate. When the pH is above 9.5 other chemical reactions start to occur including the formation of hydroxides and the precipitation of other elements in the water such as calcium;
- the total of the bicarbonates and carbonates can be read with a carbonate hardness test;

- plants (macrophytes) and algae (phytoplankton) can use bicarbonates as an alternative source of carbon dioxide should levels in the water drop below the plants' demand. As this action strips the CO_2 from the bicarbonate it increases the amount of carbonate in the water thus raising the pH. The carbonate is then available for the next cycle of CO_2 injection through reverse photosynthesis until the breakdown of pond waste finally erodes the carbonate reserves;
- for the pH to read correctly, that is reflecting the carbonate hardness value of the water, CO_2 levels in the water have to be in equilibrium with the atmosphere. If there is less CO_2 in the water then the pH reads higher, as happens in ponds during a sunny afternoon when phytoplankton activity is at its highest. If there is more CO_2 then pH reads lower, as in re-circulation systems with heavy loads and non-degassing type filters. Another downward influence on a pH reading can be the presence of nitric acid formed from the nitrite in the water; and
- CO_2, as a gas, only builds up in water to the same level as in the atmosphere. After that it forms carbonic acid. To get back out again the carbonic acid disassociates itself to CO_2. This is a laborious process, as for this to happen the levels of CO_2 have to be less than that in the atmosphere and the carbonic acid disassociating then fills that void. Plants and algae, by using CO_2, have the effect of reducing CO_2 levels thus creating the necessary void and consequently allowing the carbonic acid to become CO_2 again.

This continual ebb and flow is part and parcel of warm water aquaculture and its influence on production and fish health is a critical management consideration. Let's call it 'for the scientifically minded part II'.

pH is the measure of hydrogen ion concentration (defined as -log(H+)) and the increase is logarithmic – that is it goes up in multiples of 10. So, while at 7 pH there are 0.0000001 mole/litre of hydrogen ions in the water, when the pH falls to 1 there would be 0.1 mole/litre of hydrogen ions. That means the water is 10% pure acid!

Another way of looking at it is that water at a pH of 6 is 10 times more acidic than water at a pH of 7; and water at a pH of 5 is 100 times more acidic than water at a pH of 7, and so on. It works in reverse when going up the scale. Water at a pH of 8 is 10 times more alkaline than water at a pH of 7; 100 times more alkaline at a pH of 9, and so on.

During the day the phytoplankton bloom (they are after all made up of trillions of microscopic aquatic plants) and use huge amounts of CO_2 to build their cells. The plants also draw on the carbonates in the water as an alternate source of CO_2. The removal of CO_2 from the water causes the pH to swing to alkaline hence the rise in pH during the day. The authors have seen the pH reach 10 in inadequately buffered ponds, which is quite frightening. And it's frightening for several reasons.

- The first of these is that the amount of free or toxic ammonia in the water is higher at high pHs; and it's also logarithmic. For instance: water at a temperature of 20°C and a pH of 7 will have 0.396% of its TAN as un-ionised ammonia or toxic ammonia; for the same water at a pH of 8 the figure will be 3.82% and at a pH of 9, 28.4%! Ammonia burns on gills and fins will reduce production, provide sites for secondary infection such as bacteria and fungi, place unnecessary stress on the fishes' immune systems and cause loss of production

and mortalities. A list of things to do without, you'd think.
The most common effect of ammonia, and this is where it impacts on production, is that it inhibits the uptake of oxygen by haemoglobin in the blood, especially at the interface of the gill membranes with the water.

- Second, remember your early water quality lessons: the DO reading at dawn and the DO reading at noon will plot a climbing gradient which will have a reverse gradient as the effect of photosynthesis is reversed during the hours of darkness. Well the pH gradient in poorly buffered ponds will possess the same mirror image. In other words, the pond with the pH reading of, say, an upper critical pH of 9.5 at three in the afternoon is likely to fall to below a lower critical level of 6.5 during the night. As Paul Keating would admit, 'this is not a good set of numbers'. The cause is simple. Carbon dioxide exists in water at the same level as the atmosphere. If it goes over this level it forms carbonic acid, and water can hold loads of it. The phytoplankton, in reverse photosynthesis, puts out CO_2 during the night, and it readily becomes carbonic acid. Of course these swings can be minimised by aeration and some of the prawn farms run their aerators from dusk to dawn. Some of them even run them 24 hours a day!
- Third, fish, particularly young fish, don't enjoy pH swings. You wouldn't put fish from transport tanker water with a pH of 7 into a pond with a pH of 8.5 without gently altering the transport water to match the pond water. In extreme cases ponds can have a pH range of 5 to 10 within a 24-hour period. We're talking a 100% swing! Obviously this is not good for the fish or for the grower. The usual result: stress and loss of production.

The chemistry is relatively straightforward. The carbonate hardness of water is the basis of the pH. A high carbonate hardness provides a high and potentially stable pH. When carbonate is added to water in the form of lime (calcium carbonate) the carbonate takes on CO_2 to form bicarbonates. Carbonate hardness test kits measure carbonates and bicarbonates. How much bicarbonate, as reflected in the carbonate hardness reading, will determine what pH is reached. So at, say, 50 mg/L carbonate hardness, the pH will be around 7.6 without the influence of carbon dioxide. But once the carbonate hardness level reaches around 100 mg/L it provides a pH of 8.15 (presuming that there is no CO_2 present). That is the maximum pH bicarbonates can provide and no matter how much bicarbonate you have in the water the pH will still be 8.15, except where the pH is influenced by other factors.

Now the biggest influence on the pH is CO_2 which, depending on the level of CO_2 in the water, becomes carbonic acid; and so even though there might be a carbonate hardness buffer in the water, it will still cause the pH to read lower.

The major source of CO_2 in a fish pond is the phytoplankton during reverse photosynthesis. Reverse photosynthesis is another reason we aerate at night: to gas-off the CO_2 so that it doesn't lower the pH to dangerous levels.

There is a more constant source of CO_2 and this is the respiration of the biomass, which includes the pond's bio-filtration organisms, zooplankton as well as the fish. However, due to its constant nature, this source can usually be managed by monitoring and adjusting stocking rates and other pond management techniques.

During daylight hours the converse applies. The phytoplankton uses the CO_2 for cell structure. When this is used up it draws on the pond's carbonate reserves as an alternate source. Now for each pair of bicarbonate ions used to replace CO_2 only one is replaced by the breakdown of carbonate – therefore the water tends to become more alkaline during the day. Where there are inadequate reserves, the chain reaction set in motion can raise the pH to extreme levels.

Be wary of a build-up of calcium in the ponds from the addition of calcium carbonate. The calcium will be used by the fish in skeletal development but don't go overboard. Remember the golden rule in aquaculture – control over balance and stability. General hardness should be above 30 mg/L but in a freshwater system below, say, 250 mg/L.

Operators of re-circulation systems will have noticed that the more active the fish in the system, i.e. the more feed they are taking and hence the greater the loading on the system, the more the pH will fall and the more bicarbonate has to be added to the system to maintain stable pH levels.

Liming materials

There are several materials available to the farmer that can be used to lime ponds. They will vary in carbonate content levels and therefore vary in impact. To further complicate matters, not all of the brands of the same material will be constant in carbonate. You would be wise to compare analysis of different suppliers before you go ahead and order the cheapest on the market. Finely ground material will give a better result in these situations than coarse material.

Gypsum is calcium sulphate and won't have a pH buffering effect.

Dolomite ($CaMg(CO_3)_2$) is a natural combination of calcium and magnesium. It has a buffering effect and its addition would add calcium and magnesium to the water, adding to the general hardness.

Quicklime (calcium oxide – CaO) or *slaked lime* (calcium hydroxide – $Ca(OH)_2$) are fast-acting materials and while they would provide a quick fix to a pH problem the change would be rapid and short lived. If a miscalculation was made and an overdose applied it would also prove fatal to the biomass in the pond. These materials would only be used as a disinfecting agent in dry ponds or to kill unwanted fish in a dam.

GWQEHN says:
If you don't pay maximum attention to maintaining water quality standards in your aquaculture systems, you've missed the point of fish farming.

What to do in a water quality crisis

All water quality problems are preventable by good management, in a perfect world. But who wants to live in a perfect world? That would be too dull. There are three basic steps that can be taken once you've observed the problem.

- *Turn on the aerators* before you do anything else. One of the most effective weapons in the aquaculturist's armoury is water saturated with dissolved oxygen. This will lift the activity of the biota of the pond as well as giving the fish a welcome shot of oxygen. If this doesn't reverse the deterioration within six hours of solid aeration, start exchanging water until the situation is under control. Exchange around 50% of the water and see how the pond settles down. You may have to be prepared to exchange the water in the ponds several times if the problem re-occurs.
- *Cease putting nutrients or feed in the water immediately the crisis is observed.* This will ease the pressure on the pond's biological mechanism. Feeding should be continued once the situation has been stabilised but proceed with caution, and a finger on the aerator switch. If you deny the fish food they will lose production and call on their energy reserves to function, but just as important is the pond's nitrifying bacteria. This is a living organism and will need ammonia to keep its colony going. Remember, it's all about balance. Save the crop by all means but try not to overreact.
- *Identify the problem* and take steps to correct the procedure that was causing it. If the cause is deep-seated, such as a build-up of debris on the pond bottom, you will have to re-assess your management program, especially your feeding regime.

The problem may be due to a deep-seated imbalance in the pond's chemistry and may not be able to be corrected economically within the production cycle. In this case you'll have to move the fish to a fresh pond while you correct the problem in the old one by draining and drying it. Remember, production is the name of the game and if fish are to grow they must not be under any unnecessary stress.

Epilogue

Fish farmers operating pond and re-circulation systems ignore attending to water quality at their peril: on two scores. The first score is quite obvious, the restrictions poor quality water can place on their operation could make them sub-economic and there have been too many instances of this over the years to ignore.

The second score is much more insidious. There are those within the community who hold aquaculture as a threat to the environment and at some stage the industry will have to demonstrate its *bona fides* and comply with some kind of an environmental code of practice. This can only be good for the industry, but growers will have to understand how water chemistry operates to reduce to a minimum the impact of aquaculture on the environment in order to establish a responsible and sustainable industry.

GWQEHN says:
Aerate first, ask questions later. If that doesn't work, exchange water till the situation is corrected.

7

The environment – temperature

This chapter deals with the impact of the environment on aquaculture production:

- creating a stress-free environment
- temperature, managing its range and effects
- water quality.

Technically speaking, the environment should include water quality. However, water quality and its management is so important that it warrants a chapter of its own. In this chapter, it will be mentioned only in passing.

Let's introduce a new simile to our thinking at this stage and liken our aquaculture journey to a semi-trailer delivering a payload from Adelaide to Cairns via Birdsville. Not a bad little excursion. We'll need a lot of equipment for this journey. The going will be tough so we'll need spares for everything that is likely to break down, not to mention a healthy reserve of water for an emergency. If you liken this expedition to your aquaculture journey, fish farming might make more sense.

For instance, if you haven't prepared, a little thing can stop the journey in its tracks. If you break a fan belt or burst a radiator hose, the lack of replacement parts and water can be a showstopper. Be a belt and braces man, carry spares that are likely to be needed in that environment. Carry pieces of equipment for everything that can go wrong and check on their condition at regular intervals. If you undertake maintenance ahead of time, and prevent problems before they start, you will have a stress-free driving environment.

A stress-free environment

Creating a stress-free environment is technically part of husbandry and dealt with in more detail in chapter 8, but the impact it will have on your operation deserves another mention here. Stress is, like water quality, one of those ubiquitous items that are omnipresent in aquaculture. If the fish in your system can be kept in a stress-free environment with good water quality you'll be amazed how problem-free your system will be and how well your fish grow. Sounds simple? Sure. Making it happen is the art of fish farming.

One cause of stress is overstocking. This can be in two forms. The first is the social density of the fish and the other is the biochemical oxygen demand of the system. Low stress levels may not always be reflected clinically but it will certainly be reflected in production outcomes. While stunting within a population can, but not always, be attributed to overcrowding, it should be the first suspect.

To confuse matters, it can sometimes be attributed to under-crowding. Murray cod growers in re-circulation systems feel the fish do better at stocking densities higher than 50 kg/m^3. The reasoning being that they start fighting and knocking themselves around if the densities allow them too much room.

Temperature

Water temperature is an environmental factor that has a crucial influence on your aquaculture system. It can be likened to the gear the vehicle is in. If the water temperature is below the optimum, it is similar to driving in a low gear. If water temperature is at the optimum, it will be like cruising down a smooth road in overdrive. If temperature is above the optimum it won't be long before your aquaculture vehicle spins out of control. This is not a profitable move – neither in the transport nor the aquaculture industry.

Temperature range

Fish evolved to match the natural temperature ranges of their environment and this varies according to climate and location.

Oceans generally have the most stable temperatures. On the southern side of Australia temperatures are low, and in Bass Strait the minimum is usually around 11°C and the maximum is rarely above 19°C or 20°C. In tropical environments, ocean temperatures are higher, but the range of variation is generally no greater. Off Darwin, in the Northern Territory, seawater temperatures may climb to around 33°C during the wet season and mid-year, and during the dry season temperatures may plunge to about 26°C.

Ocean currents also influence the temperature of ocean environments. For instance, the eastern side of Bass Strait is washed by the warm East Australian Current which comes from the Coral Sea and carries warm-water species like marlin and tuna (as well as post-larval eels called leptocephali) as far south as Tasmania. The western end of Bass Strait is fed from the Southern Ocean Current that brings the icy waters of the sub-Antarctic to the southern shores of Australia and it is cooler.

While oceanic waters tend to be stable, the waters of bays and inlets often have a wider temperature range. Victoria's Port Phillip Bay, for instance, will range from 8°C to 22°C: about twice the temperature variation of the ocean just outside Port Phillip heads.

On land, water temperature variations can be even greater. However, farms situated along the coast will also be blessed with the moderating influence of the maritime environment dominating the climate. For instance, the best growing regions for silver perch seem to be along the subtropical coasts of south-east Queensland and northern NSW (even though the species is native to the inland Murray–Darling system). The winter water temperatures in these coastal areas rarely fall below 10°C and then only for a brief period in the middle of winter. The temperature at the NSW Fisheries' Grafton Research Station ranged from 10.6°C to 31.8°C between 1990 and 1996. The mean temperatures during the 1994 and 1995 rearing trials ranged from 13.2°C in July to 28.4°C in January with an overall low of 11.1°C in July and an overall maximum of 30.0°C in February. To provide some idea of the difference in the growing areas, during the 1991–92 growing trials at Grafton, the only two months that didn't experience 20°C were July and August. The pond temperatures averaged >20°C from late-October to mid-May.

Compare this with growing conditions in the southern inland regions of NSW and northern Victoria where summer pond temperatures may peak during January or February at 32°C but could be combined with winter temperatures as low as 7°C. Pond temperatures could reach 20°C in October but by Anzac Day they would be slipping below that mark. Even then the pond average, based on conversations with growers, might take until November to hold at better than 20°C and would be below that before mid-April.

It is apparent from the above that growers along the coast generally have less to contend with as far as temperature swings are concerned than growers in inland areas. But don't rush to that coastal real estate office until you've read the whole book!

There are local effects that can have an impact on water temperatures. Trout farmers in Victoria's Upper Goulburn Valley face a localised scenario. Growers taking water from the shallower upland streams of central Victoria may find themselves faced with winter water temperatures as low as 5°C. However, growers on the Goulburn downstream from Eildon Reservoir find that the winter water temperatures don't fall much below 10°C because the large body of water in the reservoir acts as a heat bank. Conversely, in the summer, the upland growers can find themselves having to deal with high water temperatures and reduced stream flows, while the Goulburn River growers will have optimal temperatures, retained by the slower warm-up of the large body of water held by Eildon Reservoir. Needless to say, it takes far less time to grow a fish to market size in the farms drawing their water from the stable Goulburn River than those reliant on the less stable and less reliable upland streams.

Stock tolerances

Fish and other aquatic life have evolved to withstand the variation of temperatures found in their indigenous waters. They have an upper critical limit (UCL) which if exceeded is fatal, and a lower critical limit (LCL) below which they die. The recognised tolerance range of silver perch is, for example, between 2°C and 38°C.

However, in an aquaculture situation you should never allow these extreme ranges to occur. While the stock might survive (in theory) at these extremes, in an aquaculture situation where there are high stocking densities and high pond nutrient loads the stress levels reached would be very likely to trigger a breakdown in the fishes' immune system with potentially dire consequences.

Optimum temperature range

Between the UCL and the LCL, aquatic species generally have a temperature band within which they perform best. Usually the optimum temperature band spans around 8°C. Depending on the habitat the fish evolved to live in, the band may start at any one of a wide range of temperatures. In the case of rainbow trout it's between 10°C and 18°C; in the case of silver perch it is between 20°C and 28°C. Barramundi like it a few degrees warmer.

The actual span of the optimum range can vary a little with species. Both the freshwater prawn (cherubin) and the redclaw crayfish have about the same peak growth temperature preference – somewhere around 28°C. Yet redclaw are far more tolerant of temperature variations, and will keep on eating and putting on weight during highs and lows that may incapacitate freshwater prawns.

Within the optimum temperature band, peak growth is found around the top 5°C. That means silver perch would be performing at their peak between 23°C and 28°C. Just to make it interesting, the performance of the animals falls away rapidly after the peak temperature has been passed, that is, the peak growth temperature is usually only a few degrees below the UCL.

Impact of sub-optimal circumstances

It's obvious that a fish farming operation in an open environment can't always have the water temperature in the slot all the time. There will be times of extremes in the natural climate. This is becoming more and more common as the globe's climate becomes unstable. During these peaks or troughs, water temperatures will be driven to, if not upper or lower critical levels, at least at sub-optimal levels.

Sub-optimal temperatures will place stress on the stock. The first thing they will do is go off their food, so the farmer should reduce feeding rates commensurate with their appetites or stop feeding altogether should the situation call for it. Uneaten food will only increase the nutrient load on the pond and exacerbate the problem.

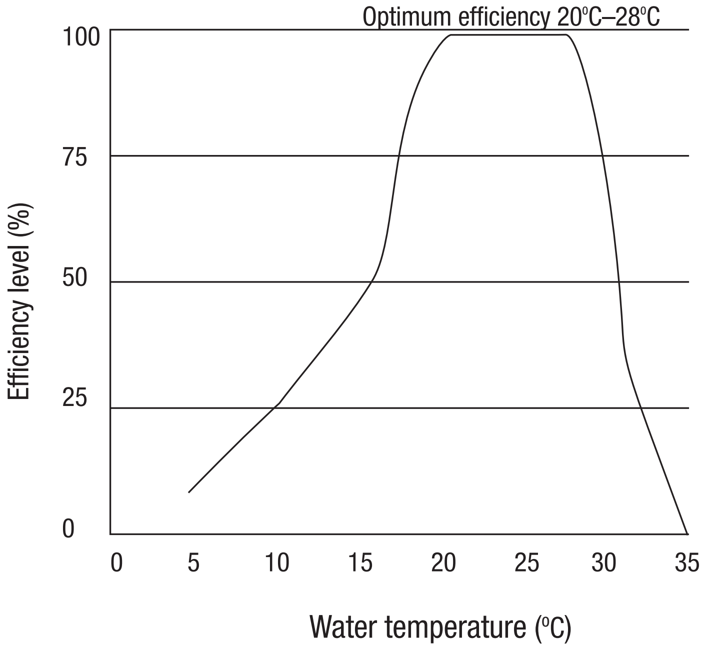


Figure 7.1. Optimum temperature bands.

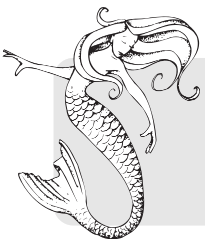
Figure 7.1 shows that the band of optimum temperature is a narrow one and there is little margin for error at the upper end crucial for production efficiency and animal survival. As a rule of thumb, the pond water should be at least within the optimum temperature band for at least six months of the year, preferably within the 5°C at the peak of the band. And in keeping with the stability factor in aquaculture, the temperature range should be as narrow across the whole season as geographically possible.

Managing temperature

So what can be done about it? Even the Aztecs found that sacrificing to the Sun God wasn't sustainable in the long term. Fortunately, there are practical approaches that work.

Getting the rights species for the site is the key to success. There is absolutely no point trying to grow barramundi in open ponds in Tasmania. Similarly, trying to grow trout in the Kimberley would be folly. (Although trout are grown in Papua New Guinea, but in the highlands where temperatures are far lower than what might be considered tropical.)

Site selection is crucial; so crucial that the authors have devoted a whole chapter to it (see chapter 10). But one story worth re-telling goes back to the early 1980s when marron were translocated to Queensland because it was thought they would grow better in a warmer climate. It would appear the promoters of the scheme had only half read the book on aquaculture when they determined that temperature was a limiting factor in the development of the marron as an aquaculture species. They deduced that the climate in the marron's native lands, the south-western corner of WA, the Pemberton and Margaret River regions, were too cold to get commercial growth from this highly prized freshwater crayfish. The story went that they would benefit from a change of climate and where else but sunny Queensland? The computations presented to the investor showed how the buyer of a starter kit of 5 kg of mixed sex marron for farm dam stocking could turn off 500 kg a year once they got going. The starter kits sold for hundreds of dollars but the rewards were measured in thousands and the great Queensland marron stampede was under way. Things went reasonably well until the first hot summer when water temperatures rose far above the upper critical limit (UCL) and the marron died in their droves. The upshot was that the Queenslanders found they had their own tropical freshwater crayfish that lent itself admirably to aquaculture, and the redclaw became the Queensland marron (until they found themselves in conflict with the Western Australians over the use of the name marron). Redclaw now stands alone as a premier aquaculture product. But only after a lot of heartbreak that could have easily been avoided if the people drawn into the scheme were aware of the pitfalls of aquaculture and had enough confidence in their own aquaculture judgement to make their own aquaculture decisions rather than believe what they wanted to believe about this get-rich-quick scheme.



GWQEHN says:
If the rewards of aquaculture were as good as some people say they were we'd all have our thumbs in our braces and be smoking big, fat cigars.

Another key to success is to find a source of water that remains at a constant temperature. Powerhouse cooling water is one such source (if industrial problems don't result in a shutdown of the station!). Another source is artesian water. Warm artesian water underwrites one of Australia's high profile barramundi farms situated in South Australia's Coorong district near Robe. These kinds of sites aren't always available and may have downsides that rule them ill-advised for an aquaculture venture. Industrial pollution and isolation are two that readily spring to mind.

One move is to place the farm indoors where temperature is controlled. As re-circulation technology grows in sophistication, this is being seen as a more viable, if expensive, option.

Another approach is to be smart about what you grow and where you grow it. Fish farmers can take advantage of variation and select sites to match growth patterns to market demand. For instance: the warmer (and plankton-rich) waters of Port Phillip Bay grow blue mussels to a marketable size in 12 months or less while the same species grown at the more oceanic zone at Flinders near the entrance to Westernport Bay take up to 15 months to reach market size and condition. So why do they bother to grow mussels at Flinders? While mussels grown in Port Phillip reach condition earlier, they also finish earlier, around February/March, just as the mussels at Flinders are coming into peak condition.

GWQEHN says:
While we don't have any control over the seasons that influence our water temperatures, we do have control over the selection of the site and the design of the farming system.

Water quality

As mentioned earlier, it's impossible to write about the aquaculture environment without touching on water quality. There is nothing like poor water quality to reduce the efficiency of your fish farm and there is nothing easier to maintain than good water quality as long as you obey the basic rules of aquaculture.

8

Fish husbandry

This chapter deals with vital aspects of husbandry in aquaculture including:

- the importance of observation
- handling
- stock management and grading
- monitoring and managing production outcomes
- feeding and feed management
- fish health monitoring
- record keeping
- plankton, algal lawns and detritus production.

Fish husbandry is the art of keeping your charges in the comfort zone or, in other words, the removal of stress from the production system. Another way of describing husbandry is to say it is the process of removing limiting factors from your production system.

The key to husbandry is having an understanding of the fish's preferred conditions. This means studying up on the biology of the species you are growing and conditions in which they thrive. True, in a farming situation we're going to be removing a lot of the habitat that we feel interferes with our management methods. For instance: crayfish love getting into nooks and crannies but having heaps of tyres providing those nooks and crannies can interfere with the flow of water around the ponds and create dead spots where pond debris and bad water can accumulate.

A very good example of husbandry goes back to the early days of trying to farm North Atlantic lobsters in Scotland. They took the half-grown animals and put them in tanks. The hierarchical and territorial aggression became so vicious that the researchers had to separate them into lobster-sized cubicles. Guess what? The lobsters became so stressed they wouldn't eat and started to die. Then someone had the bright idea of making the walls of the cubicles out of perspex. The effect was immediate. Each lobster would go to the wall of the cubicle and raise their nippers in a salute of aggression. This was all they need to get it out of their system. They began to thrive. In the tanks there wasn't sufficient personal space so the aggression became physical. In the perspex-walled tanks they could see but not touch. The trials were abandoned because of the cost and the fact that the program hadn't been able to establish successful breeding protocol.

Observation

It has been said that husbandry is 90% observation, and the authors agree with this. Finding the time to observe is the problem. Too often the busy farmer has a checklist that includes key items such water quality management, record keeping, administration and feeding but doesn't include time for observation. While all these other items are crucial to the success of your fish farm, if you can't find time to watch what your fish are doing, particularly when they don't think they're being observed, you may not have time in the first place to farm them.

Allocating time to observation during your learning years is something you must do. It shouldn't be hard work because, let's face it, we're farming fish because we enjoy farming fish, aren't we? We're here to make a living from it, too, but if you haven't got time or the inclination to spend time watching what your charges do then you should hire someone to do it for you. It's part of farming.

There's an old saying in terrestrial farming we could borrow from in fish farming: *the best fertiliser any farm can have is the footsteps of the owner*. Agreed, a bit difficult to do on water, but you get the message. Actually at times you're going to feel like you need a miracle or two to pull you through, so maybe practising walking on water would be good preparation.

Open ponds

Having a jetty extended out over the water makes an excellent viewing platform. Ask any cormorant. Lying quietly on the pier in a broadbrimmed hat and wearing a pair of Polaroid sunglasses will deliver a surprising amount of information.

Be prepared to get up early in the morning and also to walk the ponds at night with a good torch to see what happens at those times. Use the torch to look into the water column. You'll be surprised by what you see this way compared to what you saw in daylight.

A shaft of light shining down through your re-circulation or purging water will also reveal the amount of organic matter in suspension.

Don a slicker and slip into the gummies when it's raining. Slip around the ponds and see what they do in all sorts of weather.

It can be difficult to focus your eyes looking into water. The tendency is to focus on the water surface or the pond bottom. By focusing on the Secchi disc as it's lowered into the water, the eyes can look into mid-depths. The black and white segments of the disc can also be used as a backdrop to alternatively light and dark organisms in the water column.

Tank-based systems

Fish are less frightened by viewing from the side than they are by someone leering into the water from above. It may cost a bit extra to install, but tanks with viewing windows will allow you to watch what's happening in the tank.

Cages

The importance of observation is seen in the mariculture fish pens where underwater cameras are used to monitor fish activities, the most important of which in this situation is feeding. Three-dimensional cameras are also able to estimate the weight of the fish, which saves a lot of labour and time in netting and weighing.

Handling

Fish will have to be handled for all sorts of reasons: grading, health management and harvesting are three obvious ones. Be aware at all times that handling fish causes them stress. As the art of husbandry is the removal of stress, any handling should be planned and carried out in a manner that reduces stress.

Mechanical aids such as fish pumps and graders will make life easier for the operator and the fish, but they are expensive and you have to make sure they are going to be cost-effective in your operation.

The outer coating of mucus on a fish is its first protective layer. For instance, in the presence of external parasites the fish will increase the output of mucus. Should any damage occur to the mucus layer it leaves an opening for fungal and bacterial incursion. The human skin exudes an acid that compromises the mucus layer, so when handling fish you should either use a net or, in the case of large anaesthetised broodstock, a stretcher of some kind to avoid direct contact. Having wet hands will provide a prophylactic layer between the fish and the handler.

Make sure nets are made of material that will not cut into the fish or catch them by the nose or gill plates. They may be a bit dearer to buy but they will be cheaper in the long run.

Some growers sedate their stock during handling by applying a light dose of anaesthetic to the water, such as benzocaine, quinaldine, tricaine or MS222, and AQUI-S. Carbon dioxide will also anaesthetise fish and it is used in the abalone industry. Check that these anaesthetics are registered at the time of use.

GWQEHN says:
Stress is the enemy of the fish husbander. Husbandry is the removal of stress from your production system.

Stock management and grading

In the name of efficiency the fish farm should be fully stocked. You wouldn't run an interstate semi-trailer half-loaded between Melbourne and Brisbane if you could avoid it, so why would you run your fish farm half-loaded?

The market will require a consistent supply of standardised product. When you go to the supermarket or the fishmonger, they will always have plate-sized rainbow trout, baby barramundi, Atlantic salmon and ocean trout cuts available. These are all farmed seafood lines. That means that somewhere in Australia, at whatever cost and effort it takes, there will be fish harvested to match these market demands.

This means to put a crop of fish in the system as fry and sell them when they have grown to market size isn't going to give you a commercially acceptable marketing program. If you want to rock up to the market and say, 'Righto, here's the product.

Where's my money?', the market is going to say: 'Here's what we'll give you.' You're going to have to supply the market what it wants when it wants – that means every week.

Apart from the marketing angle, if you just throw the fry in a tank or pond and leave them there until they have reached market size the tank, pond, raceway or cage will be under-stocked for most of its production life. That is clearly uneconomical.

In the case of a re-circulation system where the pumps are operating around the clock, the economics of the situation dictate that it must be near full capacity at all times. Some operators make sure they're never operating at less than 85% capacity. This is not difficult. As fish are removed for the market each week they make room for new young stock to be added to the system and the rest of the stock to grow into the bio-space created by the removal of the market-sized animals.

The same rule applies in open pond, cage and raceway systems, but the high stocking density and fast growth in re-circulation systems will find the operator having to move stock more frequently to accommodate bio-space and social density requirements.

It has also been found that some fish perform better when held at high densities. This is an option mainly open to re-circulation system operations. The important issue for the fish farmer is that the fish have to be continually split to maintain the high densities. They will benefit from grading at this point.

The normal grading practice is to estimate the mean weight of the fish and grade those above the mean into one pond or tank and those below the mean into another.

Fish pumps and graders will make this job easier on the fish and the operator but these devices can be expensive. It may be possible to form a group that pools their expenditure on these items to defray costs.

Monitoring and managing production outcomes

While technically not a husbandry issue, monitoring fish numbers, weights and projecting production outcomes is an essential part of managing a fish farm. If you had a hardware business, managing the stock inventory would be accepted as an integral part of the business. Knowing the weights and projected market dates of the fish on your farm is equally integral to the operation of your aquaculture business.

The production program should be planned with the marketing program in mind. Failure to do this will leave you turning up at the market unannounced as a price taker and weaken your market position.

In a perfect world you can monitor growth rates and determine the expected market date by plotting them on a graph. They should form a decaying exponential curve as the growth rate of the maturing fish decelerates as discussed earlier. While this holds true where the impact of limiting factors are minimal, as found in a re-circulation system, there may be climatic and environmental checks in an open system that will throw the estimates off-line. Be prepared to make constant adjustments to the forward estimates but at least make them.

Weekly stocktakes are essential knowledge when:

- making informed estimates of feeding programs;
- recognising the load on the system;

- forward ordering feed and other inputs relative to stock management;
- monitoring growth rates and FCRs;
- being able to predict the time of market entry; and
- carrying a running annual production estimate.

Feeding and feed management

Feed should be the biggest ticket item on the farm. That makes it the largest target for cost pruning. We'll look at how this can be done from a dietary point of view in chapter 9, but from the husbandry aspect there are procedures that can be incorporated that will minimise the outlay on fish food by increasing its efficiency.

Constant updates on food requirements will ensure that you are not only feeding what the fish are capable of consuming, but more importantly, what they are able to metabolise. In chapter 9 we'll look at energy requirement as the trigger for appetite. If the fish are sluggish because the water temperature is below their activity levels, they won't burn much energy; consequently they won't have much of an appetite. So don't feed them as much as you would under an optimum temperature regime.

How much to feed

On the other hand, oxygen determines the amount of food they can metabolise. There's no point throwing expensive feed into the water if it's going to be consumed but not converted into growth (again see chapter 9). As a rule of thumb, fish will require 4 mg/L of dissolved oxygen in the water just for normal bodily functions; only the surplus oxygen can be used for metabolic activity. So don't feed if you don't have enough oxygen in the water to utilise the feed.

GWQEHN says:
If you wish to get the best out of your ponds, keep them at >75% of DO saturation level.

Avoid overfeeding. Sometimes it's hard to resist the temptation to stand at the pond or tank and keep tossing pellets into the water until the fish won't rise anymore. There'll always be one last fish that leisurely rises to the surface to gobble one last pellet.

Feeding rates

Feeding rates are usually expressed as a percentage of body weight of the fish or the biomass weight of the tank, raceway pond or cage. Monitor the biomass of the fish in the system and work out a feeding regime based on that.

A high feeding rate would be 2% to 3%. Between 1% and 2% of body weight is mid-range and <1% is more of a maintenance ration. By monitoring fish growth and mortalities, you should be able to keep a reasonably accurate running weight of the fish biomass in the system.

Judging how much to feed crayfish is a bit more difficult. They are shy feeders and in clear water will not feed in the open in daylight because of their innate fear of predators. In turbid water they will move around and feed all day. This is another reason for having a plankton bloom.

The optimum feeding rate has been variously given as from 1% to 3% of body weight, however, crayfish are opportunistic feeders and will get a meal where they can. In a pond with a lot of natural food it's likely that they will be satisfying some of their energy requirement from this source. As with finfish, temperature and oxygen also have a bearing on the feeding rate.

Their natural feeding regime is nearly impossible to observe in the pond so the fish farmer has to employ what evidence he or she can of the intensity of their attack on the supplementary diet. Crayfish move onto the pellets in their own time and they do it where you can't see them. One method used is to feed some of the ration on trays placed around the ponds. By checking the trays half an hour or so after they have been put out you can gauge how quickly the crays are moving onto the feed and to some degree how much they are consuming.

The growth rate of the crayfish is a fair gauge of how well they are being fed. By dragging a light net across the pond you will collect a cross-section of the crayfish in the pond. If the size variance is wide it would be a fair indication that there wasn't sufficient nutrition in the pond, either natural or supplementary, to maintain the whole population.

On the other hand, if the pond plankton bloom is out of control it would suggest you're putting too much supplementary ration in the water and the crayfish aren't eating it all.

Oxygen and water temperature

As mentioned before, available oxygen and water temperature have a major bearing on what fish will eat and what they will metabolise. For instance, rainbow trout growers rearing fish in flow-through systems will feed 1.5% to 2% of the biomass weight in the raceways under ideal temperature conditions, which for them is between 12°C and 16°C. At temperatures between 10°C and 12°C the growers will still feed at that rate but are prepared to feed on demand should it appear the fish aren't feeding as strongly as they would like them to. Similarly when the temperatures get to between 16°C and 20°C. When the water temperatures fall to 6°C in the depth of winter, the feeding rate is brought back to between 1% and 1.25% of biomass weight. At the other extreme, when water temperatures soar, for eaxmple, during an El Niño event, the feeding rates are similarly reduced. When they become extreme, say 23°C, those without supplementary aeration have to stop feeding altogether.

Juvenile fish will eat more and the same rainbow trout growers will be feeding up to 4% of body weight to young fish that can metabolise that much food because they are growing so fast, and consequently using more energy.

On the other hand, if they are holding fish back to market later in the year they may reduce their ration to <1% of biomass weight to maintain health but control growth.

It is interesting to note that should the DO be kept up to saturation levels, or even at supersaturation levels through oxygen injection, the fish will still feed and grow.

However, they are operating above their natural temperature range and this is only possible as a stop-gap during an emergency. If nothing else it shows the power of oxygen, but long exposure in an open system to these higher temperatures, even with super-saturated DO levels, is a high risk strategy.

Growers in closed systems, ocean pens and flow-through raceways don't have a DO problem under normal operating conditions. However, growers in aerated ponds, particularly those with lush phytoplankton blooms, may find the DO levels below optimum at the time of the evening feed. Should the ponds have a DO problem, the grower should look into it, but that aside, some growers turn on the aerators before feeding to build up the DO as close to saturation level as economically possible. Others turn them on after feeding while the fish are digesting and metabolising food. Some do both, aerate before and after feeding. If, for reasons known only to the fish, they feed stronger in the evening than in the morning, then aerator use should fit the normal rhythm of the pond.

Some of the more widely farmed species, such as prawns and the salmonids, even have established feed-uptake charts that give a suggested feeding rate as a percentage of biomass in relation to temperature and DO. Growers can calculate economic feeding regimes using these parameters.

Figure 8.1. Oxygen can be raised to supersaturation levels in re-circulation systems by separating O_2 from the atmosphere and injecting it into the water used in the production tanks. Here an operator is shown adjusting the O_2 generator. An oxygen storage bottle can be seen in the background. The line going off to the right is taking pure oxygen to the pressure tank where it is mixed with the production water.

Where this chart isn't available, growers will have to make their own calculations, but charts for the other species can act as a guide. You could even work out your own chart; in fact if you're going to be any sort of a fish husbander it would be a good challenge for developing a feel for these skills. In the case of silver perch, it's known that they will feed down to water temperatures of 15°C but once the water gets up over 20°C they improve out of sight. The feeding and metabolic rate keeping increasing until the temperature gets around 28°C. Over that the feeding rate falls away markedly until at 32°C they are hardly able to look a pellet in the eye.

GWQEHN says:
The water temperature represents the gear your aquaculture vehicle is in. The DO represents the setting of the throttle. The former will determine the speed the fish are travelling at, while the latter determines the amount of fuel they can burn.

Increased photosynthesis activity will lift DO to supersaturated levels during daylight hours, presuming a day free of heavy cloud cover, and the aerators will be coming on at night anyway. Granted, they aren't usually switched on until the low peak rates kick in, usually around 11 pm, but if the ponds are highly geared by an energetic plankton bloom the DO levels may start to drop very quickly once the sun is off the water. If the oxygen is in demand for the digestive and metabolic process the pond may have an oxygen deficiency at this point.

As mentioned earlier, the use of aerators can be adapted to each individual situation. If the fish feed better without aerators, they can be switched off during feeding and switched back on after feeding is completed to ensure maximum available oxygen levels during the digestive and metabolic process.

Avoid set feeding rates such as 3% of body weight a day as a rigid feeding regime. As ridiculous as it may seem, the authors have even come across growers who used that rule of thumb estimate as a feeding rate, then fed out three times a week based on 21% of body weight a week. Their poor crayfish had to consume 7% of their body weight every third day!

When to feed

Feed when the fish are most active, not when you feel like it. Some fish feed more vigorously than others. For instance, native species in open ponds tend to feed first thing in the morning and in the late afternoon or evening. Trout, on the other hand, have been farmed for decades and will get the water broiling at any time of the day when a pellet hits the water. You'll soon learn to read their habits.

Automatic feeders are used extensively in indoor systems where the fish feed around the clock in the absence of day measured by the rising and setting of the sun. They don't seem to have that much currency in open systems where they are exposed to the elements. However, where it's possible to keep the mechanism of the system dry, such as in an in-shore cage-based operation close to the land, feed can be piped from the silo to the cages under the control of a computerised feeding system.

Feed to the capacity of the system

Having discussed the feed requirements of the fish, there's also the feeding requirements of the system to take into account. It overrides the nutritional requirement of the fish. There's no point in feeding the fish if the nutrient load is going to cause the system to collapse. Remember, living organisms drive the nitrification process and the oxidisation of ammonia doesn't happen without the *Nitrosomonas* and *Nitrobacter* bacteria having enough oxygen to work with. Should the Nitrification Oxygen Demand (NOD) of the system be exceeded it will be well on the way to that catastrophic event.

As the nutrient requirements of the fish increase with growth, they can reach a level at which they will exceed the capacity of the system, be it an open or closed system, to cope. Good farmers will know the upper limit of the NOD and BOD of their system and set their stocking densities to match capacity of the system to neutralise the ammonia and other nutrient inputs created by the introduction of food and the by-products of its metabolism. Or they may maintain stocking densities and reduce the feeding rate in relation to the increasing requirement of the growing fish.

In other words, growers will feed up to, but not beyond, the capacity of the system to neutralise the nutrient input and metabolic output, even though this may find them slightly underfeeding the fish.

At some point a grower may decide that the lost growth is so great that it would be more economical to split the crop into two ponds/tanks, or at least a bigger tank/pond. This will give the fish more bio-space in which to grow.

GWQEHN says:
You'll kill more fish by overfeeding than you will by underfeeding.

It will come as no surprise that management is often faced with this situation when the crop is close to harvest and the job of harvesting, grading and re-stocking will only be for a short time. Some growers will put extra aeration on the pond to carry the crop through these last few weeks to save the cost and effort of moving the fish. Sometimes the whole farm is chock-a-block full and there are no options other than to leave the fish where they are and go for the extra aeration.

Of course there's nothing wrong with lightening the load on the system by selling off the top of the crop to make room for the others to grow into.

Pellet size

Pellet size is important. The fish are generally fed over a short time-span. You don't want to be there all day feeding out. Nor do you want to make it hard on the fish to get a feed. There are two considerations.

First, the pellet should be small enough to fit into the fish's mouth, and second, it should be large enough so the fish can replace energy without having to make a lot of extra passes at the food to get a bellyful.

The dimension the farmer uses to determine pellet size is the gape, or the size of the mouth. The gape and feeding style will vary from species to species. One of the difficulties here is that the fish in the system may be of varying size. A rule of thumb used by growers is to have the pellet size 25% the width of the mouth. Your Regional Extension Officer is a source of much valuable and practical husbandry information and would be a natural reference point. Feed manufacturers will have charts for commonly farmed species and hatchery operators and experienced growers will have the information where the feed manufacturers haven't.

Pellet texture

Most species can be weaned onto a dry pellet while some species are averse to dry pellet texture. Southern bluefin tuna are a species that can be difficult to feed dry pellets to; golden perch or yellowbelly are another.

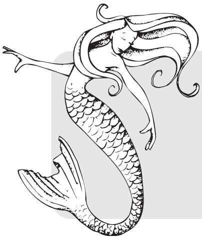
Moist pellets are available but are generally more expensive to make and handle. A moist pellet is an extruded diet that comes out of the plant with a rubbery texture, not unlike some dog foods, even more so. They are frozen so they can be transported and thawed before being fed out.

Floating pellets

Some fish will feed on the surface. Barramundi and rainbow trout are two such fish. Others, such as snapper, are mid-water feeders. Crustaceans, such as prawns and crayfish, are bottom feeders.

A number of growers prefer to see their fish feed at the surface. It gives them an idea of how much food they are taking. When the feeding stops they can see how much feed is left uneaten, if any.

When one of the authors asked Dr Michael Masser of the Department of Fisheries and Allied Aquacultures at Auburn University, Alabama, what sort of FCRs the catfish industry achieved, he responded that it all depended who was doing the feeding.

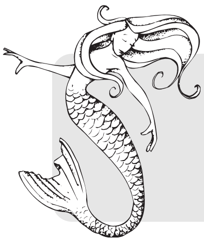


GWQEHN says:
Feeding can make or break you. Spend time observing how the fish like to be fed and follow their advice.

Fish health monitoring

Fish health monitoring should be a regular practice. Daily observation, particularly at feeding, can provide clues that the fish are off-colour and displaying symptoms of stress, but nothing will be as good as regular examination of scrapings of mucus and specimens of gill tissue under the microscope. Some growers do this on a daily basis, but weekly should be enough if things appear to be on an even keel. Don't be frightened to sacrifice a fish or two in the name of health management.

A 40/20 power binocular microscope should be sufficient and 100 power would handle anything that isn't picked up by the 40 power scope. Anything smaller than that may require a veterinary examination anyway.



GWQEHN says:
You can't farm what you can't see, and you can't see plankton and parasites without a microscope.

Record keeping

Again, technically record keeping isn't part of fish husbandry in the true sense, but it is part of management. Records are useful in all sorts of ways, not the least of which is comparing the circumstances of events in different seasons to solve husbandry problems, and that is part of husbandry.

When everything is new to you, everything looks important enough to be recorded. And there's nothing wrong with that but it can become quite time consuming. The important items to be recorded are those that give you a capacity to predict a commercial outcome, such as when fish will be ready for market or when the next load of feed should be ordered to ensure there are stocks on hand, and those that give you control and predictability over the production system, such as DO, TAN and temperature,

Throughout this book you will be taken through the key performance indicators and control factors in relation to production and management, and you will be able to establish which of them relates to your particular operation. Below is a checklist of the areas that should be monitored to provide management with a working history of the farm:

- water quality parameters
- climatic conditions where applicable
- fish health
- feeding rates
- growth rates
- stock movements
- administrative matters
- marketing matters.

Some growers keep records in relation to the particular part of the farm the stock are in and others follow the stock throughout the farm. Obviously both points are valid and the smart operator will record both. Ideally there will be a system that cross-references both.

Look around for a computer program that records all these items for you, including suitable cross-references. Anyone who is half-handy with Excel spreadsheets should be able to design something that will work. However, avoid getting financial items confused with production items. Granted the two are closely related where the success of the operation is concerned, but one is determining production outcomes and the other is what those outcomes mean in economic terms. Knowing the cost of everything is essential but it won't help you control the balance and stability of your production system.

Plankton production

As previously mentioned, fish food can be produced naturally by creating a green-water culture or a detrital food web. The authors weighed up whether to include this section in the nutrition or the husbandry chapter and in the end decided to include it in the nutrition section.

Plankton blooms are a regular part of open pond systems as a by-product of producing fish. They are also a food source for growers raising crayfish and fry. In either case their management will be a part of the husbandry program.

The first thing you will learn about plankton production is that there seems to be no rhyme nor reason to the cycle. Identical ponds, side by side, can have the same fertiliser inputs and the same management regime, yet will perform in different ways. The main thing to understand is when the bloom is nearing dangerous levels. Learning to judge this point is one of the arts of husbandry. It's not unlike leading an elephant: work out which way the elephant wants to go and walk in front of it.

It is also a lot easier to extend plankton production if you have control of the water quality management. In fact it would be fair to say that it is impossible to produce commercial levels of plankton without the resources to control water quality; these are resources such as supplementary aeration and exchange water.

The plankton bloom

A plankton bloom is made up of microscopic aquatic plants suspended in the water, sometimes referred to as 'algae'. Some species are motile while others are at the mercy of the wind and currents. The algae can become so abundant that they cloud the visibility of the water. They come in several colours and may tint the water the hue of the dominant species. The colour most inland fish farmers are comfortable with is milky pea-green. This will turn to olive-green indicating the build-up of zooplankton, but ponds can be red, yellow, brown, black, grey and shades between. Blue-green is the algae that gives fish farmers the most problems because of its toxicity in some forms and for the off-flavour it imparts to the flesh of the fish.

The term 'plankton bloom' refers to the phytoplankton in the water. However, the phytoplankton bloom supports a number of organisms, the most prolific of which is the zooplankton population of the pond. This is made up of micro and macroscopic crustaceans. Both types of plankton can form part of the fish larvae diet during the metamorphosis to fry. They also form part of the juvenile and adult crayfish diet.

Plankton spores are ubiquitous and there should be no need to inoculate an open pond system. The dominance of any particular species will depend on the suitability of the habitat. Fish farmers can apply a fertiliser regime to their ponds that will encourage colonisation by favourable species; however, there will be many species making up the plankton bloom.

Limiting factors

Phytoplankton species have optimum environmental conditions and upper and lower critical limits just as other organisms. Too little or too much of an essential nutrient will reduce and even kill plankton. Plankton deaths, particularly sudden ones, will produce a layer of rotting material on the pond bottom that can quickly turn putrid and destroy the viability of the ecosystem required for life. This is called a plankton crash and is every fish farmer's worst nightmare.

Obviously the first limiting factor is *sunlight*. Phytoplankton needs 1% of full sunlight to grow and even ponds that are so turbid with colloidal clays or organic matter can generate a bloom, but the productivity of these ponds is greatly reduced. However, believe it or not, too much light can kill plankton and there will be an intensity level at which the plankton dies.

Plants need *carbon* to grow and there is some conjecture about the source of carbon used by phytoplankton. One school of thought believes algae can utilise carbon dioxide in much lower concentrations than are present at atmospheric equilibrium. The other school of thought presents evidence that phytoplankton production is enhanced in natural waters with a higher carbonate hardness than those of the same quality with a lower concentration. In an active fish production pond it doesn't matter, as limed ponds will have a relatively high carbonate hardness content and the metabolism will be creating carbon dioxide and forming carbonic acid so there is no chance of carbon being a limiting factor if the latter science proves to be the correct one.

Phosphorus is the most common limiting factor and this can be introduced to the ponds by the addition of superphosphate in one of its several forms. We'll look at that in a minute. It should be noted that ground agricultural limestone (GLS) will help release phosphorus that would be otherwise locked up in the pond mud.

Nitrogen is the second most common limiting factor to the production of a healthy phytoplankton bloom. Again, its addition to the pond is no more difficult than it is to a crop of lucerne.

Potash has not been found to be a limiting factor as it is only taken up in small amounts but it's still an essential ingredient of plant food and many growers include potash in their fertiliser regimes.

The secondary elements such as calcium, magnesium and sulphur can occur in the pond environment or may be added. Agricultural limestone, depending on the source, often has traces of magnesium and sulphur. Trace elements, such as copper, zinc, molybdenum, manganese and iron, are generally considered to be present in most healthy environments but there would be no harm in adding small doses of liquid fertilisers such as seaweed extract, especially if you believe there to be a deficiency in the region.

Plankton production while maintaining water quality

The art of balancing plankton production with water quality, while at the same time raising a crop, is one of the most highly skilled juggling acts in aquaculture. In most cases in Australian aquaculture the grower will only be maintaining plankton crops over the short-term, in fry production ponds or in the early stages of crayfish production (see *The Australian Yabby Farmer*). Six to eight weeks would see out most intensive plankton production stages, with an extended crop being 10 weeks.

To produce plankton, nutrients are added to the water; either chemical fertilisers or animal manure are the commonly used sources. Chemical fertilisers will give the grower more control over the nutrient input. They are the same fertilisers used in agriculture to boost crop and pasture production.

Fertilisers are given ratings representing the amount of nitrate, phosphate, and potash they contain as nitrogen, phosphorus and potassium. These elements are represented as N-P-K. For instance: a fertiliser that is designated as 20-20-5 will contain by weight 20% N, 20% P and 5% K. Urea is a common form of quick release nitrogen but it hydrolyses to produce NH_4^+, which will add to the TAN levels in the pond if not taken up quickly by the plankton.

Animal manures and processing waste can also be used. Being a waste product they are fundamentally cheaper but not necessarily more effective. Because of the moisture content you will have to use more of them, as they will be lower in the actual ingredients that drive the plankton bloom. For instance, Claude Boyd in *Water Quality for Ponds in Aquaculture* (p. 239) states that 1 kg of diammonium phosphate (18-46-0) contains as much nitrogen as 36 kg of dairy manure and as much phosphorus as 230 kg of the same manure.

The use of organic material can lead to a lot of extra organic material being put into the pond. The decomposition of this material by bacteria draws oxygen from the pond. However, if the pond is being used to generate zooplankton the available food for some species will be enhanced. This will not however reduce the BOD as the increased populations of micro- and macro-crustaceans will draw down on the pond's oxygen supply.

Fertilisers used in aquaculture should be soluble and there's a good argument for dissolving the proposed fertiliser mixture in water first and applying the solution. It should be applied with the aerators running to achieve even distribution of the nutrients.

There are liquid fertilisers available. Phosphoric acid and ammonia polyphosphate are two that have gained currency in agriculture. They tend to be denser than water, as heavy as 1.4 kg/L, and they should be diluted in water to bring them up to the same weight so they don't sink to the bottom. The same rules apply in regard to agitation of the water to ensure even distribution.

Fertiliser applications

The rules that apply to feeding agricultural plants apply to feeding aquatic ones. The plankton will respond to the application of a nutrient to its environment in which it is deficient, but once a healthy bloom has been established the increase in plankton production is not commensurate with the increased cost or management risk of the extra fertilisation. Sounds familiar?

In a perfect world the pond mud and water would be analysed, the deficiencies identified and duly rectified. But we've established that we don't live in a perfect world. Apart from that, there are no established procedures that are simple enough to be used by the average fish farmer. At any rate, nitrogen and phosphorus are released at varying rates from different fertilisers and the uptake varies between species of plankton.

To further add to the confusion in this area, nitrogen is fixed in the water by blue-green algae and the activity of the nitrifying bacteria releases random amounts of nitrogen into the water column to be taken up by the plankton.

The accepted practice is to fertilise with proven concoctions and manage the bloom as it goes along. Although there seems to be as many recipes for plankton production as there are aquaculture ponds, you shouldn't let their proliferation confuse you. The following formula is based on that suggested as a guide by NSW Fisheries but, as mentioned before, each region will have different soil properties and you may have to experiment if you're not satisfied with the results.

NSW Fisheries have been producing native fish fry since the late-1970s for restocking waterways around the state and it's unlikely that there is a group in Australia with more plankton growing experience. They suggest the following application rates as a general guide for inorganic fertiliser in warm water ponds.

- **113 kg/ha of an 8:8:2 fertiliser mixture or**
- **45 kg/ha of a 20:20:5 mixture.**

These fertilising rates will result in the application of approximately 9 kg/ha of N, 9 kg/ha of P and 2.2 kg/ha of (K). The following examples of fertilisation regimes applied weekly to a 1-ha pond approximate these inorganic nutrient levels.

- **Pond size: 1.0-ha – applied weekly:**
    - **15 kg sulphate of ammonia**
    - **40 kg diammonium phosphate (DAP)**
    - **5 kg potassium chloride (Muriate of potash)**
    - **150 kg lucerne chaff.**
- **Pond size: 1.0-ha – applied weekly:**
    - **20 kg urea**
    - **46 kg superphosphate**
    - **5 kg potassium chloride**
    - **250 kg poultry manure: 250 kg initially, then 80 kg weekly.**
- **Pond size: 1.0-ha – applied weekly:**
    - **33 kg sulphate of ammonia**
    - **18 kg triple superphosphate**
    - **5 kg potassium chloride**
    - **300 kg cottonseed meal.**
- **Pond size: 1.0-ha – applied weekly:**
    - **40 kg diammonium phosphate**
    - **10 kg potassium chloride**
    - **5 bales lucerne hay: 5 bales weekly initially, and then every 14 days**
    - **60 kg poultry manure.**

Keep inorganic fertiliser away from the bottom of the pond wherever possible to avoid nutrients becoming locked up in the substrata. This can be done by either dissolving the granular fertilisers in water and pouring the solution into the pond or leaving the fertiliser in a pile on a submerged platform in the pond to allow the active ingredients to leach into the pond water.

To determine when the pond needs an addition of fertiliser, lower a Secchi disc into the water until it disappears. Read the depth at which this occurrs. If it is still visible at 50 cm then more fertiliser should be added. Most freshwater growers try to maintain Secchi disc readings at between 20 cm and 40 cm. Marine farmers like to see the reading between 25 cm and 40 cm.

There is always the possibility of the bloom crashing. Fertilisation should be stopped when the Secchi disc reading is 20 cm. Ensuring DO levels are maintained will help stall crashes.

Excessive phytoplankton will make it difficult for the farmer to maintain adequate DO levels overnight without aeration of some kind.

Monitoring

Ponds under intensive plankton production are about as volatile and dynamic as aquaculture gets and water quality and pond load parameters should be monitored daily. With high levels of phytoplankton production pushing the pond load close to maximum operating levels, the pH and DO could be unstable, unless well managed.

Because you are adding fertiliser on a regular basis TAN levels will tend to be high. To ensure that this doesn't cause an ammonia problem, the pH and temperature will have to be monitored twice a day: early morning and early afternoon.

DO readings should be taken at the same time to gauge the diurnal trend so the mirror image downward nocturnal trend can be plotted. Plankton ponds, like any aquatic production pond, should not be allowed to slip below 75% saturation.

Maximum and minimum temperatures will give you a guide to what is happening when you're asleep in your bed. Water temperature ranges should be collected daily. You can use a maximum–minimum thermometer or a temperature data logger.

The management of a plankton bloom deliberately instigated to produce food is similar to the management of a plankton bloom that is incidental as the consequence of everyday fish production; it's just more intense and you generally have a lot more at stake because you are raising juveniles that will become the seedstock for the grow-out systems.

Urea

Urea, at 45% nitrogen, and triple superphosphate, at 20.5% phosphorus, is widely used in aquaculture and is regarded as one of the cheapest fertilisers available. However, as already pointed out, urea hydrolyses with water and forms ammonium, and the granular phosphate fertilisers may not release the potency of their nutrient value before they become locked up in the pond sediment. Tests have shown that as little as 5% of the nutrient value of superphosphate releases into the water column when broadcast over the ponds. There are several problems with ammonia in water. One thing, ammonia is directly toxic if you get enough of it. Another thing is that it nitrifies with the bacteria and the nitrates and that process places a demand on the pond's oxygen and also causes a low pH because hydrogen ions are produced when the ammonia converts to nitrate. On that score diammonium phosphate is becoming more popular as a source of both nitrogen and phosphorus. If you just want to add nitrogen then you could get it out of sodium nitrate (16% N) or potassium nitrate.

Flooding a dry pond

At any given time water will carry, depending on the season and the food supply, a number of aquatic invertebrates and their larval stages. Some of these animals will prey on hatchling crayfish and fish larvae.

To minimise the initial build-up of aquatic invertebrates in the pond, plankton producers will flood a dry pond with water that has been strained through a 500 μm screen. Airborne invertebrates will quickly find the new water and begin colonising it, but by following the above procedure growers will have bought their charges precious time.

Dry flooded ponds also seem to produce a better crop of the sort of plankton fish farmers are looking for, although it's not mandatory. Growers hard pressed for pond space during a busy season will drain and remove one crop of fry and re-flood the pond within days.

Temperature

Temperature is as important to the plankton population as it is to any of the aquatic life forms you'll be cultivating. The temperature band that you require to produce the plankton you want is the temperature band that matches that of the animal you are cultivating. For instance, if you were raising golden perch fry you would be looking for water that is 20°C to 26°C.

Some growers only half-fill their plankton ponds at first and add water slowly as it warms up. However, you should be aware that sudden temperature drops can set the bloom back. Severe drops can even kill off the bloom completely. Be aware that while a body of shallow water warms up quickly, it loses its heat just as quickly. If you are trying to get the water warmed up, make sure you've plotted the weather a few days ahead so you don't run into a cold snap so common in inland Australia during unstable spring weather.

Macrophytes

Macrophytes are the aquatic plants that float free on the surface of waterways, float at the surface but are attached to the substrate, are attached but mainly grow beneath the water, as well as those that grow in the water and have leaves that emerge and grow upright.

Aeration, or more accurately, the agitation of aeration should keep free-floating plants such as azolla (*Azolla* spp.) and duckweeds (*Lemna* spp.) at bay and the turbidity of the plankton bloom should prevent sunlight reaching the substrate, which will stop aquatic plants taking root. Plants in this category that are particularly troublesome and relatively common are water milfoil (*Myriophyllum* spp. and *Glossostigma* spp.), ribbonweed (*Vallisneria gigantea*), pondweeds (*Potamogeton* spp.) and floating pondweed (*Potamogeton tricarinatus*). They are to be discouraged at all times.

Exotic plants that have been declared noxious in some states are salvinia (*Salvinia molesta*) and water hyacinth (*Eichhornia crassipes*). Hopefully you won't come across either of these, but if you do get in touch with your local Agriculture Department officer.

But the really dangerous plants to have around your fish ponds is cumbungi (*Typha* spp.). That's the tall thick-leafed plant with the orangey brown seedhead that explodes into a myriad of airborne bits of fluff on a hot day. It's the one ducks and coots love to hide and nest in but it can exude toxins under certain conditions that will kill fish.

The other macrophytes you're likely to find wanting to colonise the edge of the ponds that you don't really need are common reeds (*Phragmites australis*), sedges (*Cyperus* spp.), spike rushes (*Eleocharis* spp.) and water couch (*Paspalum distichum*). While not toxic, they can clog channels, snag harvesting nets and generally make life difficult around the ponds.

Anecdotal evidence from the USA catfish and crawfish industries suggests that some macrophytes are toxic to phytoplankton, which would make sense seeing as they're vying for the same environmental niche.

Types of phytoplankton

Individual phytoplankton are very small: 10 µm to 50 µm. Water colour and Secchi disc depth are reliable indicators of plankton volumes on a working fish farm. Trying to get too scientific about the cell count will drive you crazy and keep you away from more important things that will have to be done around the farm. Having said that, if the local high school or TAFE college wants some field work for some of their science students then set them to compiling a colour chart for the various phytoplankton populations that you can use as a comparison at a later date.

There are exceptions to the above generalisation about phytoplankton. Blue-green algae (*Cyanobacteria*) consist of chains of cells, which are either found in strings or clumps. Ponds can become dark green with blue-green algae.

Anabaena is a particularly troublesome species, especially in crayfish ponds, as it can settle like a carpet, blanketing the substrate and the crayfish with a green slime.

As a rule of thumb, blue-green algae prefer turbid water with a low nitrogen content. The theory is that blue-green algae are motile so they are able to find their way to the surface to drawn energy from the sun; and, being able to fix their own nitrogen, can thrive in phosphate-rich, nitrogen-poor waters.

Filamentous algae (*Spirogyra*), is a common problem during the spring warm-up. It will create problems with harvesting as it clogs nets and entangles fishes' gill plates and other protruding spiny bits. Maintaining an algal bloom will prevent the *Spirogyra* from getting a start.

Both filamentous and blue-green algae are large enough to clog harvesting nets when present in large volumes.

Plankton crashes

Sadly blue-green algae are part of fish farming. The algae will give an off flavour to the fish and they are associated with plankton crashes. Uncontrolled blue-green algae blooms can cause shallow chemical and thermal stratification by creating a surface layer several centimetres thick completely blanketing the pond's surface. During long periods of strong summer sunlight, photosynthesis can produce supersaturated DO levels and low carbon dioxide concentrations with associated high pH. These conditions can lead to blue-green algae die-off, which in turn can quickly lead to major water quality problems as oxygen is used to break down the sudden influx of decaying vegetable matter.

Aeration and water exchange are the simplest and most effective cures for the problem. Of course an ounce of prevention is worth a pound of cure.

Having said that, most plankton crashes are caused by sudden nutrient depletion, and that includes sunlight. It may seem frightening and daunting reading all this but, in reality, plankton blooms are quite easily managed as long as you have sound management practices, sufficient water and mechanical aeration to deal with an emergency.

Zooplankton

Zooplankton is the collective name for the small crustaceans, some microscopic, others macroscopic, that live on the detrital food web, the phytoplankton bloom and each other. They will appear a few days to a week after the phytoplankton bloom gets under way. Zooplankton make up part or all of the diet of some finfish larvae, notably the predacious breeds, and freshwater crayfish. Their cultivation in fry ponds is part of the operating some hatcheries. They will be present in the water regardless of whether the phytoplankton bloom is generated by the farmer or as a consequence of feeding fish.

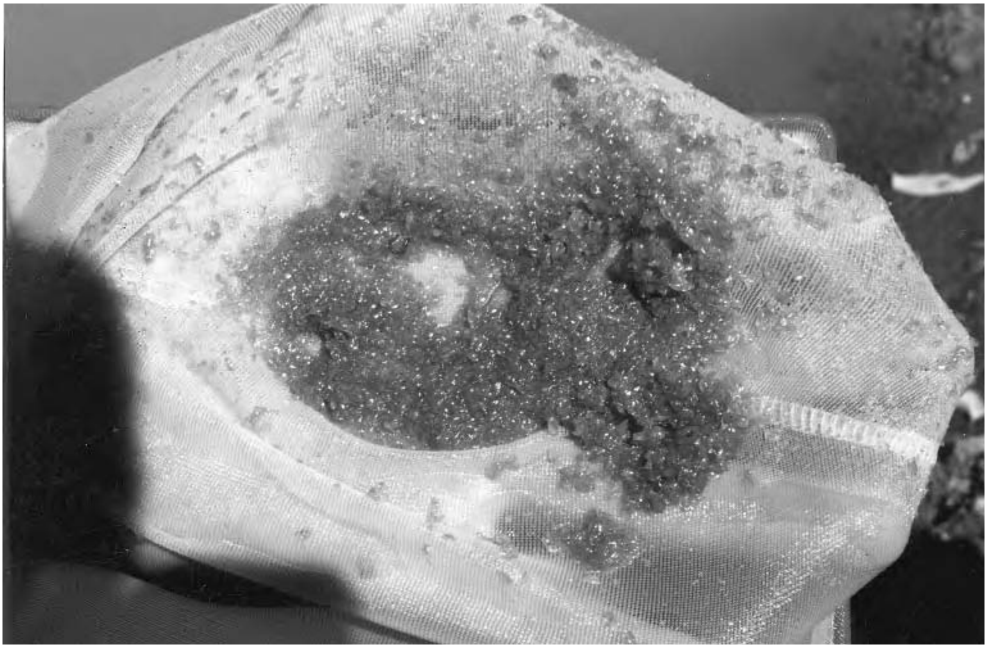


Figure 8.2. Zooplankton can be produced cheaply in copious amounts and it makes a cheap and nutritious food for certain species at certain stages of their life cycle.

The authors would like to acknowledge Bruce McInnes of Wartook Native Fish Culture (WNFC) at this point for allowing us to borrow in part from his Hatchery Technician course notes. Bruce is a native fish breeder and one of warm water aquaculture's most efficient plankton growers. He's well known for his introductory statement to each student intake that he is a plankton farmer first and a fish farmer second. WNFC is situated 30 minutes from Horsham at the foot of Victoria's picturesque Grampian Ranges.

Main types of zooplankton

There are many kinds of zooplankton you'll find in your ponds, which should come as no surprise to you at this stage. The different groups are made up of different species and each species will have its preferred temperature range and nutrient conditions. That means, that unless you can manipulate the climate you'll be raising yet another crop of organisms to feed a third. Now that's polyculture.

Rotifers

Rotifers are small animals that can range in size from 100 µm to nearly 5 mm but most species are no more than 2 mm in diameter. They can be herbivorous or carnivorous and some are parasitic. They can be identified by the fine fibres, called ciliates, surrounding the mouth region. These ciliates are used for locomotion and to create currents to direct food to the mouth. They can be mistaken for ciliated protozoans and becoming proficient in being able to tell the difference is part of fish farming. It's not a difficult skill to pick up with the aid of a good reference book.

They are the first animal to appear after the algae bloom; sometimes as little as five days after flooding. Most rotifers are small herbivores less than 400 µm (microns) in length and consume phytoplankton 3–17 µm in diameter. They form a major part of the diets of larval fish and invertebrates at first feeding and, because of their size and swimming behaviour, they are easy prey for larval predators. At WNFC they have found at least seven different species of rotifer in the ponds. Some like the cooler spring temperatures, others the hot summer temperatures, and still others the declining temperatures of autumn. It's not uncommon to have one species die off to be replaced by another, or to have up to three species at once.

Individual rotifers do not live very long. The female life span is about six to eight days at 25°C; and males only live about two days. Females produce their first offspring when they are about 18 hours old and continue producing throughout their life, asexually producing 20–25 daughters if the food supply is adequate and water quality good.

While this doesn't sound like much of a life span, under ideal conditions they can produce huge volumes of food.

Most rotifers are light brown or clear in colour, which doesn't affect pond colour greatly. But the black variety is easily seen in mid-afternoon, when they collect just below the surface in colonies; on frosty mornings they gather at the surface. Rotifers are affected by wind and subsequent wave action, which can make them unevenly distributed around the pond.

Copepods

Copepods are extremely common in fresh and marine environments. Most species are herbivorous or omnivorous. They'll feed on detritus, phytoplankton and the nauplii (young) of other zooplankton.

They tend to be more evenly distributed throughout the ponds and the vitality of a population can be judged by the number of adults carrying eggs on their tails and by the density of the nauplii in the population.

They are the most common zooplankton you'll find in ponds and the easiest population to maintain. At WNCF they have maintained copepod populations for at least five months at a time. They do best at water temperatures of between 20°C and 25°C. There has been work carried out that states some species can live up to two years. Copepod young (nauplii) are about the same size as adult rotifer, <100 μm. Adult copepods are four times bigger and range from 300 μm to 3 mm depending on the species. Copepods graze on algae and prey on other animals like rotifers. They have been known to eat into the sides of very young fish larvae, although this doesn't appear to be a problem in fry production ponds. Ponds should not be flooded for more than 10 days before stocking fish larvae to avoid this problem.

Cladocerans

The members of this family likely to be found in aquaculture ponds under culture conditions will range in size from 200 μm to 4 cm. They can be identified by their jerky swimming motion, hence the common name of 'water flea'. Their head protrudes from the carapace and they have two pairs of antennae, the larger of which is used primarily for locomotion. They have a life span of 40 to 50 days, and will be breeding within a week of hatching.

They feed on bacteria found on the detritus, phytoplankton, protozoans and small zooplankton. They make up the diet of fish larvae and fry as well as being an important part of the food of freshwater crayfish.

The females carry the eggs and embryos in a brood pouch over the dorsal surface. Normally the females reproduce parthenogenetically, i.e. without fertilisation of the eggs. Males only appear in the population at the approach of unfavourable conditions and the fertilised eggs that result, the resting eggs or cysts, are drought resistant. They are enclosed in a case or ephippium that protects them when the pond dries up. Rotifer and copepods also use this resting cyst stage. The cysts can be carried on the wind and are ubiquitous.

Moina and *Daphnia* are the most significant species in the rearing of native warm water species. Although they form a major part of the food supply in fry ponds, they can be a difficult population to maintain over any length of time. They are a herd animal, and at times are hard to find. Samples from different parts of the pond should give the most reliable idea of the population density.

Ostracods

Although not a significant food source in fry ponds, ostracods (or seed shrimps) can be found in ponds. They are usually observed as rafts of round black objects swarming near the lee shore of the pond. They are normally <1 mm. They are generally associated with a pond that has built up a rich organic substrate and are regarded, in a pond that has lost its 'vitality', as a productive food source for finfish fry and crayfish populations.

A few hints

This may be starting to sound a bit daunting, and in a way it is. Plankton production is a serious business, but so is aquaculture. In practice you'll be amazed how it all fits together once you get under way. Here are few hints that will help it come together.

You should only use enough fertiliser to induce plankton growth. To overload your ponds with nutrients will encourage violent DO and pH swings beyond the capacity of the pond's natural control mechanisms and your own management tools to cope.

Following on from the above, it is better to feed a little fertiliser to the pond every few days, or on demand, to maintain continuous levels of production rather than loading up the pond and letting it assimilate a fortnight's food at one sitting.

GWQEHN says:
If you think of fertilising a plankton pond in terms of feeding a baby you won't go far wrong: too much too quickly and you're up all night with it.

Don't let it become an obsession. At some stage, the maintenance of conditions conducive to plankton production will be in conflict with conditions conducive to water quality management and fish health, which will bring about a management decision in favour of the water quality management and fish health. This is particularly so in crayfish production ponds. At this stage exchange water until the plankton bloom has settled down, then start cautiously again.

One way of stimulating plankton blooms and zooplankton populations is to freshen the ponds with new water. As most plankton production is carried out at the time of the year when evaporation is at its height the replacement water can be used as a stimulant. If you feel more fresh water is needed than that provided by the action of the sun and the wind you can drain a bit off to make room for the fresh water.

Zooplankton monitoring

Monitoring zooplankton populations is done with a plankton net. The mesh size of the net is usually around 60 µm. It's important to collect from the surface, as well as near the bottom. The sample can be looked at through a microscope to determine the composition of the population but experienced growers can make a judgement with the naked eye. A good magnifying glass is a handy tool to assist pondside evaluation.

A plankton net can be an air sock-shaped construction that is 'frisbeed' out into the pond, or a hand-held plankton net that you can scoop through the water while standing on the bank. Growers using 1 m deep ponds will wade through the ponds in search of plankton, particularly the wandering cladocerans, as a method of determining population density. It won't take long to become proficient at taking samples.

Determining zooplankton density

Scientists at research stations and students at aquaculture colleges are taught how to calculate the zooplankton count of a given body of water. This painstaking procedure will certainly develop a greater understanding of what's happening in the ponds but most growers, especially those dependent on plankton production for a living, will develop a few short cuts, one of which will be visual appraisal.

A simple way of getting a good look at the zooplankton population of the pond is to collect a sample in the plankton net and put it in a jar or beaker of clean water. A 500 g or 1 kg jam or coffee jar is fine. Naturally you'd remove the label. By holding the jar to the light you'll get a good look at the sample. After a while you'll become proficient at identifying species in this manner. Should you come across anything you can't identify, the sample can be scrutinised under a microscope.

For the more scientific minded, the standard procedure for calculating zooplankton density is to estimate the volume of water from which the sample has been taken and strain the plankton from the water, separating it from other pond debris collected in the haul. Then place the sample in a litre of water and take a sub-sample of 10 ml. This will give a representative sample, and one from which it will be practical to count the number of animals.

The sample can be further broken down by using what is called an Endecott sieve. This is a series of nesting sieves with a descending mesh size. For instance the top sieve might be 250 μm, the second sieve 125 μm and the final sieve mesh 60 μm. This will separate different species and size ranges of the same species within the general population.

If, for argument's sake, our plankton net has a mouth of 30 cm and each haul through the water is 3 m. Therefore:

$$\text{the volume of the shot would be } \pi r^2 \times 3\text{ m}$$
$$= \pi \times 0.15^2 \times 3\text{ m}$$
$$= 0.0707\text{ m}^2 \times 3\text{ m}$$
$$= 0.2121\text{ m}^3$$
$$= 212\,100\text{ cm}^3$$
$$= 21.21\text{ L}$$

The volume of the sample would be the number of shots taken. It doesn't matter how many samples you take from the same pond. As long as you feel the sampling is representational, take as many as you like. Just remember you've got to count the individuals at the end of the procedure.

The formula for calculating the zooplankton density is:

$$\text{Zooplankton density (individuals/L)} = n(CV \div SV) \div TV$$

Where:
n = mean number of individuals counted in 100 ml sub-samples.
CV = volume of water (in ml) containing the concentrated sample
SV = volume of water (in ml) containing the sub-sample from which the zooplankton are counted
TV = volume of water (in litres) from which the sample was collected.

Let's say we found the average number of individual zooplankton counted from three 10 ml counts was 240 and we did two shots to get them. That would make TV 282 800 ml^3 and n = 240. The equation would look like this:

$$\text{Zooplankton density (individuals/L)} = 240(1000 \div 10) \div 42.42\text{ L}$$
$$= 240 \times 100 \div 42.42\text{ L}$$
$$= 24\,000 \div 42.42\text{ L}$$
$$= 566 \text{ individual zooplankton per litre of pond water.}$$

If you want to estimate the total number of zooplankton in the pond just multiply the number per litre by the number of litres the pond holds. Each megalitre of pond water is 1 000 000 litres. If the pond is 2 ML the total number of animals will be 566 000 000. Sounds impressive, doesn't it? And they're breeding overnight when the conditions are right.

What do we do with the information?

Being able to calculate the numbers of the different sizes of zooplankton will help the hatchery operator evaluate the number of mouthfuls his developing larvae and fry are going to be able to get from their feed source. However, as the fish get larger it becomes more about mass than numbers.

Estimating the weight of food available is a much quicker and simpler version of the above procedure. Calculate the volume of the pond sampled as before and let it drain off any excess water. Weight the sample in grams. You may need laboratory scales to do this accurately. Then divide the weight of the sample by the volume of the sample in litres. The answer will be the number of grams of wet weight food available to your stock per litre. Again multiply the number of litres in the pond by the weight of zooplankton per litre and you'll have the total weight of zooplankton available in the ponds to feed your charges.

Let's say the sample of zooplankton weighed 20 g after the water had drained off it. The volume of the sample water was 42.42 L so the weight per litre of the pond is 0.471 g. Multiply that by 2 000 000 to get the total wet weight of zooplankton available in the pond. The answer is 942 000 g or 942 kg of wet weight food. That means, on face-value and based on these calculations, the fish or crayfish in the pond will have access to nearly a tonne of food.

That may sound like a lot of food when you consider that a 2 ML pond probably would be close to its maximum carrying capacity at 1000 kg of stock. But remember, in nutritional terms our feeding rates have been worked out feeding dry feed that is around 10% moisture. Zooplankton is a wet food and will probably be around 80% moisture. That means only 20% of the plankton is made up of dry matter that could be nutritious to the fish. That means our 942 kg of zooplankton will only contain around 188 kg of dry matter food, a good deal of which will be the carapace of the micro and macrocrustaceans that make up the zooplankton.

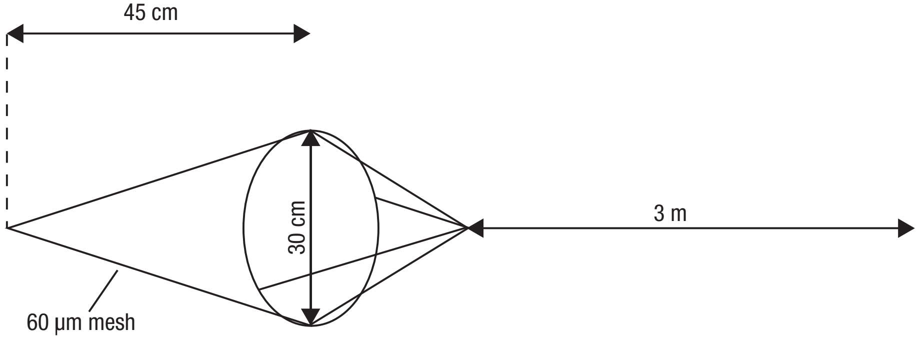


Figure 8.3. A typical 'wind sock' plankton net. The length of the sock is not critical but a deep sock will allow a good flow of water through the net. Make it longer rather than shorter but if you have it too long it becomes cumbersome to cast. The authors recommend 1.5 times as long as the opening.

Other pond life

The above comments only touch on the main food source plankton. There's a fascinating myriad of pond creatures that will keep you enthralled over the microscope or wading the ponds, plankton net in tow. The bibliography includes a few titles that will help you identify your discoveries.

Algal lawns

The larvae of some species eat algae, but not planktonic algae that float in the water column. The larvae of species such as abalone, trochus and trepang (the sea slugs used to manufacture beche-de-mer) very quickly settle to the seabed where they take up life. They feed on slimes living on the solid substrata. A more polite name sometimes substituted for 'slime' is 'bio-film'.

Natural bio-films consist of a variety of life forms. They can include bacteria, and single-celled algae, predominantly diatoms. In some cases they also include the smaller multi-celled algae.

Good husbandry requires a farmer to provide food that suits the species' natural feeding habits. Abalone, trochus and trepang are animals that graze on the seabed and farmers of these species grow natural food to feed their charges during the hatchery phase.

An extensive approach is to create a large area of substrata in an open pond and run nutrient-rich seawater over it, at the same time allowing the sunlight to filter through to the substrate. The combination of sunlight, nutrient-rich seawater and a suitable propagation surface will generate a crop of natural slime.

In intensive situations, such as a shore-based abalone operation, algal plates are set up in trays with sufficient space to allow sunlight and seawater to reach all the surfaces of the plates. The natural algae spores in the seawater settle on the substrate and start to grow, forming an algal 'lawn'. This lawn is then used as a source of fodder for the just-settled larvae. The algae will form in the same way that it does in the open ponds but the crop will be more concentrated and the management of the animals and crop is far more efficient.

In a situation where the operation requires a more sophisticated approach, monocultures of algae may be cultivated in much the same way shellfish hatchery operators grow monocultures of planktonic algae. A particular species of algae may be selected for nutritional value or it may be selected to suit the size of the dental equipment of the farm species, which will of course change as the animal grows.

Managing an algal lawn grown on a plate can be tricky. If there are not enough algae growing on the plate, the larvae will starve, or at the least, will not grow at the optimum rate. If the lawn has grown too lush, the larvae will not be able to find a place to live, and may be swamped. A balance must be struck. But it gets more complicated as time goes on: as the larvae grow, they eat at a faster rate, and ideally, the rate of growth of the lawn should be increased to match. By manipulating the amount of sunlight reaching the plates the hatchery manager can control the UV stimulation of the growth on the plates.

Some larger finfish species also benefit from being fed by algal lawns. In the aquarium sector there are several species of catfish and loaches that live by sucking off bio-films and eating the algae. Sometimes these species can be fed using normal formulated fish food, but in some cases the juveniles are fussier about the way they get their food. One of the authors remembers the technique used by his old boss back in the 1960s. The catfish were kept in a fish tank that was covered by glass to prevent fish jumping out. These glass lids were continually watered by spray rising from aeration and the water contained fish waste products, which were plant nutrients. The tanks were lit from above and there was an abundance of light. Nature abhors a vacuum and an algal lawn grew on the glass. Most operators thought of the algae as a problem that had to be cleaned, but the old boss saw it as a solution, taking the plates, putting them in the water to feed his juvenile catfish.

Similarly, the authors have noticed juvenile crayfish cleaning the settled green bio-film that had formed over the sides of a glass aquarium. When newly hatched juvenile yabbies were placed in the tank it was found that they fed off the algae, cleaning the glass progressively from the bottom to the top. It says a lot for the animal's ability to feed on vertical surfaces if nothing else.

Some growers will put algal mats of a fibrous material in the water of their crayfish nurseries to grow an algal lawn for their juveniles to feed on.

It is possible to provide supplementary nutrition to animals whose feeding apparatus insists that they feed off a surface. The food does not necessarily have to be algae, but it does have to stick on a surface. To do this, growers mix the required fish food in a crumbled form with a jelly in the liquid stage to form a liquid nutritional blend of the diet. The feeding plates are then dipped in the liquid so that a film of the setting jelly forms on the surface. This provides an approximation of an algal lawn and can be put in the tanks to feed the animals.

Detritus production

Detritus is rotting organic material; in an aquaculture sense this is normally plant material such as hay and dead phytoplankton but can also refer to animal material. Dead fish on the bottom of the pond for instance, or zooplankton: victims of a plankton crash.

The microbes and worms breaking down the organic matter on the bottom of the pond form an important part of the natural food supply of freshwater crayfish and some crayfish farmers develop a method of producing and managing a detrital food mat on the substrate of their ponds.

There are two ways in which a crop of detritus can be produced. One is by growing a crop in the pond before flooding, waiting for it to hay-off (dry out) and then flood the pond. The other is to introduce hay and fertiliser to the pond before it is flooded.

More hay can be added to the ponds during the growing period if the detritus appears to be used up, however, some farmers find the management and risk involved in maintaining a detritus crop not as beneficial as changing over to a supplementary ration.

There's also a limit to the amount of food that can be produced in this manner. The breaking down of organic matter takes a huge amount of oxygen from the pond's DO reserves. Remember the pond is being asked to metabolise nutrients, nitrify the ammonia and supply oxygen to all the animal life that is being encouraged by the biological soup the pond is becoming. While the food is extremely nutritious, there comes a point where it is counterproductive to continue producing detritus.

As with any production pond operated with high organic and nutrient loads, the maintenance of conditions conducive to detritus production will be in conflict with conditions conducive to water quality balance and stability, which present a threat to animal health. The sensible management decision under these circumstances is to stop adding organic material and other nutrients, give the pond a good flush out and change over to a supplementary ration.

Standing crop

The crawfish farmers of America's Mississippi Delta are masters of producing a detrital food web from a standing crop. They have made a fine art of flooding rice, sorghum or forage crop stubble in late autumn for spring harvesting of the crawfish that have been raised there during the winter. The standing stubble will range from 0.5 kg/m^2 to 1 kg/m^2: that's 5 t/ha to 10 t/ha. It's also a lot of hay. They will flush the water through the ponds between 10 and 20 times depending on the season and the organic load. And that's a lot of water. Obviously this production method is not applicable to many situations in Australia. The cost and scarcity of water is one compelling reason and the single figure winter water temperatures in most parts of inland southern Australia would rule it out as an economic option: the crayfish just wouldn't grow enough. However, there would be places in tropical and subtropical Australia where the routine could be followed.

In southern and inland Australia a standing crop could be used to generate a detrital food web by growing a winter crop in the pond and flooding it in the spring or early summer. Choose an early maturing, strong-stemmed, straight-standing crop. Cereal crops present the best option. The juvenile yabbies like hanging from the straight-standing stems and the slow breakdown rate of the heavy stems will create long-term nutrient availability from the subsequent detrital food web. The density of the crop should be commensurate with the amount of water available to flush the pond should the BOD drop the DO to dangerous levels, say below 2 mg/L over any length of time, say 24 hours. Aeration is an option as long as the water can be pushed around the pond through the stubble. However, if aeration alone can't maintain adequate DO levels, flushing will have to be used to bring the ponds back to a stable balanced condition.

Some growers only half-fill their ponds during the early stages of developing the detrital food web to save on the water exchange. Make sure the crop is mature before flooding the pond; in other words, the greenness is gone from the stalks. Obviously this method suits growers operating in a situation where water is being pumped onto the farm continuously for agricultural purposes. In this case the water could be diverted to the ponds and the flushed water sent on to the irrigation bays in its place.

Should the crop look too heavy once it's matured, harvesting strips through it can lighten it off. If you can't get a baler into the pond you may find yourself looking around those clearing sales for a scythe or a sickle. Dropping off the idea yet?

There's no established volume of dry matter but if you started with 0.1 kg/m^2 that would be the equivalent of 1 t/ha. For beginners, 2 t/ha would be as dense as you'd want to go. If you do incorporate a standing crop as a source of material, make sure you have enough water and aeration available to handle the situation.

Once the nutrient value of the organic matter and the associated organisms has been consumed you could add more hay or change over to a supplementary ration.

Naturally, don't stock the crayfish until you have stabilised pond conditions. This may take a couple of weeks.

Introduced hay

The outcomes sought from introducing hay are the same as those sought from flooding a standing crop of stubble, and in many ways this method is more practical. The amount of hay that is put in the pond can be controlled and the quality of the hay going into the pond can be monitored. You'll probably remember from your composting days that the ideal carbon to nitrogen ratio (C:N) for aerobic microbial breakdown is 17 parts carbon to 1 part nitrogen (17:1). Well, surprise, surprise, it's the same in your water farming days. The best hay is lucerne or good meadow hay. It should be teased out and distributed evenly about the pond bottom: 1 t/ha to 2 t/ha would be sufficient. (Again you would have to have access to good water resources in order to control the situation.) Ideally it would rain 100 mm the day after you spread the hay. But it won't, so slowly flood the pond to get the hay saturated to prevent it floating and forming rafts blown up against the lee shore. If you can't manage it, don't worry. The crayfish will find the rafts of hay and they soon waterlog and sink. Some growers stake the baskets of hay to the pond floor.

Some growers even feel the floating rafts provide good cover for the crayfish as they are often found hanging onto the underside of the rafts. Crayfish don't appear to have a need to stay right side up and seem happy at any angle.

With regard to maintaining DO levels, the same rules apply in developing a hay-based detrital food web as they did in a stubble-based one. The main thing to ensure in this process is to tease the hay out so that the oxygen can get to the microbes breaking down the vegetable matter. Without this life-giving gas they can't do their work and anaerobic bacteria will take over.

Thick-stemmed lucerne hay will last longer than fine-stemmed meadow hay, which is traditionally made up of clover and rye grass. Other baled crops can be used, but keep in mind the C:N ratio of 17:1. If you use straw with a high C:N you will have to add some nitrogen to the water to assist the degradation process and ensure that it does not rob nitrogen from other natural biological activities that will be occurring in the pond.

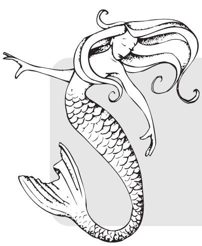
Some growers add fertiliser at this stage to generate a plankton bloom at the same time. If the hay loads are up near the 2 t/ha mark it would be a wise strategy to wait until the initial flooding of the pond has stabilised before adding additional fertiliser.

Once the nutrient value of the detrital food web is spent, it's possible to add more. Some growers start off with a light hay base of 0.5 t/ha and add extra hay each week or when they consider it to be necessary. However, there will come a time where either the detritus crop can't be maintained without jeopardising the stability and balance of the pond's water quality, or the detritus just can't keep enough nutrients up to the crayfish. At this point abandon the detritus and change over to a supplementary ration.

Managing a detrital food web is one of the most challenging aspects of husbandry but once mastered is an incredibly cheap and efficient source of crayfish nutrition. Jay Huner in his highly informative volume *Freshwater Crayfish Aquaculture* (p.33), states that detrital food-based crops have occasionally generated yields approaching 3000 kg/ha/yr against an industry average of 500 to 600 kg/ha/yr. This is based on a forage base ranging from 5 t/ha to 10 t/ha of dry matter and a minimum of 10 water exchanges.

Epilogue

There's a saying in some aquaculture circles that you're not a fish farmer until you've killed 10 tonnes of fish. Makes you think that a bit of practice wouldn't go astray, doesn't it? Practicing on someone else's fish is always cheaper, and safer with them there holding your hand.



GWQEHN says:
The best advice you can get about farming fish is from the fish themselves. Husbandry is all about listening to what the fish tell you.

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9

Nutrition

This chapter deals with the issues of nutrition in relation to the type of food to use under different circumstances. It includes:

- the role of nutrition in aquaculture
- understanding nutrition
- the components of nutrition
- specific diets for particular species
- natural food
- supplementary food
- phase feeding
- the impact of the environment
- how to use nutrition to make a dollar
- oxygen and metabolism
- growth priorities.

Having discussed the importance of nutrition and what fish like to eat, this chapter will look more closely at how nutrition works and explore the options available to fish farmers.

The authors are going to borrow shamelessly from the lecture notes of Bill Wiadrowski of Natural Balance Pet Foods, Tullamarine, Vic. Bill is one of Australia's leading animal nutritionists and has been delivering the Commercial Warmwater Aquaculture Introductory program with John Mosig through the TAFE system since 1995.

Nutrition is another of those strategic alliance areas. Like genetics, nutrition is an exact science. It will be more economical for growers to develop a relationship with a food supplier who knows his or her job rather than blunder about trying to design their own ration, unless of course, they happen to be crash hot nutritionists or have knowledge of some secret ingredient.

Fish, like other animals, require certain components in their diet to maintain health and to promote growth. Protein, fats, carbohydrates, vitamins and minerals all play their role in this process.

In the wild, the fish's prime purpose is to survive as a species. They do this by keeping their numbers up; in other words breeding. Growth is a secondary consideration. Their main purpose of feeding is to replenish energy, or even to build up a surplus. The tendency in the wild is to eat the most available feed to conserve effort, but still take aboard sufficient energy for daily function and reserves for the hard times ahead.

In aquaculture, the farmer's main aim is to stack on as much weight in the shortest possible time at the lowest possible cost; weight gain, not numbers, becomes the major consideration.

The role of nutrition

The role of nutrition is to enable the farmer to maximise genetic expression. A fish individually, or a species as a group, can only perform to the maximum of its genetic potential.

We have seen how any limitation to the fish or crayfish being able to express that maximum potential will reduce the efficiency of the animal in a commercial sense. For the sake of this exercise we'll only look at the limiting factors in two ways: environmental factors, such as water quality, husbandry issues or climatic impacts; and nutrition. As with the early discussion on limiting factors, the most limiting factor will dominate the overall efficiency of the whole operation.

Looking at Figure 9.1 below, if the limitation is the nutrition, it doesn't matter if the water is supersaturated with dissolved oxygen, the fish or crayfish will only grow as fast as the nutrition will allow.

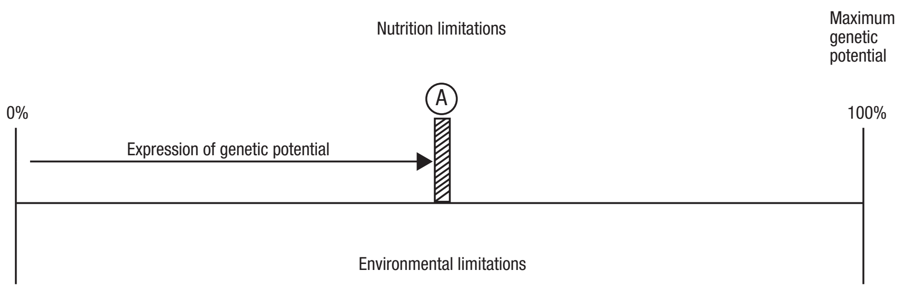


Figure 9.1. Expression of maximising genetic potential – the brick wall above the line.

If the nutritionist builds a brick wall by leaving out a key ingredient, then the animals can only grow to point A, which for the sake of the exercise we'll say is 50% of efficiency.

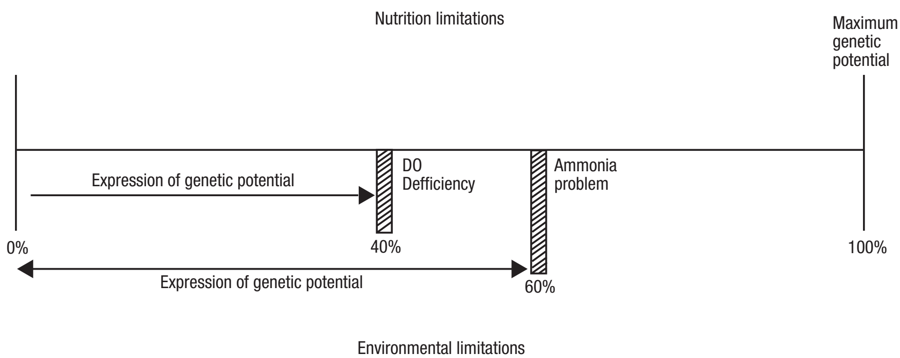


Figure 9.2. Expression of maximising genetic potential – the brick wall below the line.

In the same way, as in Figure 9.2, if the nutritional blockage to the expression of maximum genetic potential is removed, then management and environmental issues become the limiting factors.

If, on the other hand, there are brick walls below the line, among the environmental factors, the efficiency will stop at the first brick wall. It may be an oxygen deficiency limiting the efficiency factor to 40%. And after that has been removed there may be an ammonia brick wall at 60%. These will have to be removed before any assessment of the feed can be made.

GWQEHN says:
The role of the nutritionist is to remove nutrition as a limiting factor to allow the expression of the genetic potential of the crop we're producing.

Understanding nutrition

'Nutrition' is defined in the *Collins Australian Dictionary* as 'the process by which an organism takes in and assimilates food'. Another way would be to say it is the process of building and operating one organism by absorbing the nutrients from one or more other organisms.

Each organism has its own complex components and the absorbing organism takes from the absorbed organisms those components that it requires to function as well as to replace its energy reserves. Those components of the absorbed organism not required are discarded as waste.

Metabolism is defined in the *Collins Australian Dictionary* as 'the process in organisms by which food is built up into protoplasm and protoplasm is broken down into simpler substances or waste matter, with the release of energy'. In other words, fish eat what they find palatable, break it down into simple components, select those they want for energy requirement, growth, energy storage and cell and organ function and maintenance, discarding as waste those components that aren't required.

What does this mean to the fish farmer? First, it means nutrients that aren't utilised by the fish have to be neutralised by the production system's biochemical processes, processes that will use oxygen, oxygen that would be more profitably utilised growing fish.

Second, the amount of nutrient not being utilised is still part of the weight of the feed and it will appear on the account from the feed manufacturer, and the account from the carrier delivering the feed and you'll have to build a vermin-free, insulated shed to store it, maybe even a cool room (if you're farming in a climate, the heat and humidity of which makes it necessary to store the feed in an atmosphere-controlled environment).

Third, once the fish have satisfied their energy requirement they will stop eating. If more nutrients could have been utilised for growth that's not going to worry the fish. They've taken aboard all the fuel they require. It's the farmer who misses out if insufficient nutrients have been attached to the energy pill.

Energy requirement is the trigger for appetite

Fish eat to replenish energy reserves. What they eat for energy also provides them with the balance of nutrients they need for body function and growth. In the wild they eat what they are genetically programmed to eat; what the enzymes in their body can break down and utilise. Some animals have a narrow diet range and others will eat just about anything. For instance, abalone eat certain seaweeds while anything from cormorants to carp have been found in Murray cod.

When we feed farmed fish and crayfish, we can't feed just anything because the impact of un-metabolised components of the food would compromise water quality and consequently production. The secret of good nutrition, as close as current knowledge will allow, is to design a diet that supplies the fish's every need.

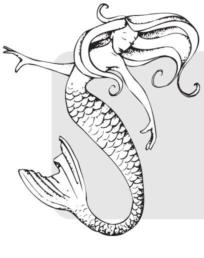
No nutrient is used in isolation

If there is anything you should take away from this chapter, it is that *no one nutrient is used in isolation*. This is one of the most important aspects of nutrition. Each component functions as a component of the whole, this highlights the importance of a balanced ration.

As it is beyond the scope of this book to offer an in-depth discussion on the science of nutrition, we will just make the point that nutrition is linked to energy.

We can take Gerald as an example. Gerald is a silver perch in a half-hectare pond. It was an ornamental pond and a patch of cumbungi has been allowed to establish itself in one corner so the ducks and the water hens had somewhere to nest. Now one bright sunny morning Gerald woke thinking he was Kieren Perkins so he went for a 1500 m swim. He set up quite a bow wave and at the end of it all he was exhausted. He'd burnt a lot of energy and when it was tucker time it took a cup of energy to replenish his fuel tank. He also needed to rebuild worn tissue and joints, not to mention the normal bodily functions that a silver perch has to do. For this he required a set amount of amino acids, vitamins and minerals to go with the cup of energy. For instance he required a dollop of methionine, a teaspoon of lysine and a pinch of tryptophan to go with the cup of energy.

Gerald had pretty much had it at the end of the swim and he retired to his favourite patch of cumbungi to rest for a few days. His energy requirements were low and at the end of the three days he only required a cup of energy to top up his tank. How much methionine do you think he'd need? That's right, a dollop. And the lysine? Did you say a teaspoon? And of course a pinch of tryptophan.



GWQEHN says:
No one component of nutrition is used in isolation. They are all used in relation to each other and to energy.

The components of nutrition

The components of what fish eat can be divided, in simple terms, into those used to build the organism, those used to operate the organism and those that have no use to either process, the waste.

Each species has its own dietary requirements and this is called the 'nutrient profile'.

As maximising growth and minimising waste is of prime importance, matching as closely as possible the nutrient profile of the species being cultured is one of the more important challenges the fish farmer will face. Fortunately highly trained and motivated people working in the nutrition industry will assist the farmer in this task and their advice should be valued. Nevertheless, knowledge of nutrition and how it works is an important tool to have in our aquaculture kit.

Energy

Strictly speaking, energy is not a nutrient. We've established that across the board, not just in aquatic organisms, the body must maintain a state of energy equilibrium. When our energy reserves start to fall our body says, 'Hey, this is not right. I'd better eat something. I'd better get some more energy into the system.'

Energy in a true sense is the trigger mechanism for appetite and if it's going to get the animal to eat in the first place, it's what's going to tell the animal to stop eating in the second place. If you think about it for a moment, that makes the energy quotient in the feed terribly important. It dictates precisely how much food the animal is going to eat. By judiciously attaching nutrients to the energy content of the feed we can determine the productivity of the animal being fed.

Energy in aquaculture diets comes from two sources. One of them is fats, or lipids, and the other is carbohydrate. In most of our fish diets, fats are a far better source of energy, in fact it's the preferred source of energy in the high order predators such as Murray cod and barramundi.

Carbohydrates, on the other hand, aren't as good as an energy source until you get to fish further down the feeding table. Fish such as carp handle carbohydrate in quite large quantities. Carbohydrates in the diet of a high order predator can be toxic. For instance, feeding too much in a diet can trigger a condition know as fatty liver, which kills the fish pretty quickly.

If we're going to put a good diet in the water, we need to limit the carbohydrates and structure our diet so we get most of the energy in the form of fat. Fat also has a much higher energy density so, in round figures, we only need half the amount of fat in the diet that we'd need to get the same quantity of energy from carbohydrates.

One of the real dilemmas in putting efficient diets together is that there's only so much room in a kilogram of space and to make a diet high performance we've got to pack as many nutrients in that one kilogram of room as we need to get an efficient ration. Fat, being so concentrated, is a very good ingredient in this regard.

In their wisdom, when we converted to the decimal system, the people responsible chose megajoules as the measure of the energy in Australia. It's usually written up as megajoules of digestible energy per kilogram (mjDE/kg). Internationally, if you're reading any of the overseas literature, it is measured in kilocalories and you'll see it written up as kilocalories of digestible energy per kilo (kcalDE/kg). The conversion is 1 megajoule = 238.8 kilocalories, so a middle of the road diet that has an energy density of say 15 mjDE/kg, would have 3582 kcalDE/kg.

Protein

Protein builds the flesh of fish and without it they cannot grow. Stockfeed manufacturers, by law, have to show the minimum crude protein, the minimum crude fat and the maximum crude fibre. It was a requirement legislated in the middle of last century when our knowledge of nutrition was, by comparison with what we have at our fingertips today, extremely limited. No one has bothered to point this out to the legislators.

GWQEHN says:
The collective name for protein is crude protein, and as the name suggests it is a crude measurement. Those who understand nutrition look well beyond the crude protein rating of a ration.

Protein is made up of smaller components called amino acids. Amino acids are divided into two groups: essential amino acids and non-essential amino acids. Some amino acids can be synthesised by the fish from other amino acids. These are the non-essential amino acids. Those that can't are called essential amino acids and must be present in the food in their actual form for the fish or crayfish to be able to utilise them.

Amino acids are sometimes regarded as the building blocks of cells. If you imagine a brick wall as the body of a fish, the amino acids are the bricks. If we don't have the bricks, we don't have the building blocks of cells. It goes without saying, that if those essential amino acids are missing from the diet we don't build any cells and we don't get any growth.

Different proteins sources are made up of varying combinations of amino acids. During digestion, the fish will break down the protein and absorb the amino acids it requires as building blocks. This is called the amino acid profile. Different fish have different amino acid profiles, and therefore require diets specific to that amino acid profile.

The essential amino acids are:

- arginine
- histidine
- isoleucine
- leucine
- lysine
- methionine
- phenylalanine
- threonine
- tryptophan
- valine.

Any deficiency of an amino acid will show up in fish health and growth as it will inhibit the utilisation of those that may be in the right proportion but can't be metabolised.

Any particular amino acid utilised for growth will only be in combination with the others that make up the profile in the proportions required. This means that the fish will only metabolise the required nutrients from the available pool, an amount in proportion to the level of the least available amino acid.

The other really interesting thing about essential amino acids is that they are used within the body proportional to energy consumption.

So summing up, there are fixed ratios of essential amino acid use in proportion to energy and to each other. The formula for these ratios is specific to each species and if we want to delve further, for each genotype. This knowledge, accumulated over 35 years has, along with genetics, underwritten the huge lift in efficiency in the pig and poultry industries. In fact it could be argued that we know more about the nutritional requirements for the animals we farm than we do for ourselves, or so it would seem from the plethora of fad diets about the place.

The quantity of the non-essential amino acids isn't as demanding as they can be broken down from the essential amino acids. However, one that needs watching is the amount of cystine because there are only two components in the whole amino acid structure that has sulphur in them. Cystine is one and the other is the essential amino acid methionine. They're called the sulphur amino acids so if there isn't enough cystine in the diet the body will borrow from the methionine at the risk of leaving the feed short of one or the other, or both, in relation to the amino acid profile. The 'aromatic amino acids', namely phenylalanine and tyrosine are a similar example whereby the entire aromatic amino acid requirement can be satisfied by phenylalanine alone, but tyrosine can't be used to replace phenylalanine.

What do we know about fish and crayfish diets? For some mainstream species such as salmon and trout, quite a bit. For frontier species, such as jade perch and Murray cod, not so much. Trials take time and cost money – a tremendous amount of time and a frightening amount of money. To provide some idea of what that market is worth to a feed manufacturer on a global basis, consider the value of the crop and divide it by two. The exact figure doesn't matter as it's in the billions of dollars. Striving for a small share of that market is worth the candle. Even the value of the entire Australian native fish food market at this stage wouldn't justify the time and money that would have to go into the research to do the job thoroughly. We'll be looking at this later in the chapter.

But don't become too despondent. Enough is known of aquaculture nutrition for manufacturers to draw on a database to provide the grower with a diet that will be

GWQEHN says:
If you take aboard only one thing about amino acids, let it be that they are used in proportion to energy and in proportion to one another.

economically efficient in a thereabouts way. How they use that knowledge is another matter.

The next thing we have to look at is the source of amino acids. These three aspects should be considered in relation to the specific requirements of, as far as current knowledge will allow, the fish or crayfish being grown:

- the quality
- the quantity
- the availability.

A high quality source of protein will have a high proportion of essential amino acids.

Next we have to consider the essential amino acids required for the particular species being farmed. The protein source must have sufficient quantities of the essential amino acids needed to make the fish grow.

But, if the essential amino acids are in a form that can't be broken down and extracted by the digestive system of the species, then they may as well not be there because they will finish up going out the back end of the fish in much the same form as they went in the front end.

This is costly from two points. First, it is a waste of money. Second, the farmer will have to deal with the nutrient load in the course of their water quality management procedures. This will add to the biochemical oxygen demand (BOD) without adding any growth to the crop. In fact it will reduce the amount of dissolved oxygen (DO) available for growth.

As an example, let's look at three protein sources. It is only a comparative study so the prices themselves don't matter. The marketplace, i.e. the feed manufacturers, will be valuing every ingredient in it in relation to the amino acid content anyway so the prices will have a certain relativity. The ingredient values in a given season will be determined by the availability of the component concerned but considered in relation to optional sources.

For the sake of the exercise, as it's a key essential amino acid in most animal feeds, we'll look at lysine as the particular amino acid we're evaluating. It's usually the essential amino acid the diet runs out of first. We'll look at the cost of the basic ingredient and the cost of the lysine as it would be utilised in an aquaculture diet. Remember fish have a digestive system that digests and metabolises food in a particular way, and ingredients that are able to be broken down and utilised by a ruminant are not necessarily available to aquatic species.

Table 9.1. Comparison of the real value of ingredients in an aquaculture diet based on the availability of lysine.

	Lupins	Meat meal	Fish meal
Price per tonne	$250	$440	$1100
Quantity – amount of lysine/tonne	13.5 kg	26 kg	59 kg
Cost of lysine	$18.52/kg	$16.92/kg	$18.64/kg
Availability – amount of lysine/tonne	75%	85%	95%
Cost of lysine per kilogram	$24.69	$19.90	$19.62

In this table lupins were by the far the cheapest ingredient but were only on a par, as far as the lysine content was concerned, with the fish meal, which was nearly five times more expensive. Meat meal shaded them both for lysine cost and was only twice as dear as lupins and less than half the cost of fish meal. But when it came to availability, lupins dropped out of the calculations and fish meal proves to be the cheapest source of lysine, if only marginally.

However, it doesn't stop there. Fish, generally speaking, eat seafood, and most of the ingredients they require are found in seafood. Therefore, it follows that the fish meal has many of the other essential amino acids required by fish and crayfish. What does this mean to nutritionists? They are able to get other key amino acids and probably other essential nutrients from the same ingredient, fish meal, that they're already using.

The final figure in the equation is the waste. It goes without saying that there is less waste material from fish meal as an ingredient than the other two. Removing unwanted nutrients from the farming water, whether it is in the form of organics in solution or solids in suspension is expensive. Un-metabolised protein will boost the total ammonia nitrogen (TAN) levels in the water placing an extra load on the bio-filter and the BOD reducing the amount of fish that can be carried, and dealing with sludge is costly. In a re-circulation system it is particularly so; it is one of the major drawbacks of these otherwise highly efficient methods of producing fish.

The moral of the story? Let's leave that to GWQEHN. While she's not always original she's always spot-on.

GWQEHN says:
The cheapest may not always be the best, but the best is always the cheapest.

Dietary lipids or fats

Dietary lipids or fats perform two roles in a fish diet. The first is to supply energy and the second is as an important component of cell structure as it carries essential vitamins around the body.

Crude fat is the general name found on the feed bag label for this nutrient. More specifically they are called fatty acids. Once again we have two categories: essential and non-essential fatty acids.

Essential fatty acids are an important group in fish nutrition and like the essential amino acids, the fish can synthesise some but certain levels must be maintained otherwise fish health and growth will be affected.

They are used for specific metabolic processes within the body, but they are used in different forms to what the fatty acid actually is. Many of the species we farm can do what is called 'chain elongate'. They can join the fatty acid molecules together to make the desired end product that they need for the metabolic process. The fatty acid balance is not as critical as the amino acid balance where there is no leeway for error without impinging on efficiency. As long as we've got an adequate supply in total of essential fatty acids in the diet it will be enough.

Essential fatty acids include:

- linoleic acid
- linolenic acid
- arachidonic acid.

These essential fatty acids are also used in the diet in proportion to energy use. They are unsaturated fatty acids.

The non-essential fatty acids are used as the energy source in the diet. These are saturated fatty acids.

The most common source of those unsaturated fats that are available to fish is other fish. Significant quantities of fats from vegetable sources are not suitable for high order predators, such as Atlantic salmon, Murray cod and barramundi, although they can be more readily incorporated in rations for omnivores such as silver perch and yabbies.

If there is insufficient energy in the diet the fish will 'borrow' protein to make up the shortfall to the detriment of growth. Surplus protein will be converted and stored as fat.

Carbohydrates

Carbohydrates, together with fats, comprise the source of energy in the diet. Fats may provide a cheaper source of energy for the animal than grain (it depends on the season), however, the manufacturing reality is that carbohydrate is required to provide a base on which to extrude or pelletise the diet.

Processing, storage and handling considerations often limit the addition of fat in a diet.

High order predators are limited to the amount of carbohydrate they can assimilate and too much can be fatal. However, omnivorous species are able to tolerate more carbohydrates; the quantity of carbohydrate that is tolerable increases as we move from carnivorous species through omnivorous to true vegetarian species like some of the carp.

Minerals

Minerals are also required in small amounts and their uptake, too, is essential to maintain health and growth. They also come in two groups: macro-minerals and micro-minerals, or trace elements.

Macro-minerals are elements such as:

- calcium
- phosphorus
- sodium
- copper
- iron
- zinc
- magnesium
- manganese.

Some of them are used in quite large quantities. For instance: the calcium level might be as high as 1.5% of the diet.

It should come as no surprise to hear that they are used in proportion to each other and in proportion to energy. For instance: calcium can't be incorporated into bone in the absence of phosphorus. A diet should be constructed so the calcium:phosphorus ratio is in the vicinity of 1.2:1 to 1.5:1. The amount of these elements that can be incorporated into the body will depend on their proportion in relation to energy.

Micro-minerals may appear minor elements but they are just as essential as the macro-minerals, and all the other ingredients for that matter. Take the rotor button out of a car and it won't go. Remove a micro-mineral from a diet and it won't operate efficiently. To take a terrestrial example: large areas of Australia are cobalt deficient. The grass that grew in those areas was cobalt deficient and the stock that ate the grass had a cobalt deficiency. Cobalt salt licks and cobalt bullets injected into the stock corrected the deficiency and now those regions are highly productive areas.

Take another example: iron is essential for the haemoglobin in the blood. Iron can't be incorporated without the presence of copper.

Micro-minerals include such elements as:

- sulphur
- molybdenum
- cobalt
- selenium
- iodine.

Vitamins

Vitamins are required in small amounts but their uptake is essential to maintain health and growth. For instance, the absence of essential vitamins suppresses the fish's immune system. Vitamins are divided into two groups two ways. Nothing changes.

Vitamins are taken up relative to one another and other nutrients in the diet as well as being used in proportion to energy.

The anti-oxidant vitamins are:

- vitamin A
- vitamin D_3
- vitamin E
- vitamin C.

The other group is made up of:

- the B group
- vitamin K
- vitamin H (biotin).

Remember we talked about calcium needing phosphorus to be incorporated in bone? Well, none of that will happen in the absence of D_3, because that's the catalyst for the process.

Single nutrient therapy regularly rears its ugly head as a panacea for all ills. Sometime ago injecting horses with vitamin B_{12} was all the go. It's not illegal, but then again what good is it doing, except making some vitamin-enriched stable manure for the local market gardener? Maybe a horse somewhere down the line had a vitamin B_{12} deficiency and responded dramatically. Maybe the horse thought he'd better lift his game or there would be more injections. He should have known better. We'll leave GWQEHN to give us the underlying lesson from all this.

GWQEHN says:
No one nutrient is used in isolation.

If anyone tries to sell you a single nutrient tell them to go away. GWQEHN will tell you, it's voodoo aquaculture. If you're deficient in one nutrient, it's very likely you're deficient in more than one.

We'll now look at vitamins as water-soluble and fat-soluble vitamins.

The fat-soluble vitamins are:

- vitamin A
- vitamin D_3
- vitamin E
- vitamin K.

The water-soluble vitamins are:

- the B group
- vitamin C.

Vitamin C is a crucial ingredient in the diet. It can't be synthesised by most fish. It's essential to most of our farmed species. It's water-soluble and highly unstable. It's one that nutritionists have to pay a fair bit of attention to. There are some very good forms of vitamin C now on the market and the food manufacturing industry has spent a lot of time researching ways to stabilise the vitamin.

Fibre

Fibre is essential to the function of the digestive system.

What we would call 'high fibre diets' in human nutrition terms, we would call 'low fibre diets' in animal nutrition terms. The reason for this remarkable set of circumstances is because the human food industry has evolved as an industry that processes the food to enhance appearance, flavour and shelf life. By and large the processing has removed much of the natural fibre. We need a certain amount of fibre to push the food through the gut, the process of peristalsis. That's the continual contraction of the muscle that pushes the food along. If we don't have enough fibre, we become constipated.

In animal nutrition we are using unprocessed ingredients or human nutrition by-products and the rations have plenty of fibre. In actual fact, especially in the case of high order predators such as salmonids, Murray cod and barramundi, too much fibre can be a problem because these species have very short digestive tracts. If you have too much fibre it makes it difficult to find the nutrients. It's a bit like looking for a needle in a haystack. Once again the nutrients are going out the back end in pretty much the same form as they went in the front end. So for high order predators we have to keep the fibre levels down. As we come down the feeding scale to omnivorous species, such as silver perch, we can include more fibre, until we get to species such as carp, which are herbivores that can, with their long digestive tracts, break down fibre and carbohydrates.

Freshwater crayfish are pancreatic digesters. What the crayfish eats gets dissolved in the pancreatic juices, that's the 'mustard' found in the body, and from that nutritional soup the crayfish extracts the nutrients that it wants. Some cuisines prize the yellow digestive juices as a flavouring, notably French and Cajun cooking.

Interestingly enough, crayfish can't handle high fibre diets. Over the years people have believed they ate grass because when stocked in a freshly flooded pond with grass growing in the bottom of it they have proceeded to nip off the grass. This has floated to the surface or been washed to the pond's edge, supporting the theory that they were eating the grass and that the flotsam was the residue. In actual fact they are harvesting the grass so it will be colonised by bacteria. A bit like making their own compost heap. They then feed on the coating of bacteria. They are opportunistic feeders and will hop into a hunk of fillet steak or a skinned rabbit, but technically they are detritovores. That means they live on detritus: decaying organic matter.

Water

Water is an essential nutrient for life. Interestingly enough, freshwater fish don't drink water; marine, estuarine and catadromous species do and get the bulk of their mineral intake from the water they drink.

However, you can't put salt in freshwater to satisfy the mineral requirements of the fish. All the water a freshwater species requires, it gets from the metabolism of the food. The oxidation process within the cells of the body produces water as a by-product and that's the water the fish utilise. As a matter of interest, humans acquire most of their water requirements in the same manner.

Specific diets

Because each species has its own nutrient profile requirement, it is not possible to serve the dietary needs of trout by feeding it silver perch pellets. In fact, in some cases it can be downright dangerous. Fatty liver is a condition that can develop from feeding Murray cod with a high fat, high oil content food designed to make Atlantic salmon grow. It is altogether impossible to gain any more than the most marginal growth by feeding chook pellets or carrots to yabbies.

By utilising natural food grown in the pond we may eliminate the need to target a nutrient profile by relying on Nature to provide enough live food in balance with the natural environment. We also present the fish with a choice of food. However, we must be sure the natural food grown is the right food and that we can keep enough of it supplied to the fish to maintain health and growth.

If we are unable to keep up the supply of natural food we can fall back on formulated food. Fish food manufacturers will be striving to corner the market by researching the nutrient profile of the target species and maintaining quality standards. They are also able to draw on data from around the world on similar species.

GWQEHN says:
Any nutrient not utilised by the fish becomes pond waste. It is running free in the pond and has to be neutralised promptly in order to minimise its effect on water quality. It also increases the loading on pond management and reduces the pond's fish carrying capacity. And who needs that?

Natural food

The least expensive feed is the natural food, which can be grown in the ponds. Natural food is part of the so-called 'food pyramid' or 'food chain' which in reality is a food web: each part being linked in a complex way to one or more others. Phytoplankton forms the anchor of the food web in our ponds. As the phytoplankton food source grows, the zooplankton depending on it for nutrition will develop. It is the sun's energy captured and stored by the plankton that drives the pond's natural food production. The other natural foods will develop in the pond as a consequence.

The general term plankton can also be used to cover the pond's total macro- and micro-plant and invertebrate life which includes the aquatic insects and their larvae; even the microbes breaking down the rotting vegetable material (detritus).

Plankton is grown in ponds to rear many of the finfish larvae we use in aquaculture and is an important part of the diet of yabbies, especially when maximizing the growth of young yabbies.

Algae and zooplankton are also raised indoors in algae bags and tanks for those species of fish, crustacean and shellfish larvae reared more efficiently in hatcheries than plankton ponds.

The art of balancing natural food production with water quality, while at the same time raising a crop, is one of the most highly skilled juggling acts in aquaculture. However, once mastered it becomes a cheap supply of efficient food. Many finfish species are raised in plankton ponds from larvae spawned in a hatchery. Being able to manage a plankton pond is a crucial part of the operation.

Detritus and the microbes and worms breaking down the organic material on the substrate form an important part of the food supply of crustaceans and some zooplankton, notably *Daphnia*. Detritus can be produced by introducing hay into the pond but care should be taken that water quality is not compromised.

Note that crayfish are not monogastric animals, they are pancreatic digesters and as such are not good fibre digesters. In other words, they don't benefit from eating hay in the same way that a ruminant such as a cow or a sheep does; it's the microbes eating the fibre from which they glean their nutrients.

Small species of native fodder fish such as smelt, gudgeon and minnows can be introduced; and the common goldfish will breed in the ponds thus providing a source of food. Freshwater mussels can also be introduced as filter cleaners and a source of food for some species, notably Murray cod, but generally speaking it is not possible to maintain a supply of natural food sufficient to raise commercial volumes of fish to market size unless the grower is receiving a premium price for naturally or organically grown products.

(The production of natural food is dealt with in greater detail in chapter 8.)

Supplementary food

If we're looking for production beyond the capacity of the pond's natural food supply, it will be necessary to feed a supplementary ration. There is no alternative: if we want our fish to grow at commercial rates, we must adopt commercial methods.

Supplementary feed can be divided into two categories: an opportunity ration, or 'cheap' feed; and a formulated ration prepared by a nutritionist and manufactured by a feed miller or an extrusion processor.

Cheap food

Cheap food is the food that can be picked up for next-to-nothing as a by-product or grown by the farmer. Examples of the former would be chicken or fish frames, and butcher's and abattoir bones and offal. Examples of the latter would be legumes and cereal grains.

While frozen blocks of bullock liver and similar 'cheap food' make good yabby trap bait, they have no role in a commercial operation and belong firmly in the area of the hobby farm and cottage industry. Even then their use is questionable as it adds a volatile nutrient to, in most cases, poorly designed systems with minimal water quality control facilities.

Formulated food

Any fish food manufacturer, if they're being honest with you, will tell you that natural food is by far the cheapest and the best; and that they're only human and the best they can do is emulate natural feed by drawing on a database of information and produce a food that is pretty close to the preferred natural option.

Formulated feed is expensive so it has to be good. As well as information from overseas and local aquaculture, food manufacturers can add the results of their own observations and the feedback from their customers to put together the best possible formulated feed.

There are two styles of formulated food: milled and extruded.

Milled food

Milled food is the process favoured by the pig and poultry industry. The grains are roughly ground and pressed under pressure into a pellet. This is a relatively cheap process and as pigs and poultry have sophisticated digestive systems, they can handle the texture of the milled pellet.

Extruded food

Extruded food is the manufacturing process whereby the ingredients are finely ground and cooked as a part of the pellet-making process. Most high performance rations are extruded. The processed bran you have for breakfast is extruded. The advantages of an extruded ration are that the starches in the grains are gelatinised, the proteins denatured and the cellular structure of the ingredients ruptured. This effectively 'pre-digests' the food, thus improving the efficiency of use of the food in the fish. (Denaturing can be advantageous or disadvantageous depending on the state of development of the animal's digestive system. For most mature animals, denaturing is neutral. However, many anti-nutritional factors in the food are protein-based and denaturing nullifies their activity. Denaturing can also change the state of the protein to a more useable form: e.g. cooked egg white versus raw egg white. Denaturing can also aid digestibility of proteins in immature digestive systems: e.g. baby formulations and milk replacers. In the context of fish diets, the main benefit is in the formation of nutritional complexes that occur during the denaturing process and can improve protein digestibility by a factor in the range of 5–8%. This cannot be achieved by denaturing the protein in isolation, but only as a function of co-extrusion.)

Extruded food, under cool, dry conditions, also has an extended shelf life which is comforting to know when making large purchase orders to gain price and/or freight advantages.

It is also water stable, which means that it will hold together underwater without the need of additives that can inhibit nutrient uptake in the fish's digestive system.

On the downside, it's dearer. The process is more costly than making a steam-pressed pellet. As a rule of thumb, it costs around $150 a tonne more to produce an extruded diet than a pelletised diet from the same ingredients. However, the increase in digestibility of those same ingredients is such that the extruded feed generally finishes up making the dearer food more cost-effective than the cheaper.

To give some idea of the difference in digestibility let's look at the following examples.

Table 9.2. Digestibility coefficients (silver perch).

	Dry matter	Energy	Protein
Raw wheat starch	41%	46%	n.a.
Cooked wheat starch	50%	52%	n.a.
Fish meal (cooked)	85%	99%	93%
Pelleted fish food	65%	75%	89%
Extruded fish food	90%	99%	88%

Compiled from the FRDC Sub-Committee on Nutrition – Fish Meal Replacement in Aquaculture.

The reality of using supplementary food

Without using supplementary food there is no way you are going to lift the production of your ponds to commercial levels. Infrastructure comes at a price and the more productive your ponds or your 'you-beaut' re-circulation system is, the more profitable will be your aquaculture enterprise.

In other commercial intensive animal production industries, the cost of food makes up between 60% and 80% of the total production cost. This does not include administrative, processing or marketing expenses and refers strictly to cost of production, so it can be seen how important it is that a highly efficient food be used. In the well-established aquaculture industries around the world and in Australia they would already have their feed costs up to this proportion of their production costs.

GWQEHN says:
We are really only converting one form of protein into another form of protein so we can sell it to make a profit.

A highly efficient food also reduces pond and tank residue and minimises management input. You probably won't realise the importance of this until you have to manage your own water quality to keep your fish growing. For example, let us refer back to the digestibility coefficient table, Table 9.2. The pelleted fish food in that table has a dry matter digestibility of only 65%. This means 35% of the food fed remains as waste in the form of sludge. Look at it this way: 1 kg of dry matter waste is roughly the equivalent of 5 kg of sludge, so for every one kilogram of pellets you feed to the fish, your fish will generate 1.75 kg of sludge. On the other hand, for every 1 kg of the extruded food fed, the fish will only produce 0.5 kg of sludge.

There are several benefits associated with using formulated feed. The most important one is that you know exactly what nutritional input is making your fish grow, or not grow, as the case may be. Good suppliers will ensure that their product is stable and efficient by using the best available ingredients. This is critical when it comes to running a commercial operation as management decisions are based on being able to monitor and control the tools of production. Feeds that vary dramatically from one batch to another will confuse production figures and frustrate good management. As new information comes to hand, feed formulas can be altered and other options trialled.

Other benefits include the fact that it is purchased on a dry weight basis so you are only paying for what you get; and caring manufacturers will provide a back-up service to their clients.

The apparent disadvantage of formulated food is the cost, but on a well-managed farm production advantages will outweigh the initial cost.

The importance of balance in the diet

The various components of nutrition taken up by the fish are in proportion to energy and to each other, according to the nutrient profile of the species being cultivated. Any nutrients that are surplus to that balance are not metabolised and are passed into the production water. That's the biochemistry side of the equation.

Then there's fish health. Fish and crayfish on a balanced ration will be healthy and have stronger immune systems than those that are not.

They will also reach market size faster, thus reducing the turnover time of the production system. This dramatically reduces the cost of production. Let's take a peek at an industry that has been there and done that – the poultry industry. In 1973, meat birds took 60 days to reach market size (1.59 kg) and retailed for $5.62/kg (value adjusted for inflation). Twenty years later it took 42 days to grow a meat bird to market size of 2.04 kg (Reddy, *Feeding the Birds of Tomorrow, Today,* 1996, p. 10), and the grower was still profitable (before a poultry producer reading this blows a valve, profitable could be qualified with the adjective 'arguably') at $2.91/kg (value adjusted for inflation).

The formula looks something like this:

$$365/60 \times 1.59 = 9.675 \text{ versus } 365/42 \times 2.04 = 17.7285.$$

This equals an 83.2% increase in productivity related to investment in growing facilities. In other words, each bird space returned 83% more saleable product for the same investment in infrastructure.

During the same period FCRs went from 2.0:1 to 1.8:1, a reduction of feeding costs amounting to 10%, all things being equal. A reduction of overall cost to the industry of 6%. Mortalities fell from 5.0% to 4.5%, another 10% reduction of a cost area over two decades.

This allowed for a reduction in retail prices of 48.2%, which in turn led to a substantial increase in per capita consumption and the resultant expansion of the industry and individual production facilities (Vorstermans, *A Strategic Review of the Chicken Meat Group*, 1998, p. 50). Looking at it another way, let's say an atmosphere-controlled poultry shed houses 20 000 birds and costs $350 000. Those birds are turned off at a live weight of around 1.8 kg. At a growing time of 60 days the poultry farmer can produce 218.88 tonnes annually of live product from his investment of $350 000. With a growth rate that is allowing him to turn off a live bird every 42 days he can, for the same investment in infrastructure, produce 312.84 tonnes annually. That's nearly 100 tonnes of extra product by just using a balanced, species-targeted ration. The only extra cost is that you'd have to buy enough seedstock to give you the extra 100 tonnes and you'd have to buy more feed to grow them. You'd be tempted to give it a go wouldn't you?

In short, the investment in the infrastructure and equipment is being utilised 8.69 times a year against 6.08 times 30 years ago.

True, a lot of this improvement came from genetic development but the genetic development couldn't occur until they had the production methods, call it the husbandry, and the nutrition sorted out.

The commercial side of the equation is more sinister. If we settle for an inefficient diet and we start selecting for the genotype that responds to that inefficiency we will find ourselves actually fine-tuning a limiting factor. It's possible to get away with this as long as the whole industry is equally compromised. However, should someone persevere with diet development, that someone will find themselves in a dominant position in the industry. Most importantly, they'll be able, as we shall see in the following sections in this chapter on nutrition, to dramatically lower their cost of production. And we all know what that means in a competitive marketplace.

Phase feeding

When we look at the pig and poultry industry models we see that they have different diets for males and females and different diets for summer and winter. They even have diets for different genotypes. But more importantly they have different diets for different stages of their development. Young animals have a higher specific growth rate (SGR) than older animals. Their prime biological focus at this stage of their development is on growth and survival. As they get older, their attention turns to other biological needs such as status and reproduction. They require the same amount of energy in relation to their body weight but they require more nutrients when they're young to make them grow.

Everyone would have noticed the amount of food growing children, particularly boys, can put away. Boundless energy and a seeming insatiable need for nutrients drives them to raid the pantry as soon as they get home from school. In an aquaculture sense that means our energy pill has to have more protein and more everything else wrapped around it. Pig farmers will change their diets every couple of weeks. This is called 'phase feeding'. Aquaculture nutrition in Australia hasn't reached that level but most feed mills will have a starter crumble for young fish. As the industry becomes more sophisticated we'll see phase feeding introduced.

Even now, it's possible to maximise production with the existing diet options. By making sure the young fish are fed a high density diet designed for their species, the grower can optimise growth.

Look at it this way. If a young fish is growing at an SGR of 5%, that means it's adding 5% to its body weight each day. This is not an unrealistic figure for young fish. It will be doubling its body weight every 14 days. That is a very efficient growth rate. If the same fish as it gets older has an SGR of 1% it will be doubling its weight every 72 days.

Which is the most efficient period of the fish's life? When it is growing at 5% or at 1% a day? Obviously it's the time early on when the fish is doubling its weight every 14 days.

When is the time we should be spending the most attention to growing the fish? Right, when it's young. Every dollar spent in that period is worth five dollars later on. But so many people don't worry about really driving the feeding program hard until the fish are big enough to be able to measure the fish in grams per day growth terms. If you haven't driven them hard from the word go you've lost a lot of profit. Within reason, you can't spend too much on feeding juvenile fish in the nursery stage.

The figures themselves are quite startling. Let's say a high density starter diet costs as much as $4000 a tonne. Remember it has a lot more nutrients packed into it than a grower ration. If the fish are 1 g and converting at an FCR of 1:1 and growing at the rate of 5% a day they will consume 0.05 g of feed a day. That means each fish will be costing 0.02 cents per day to feed.

If the grower ration costs $1500 a tonne and 500 g fish are converting at 1:1 and growing at 1% of their body weight a day they will be consuming 5 g of feed a day. That means each fish will be costing 5 cents per day to feed. At 1 kg the 5c per day becomes 10c a day.

The nursery fish are giving you 5% growth while the grow-out fish are giving you 1% growth. Each day those fish are in the system they are costing you money, whether you feed them or not. The quicker you get them in and out of the system, the more money you make. Any potential growth lost in the nursery phase at a 5% daily gain has to be made up in the grow-out phase at a 1% daily gain. You do the sums.

The balance of the diet is governed by the energy requirement and the nutrient requirement in relation to the physiological stage of the fish.

The impact of the environment

To further complicate matters, nutritional uptake varies with climate. A silver perch reared in the subtropics will have a different dietary uptake from one reared in, say, Victoria. In a perfect world, the fish grown in the subtropics would be selected for their farming attributes in that climatic zone and a genotype for farming in southern NSW and northern Victoria would be developed for those climatic regions. Then they'd both have a different requirement in the summer and winter feeding periods.

In the case of most native species this is a long way down the track but in highly developed industries, such as the salmonid aquacultures (i.e. Atlantic salmon, rainbow trout), winter and summer diets have been developed and are being developed for the abalone industry.

However, the more important aspect of the environment is on a daily basis: the amount of food the fish can metabolise. When the temperature is outside the optimum performance band the metabolic rate is reduced, therefore the amount of food that is offered to the fish should also be reduced.

The feeding rate of the fish may continue at the normal rate for some time after the temperatures start to fall below the optimum, but the metabolic rate will be slowing. The rate at which you reduce your feeding will come with experience, but the parameter to watch is the ammonia levels. Should the total ammonia nitrogen readings start to rise, it could well be because less of the food is staying in the fish and more of the nutrient value is going into the water column. This is common when feeding warm water or tropical species in open ponds, particularly in the spring when the ponds are trying to warm up but find themselves subject to the odd burst of late-winter weather.

Temperature has an upper optimum level and an upper critical level as well. When water temperatures go above the upper optimum level the metabolic rate will fall away. Above the upper critical limit they will be in the stress zone and, while mortalities don't always occur immediately, the fishes' immune system will be sorely tested and mortalities may soon follow.

GWQEHN says:
When temperatures approach or exceed the upper critical limit stop feeding immediately and maintain maximum dissolved oxygen levels possible.

The interesting thing about all this is that the upper optimum temperature is very close to the upper critical limit. For instance: silver perch will thrive in water temperatures of 28°C, but their feeding and metabolic rate will slow down at 30°C and stop altogether at 32°C. Much beyond 32°C and they can start to go belly up. In poor conditions, such as low DO levels or high parasite numbers, mortalities can occur very quickly.

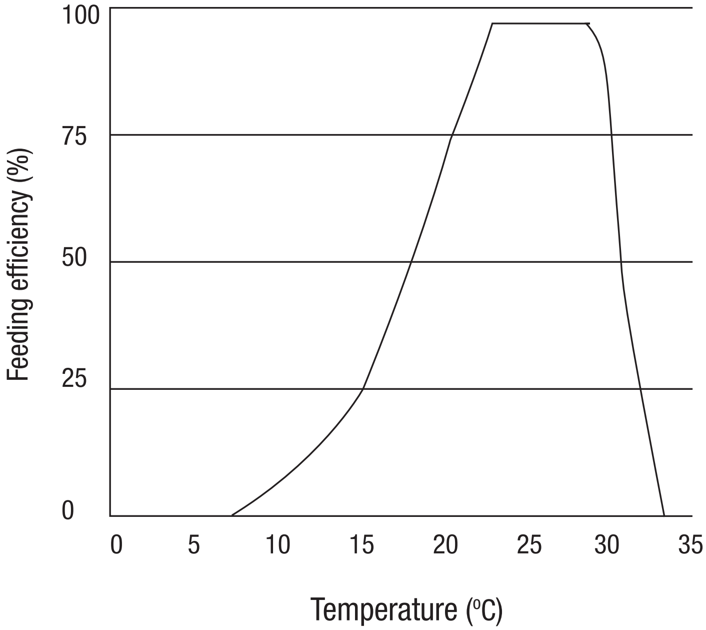


Figure 9.3. Feeding efficiency in relation to temperature.

The above graph is not a strict representation of any particular species, more an indication of the pattern. Let's say it's for silver perch. Without taking into account regionally acclimatised populations, let's say that at 15°C they have to be coaxed to feed but when the water temperature reaches 20°C they're hitting the feed hard. At 23°C they're feeding like crazy and showing good growth. They're right on the money at 28°C but once the water gets to 30°C they start to slow down markedly. Much over that and they're off their food and by 35°C showing signs of stress. On those assumptions the graph would look something like the one above.

How to use nutrition to make a dollar

What is about to be demonstrated is one of the amazing things about nutrition. If you get one element of it right you get the other key elements right too. That's a win all round.

To establish the *bona fides* of this, we'll look at the graphs resulting from a simple experiment. It will show what happens when we change the level of nutrients relative to energy in the diet and reinforce all the things we've been talking about. While the data is not real in itself, it's the sort of figures you'd expect to get back from a trial of this nature. However, the protocol used is the method employed to determine the most economic diet density.

The trial involves six different diets. We're going to classify each diet by the level of the amino acid lysine in relation to energy. All the other ingredients will be present in their correct ratios relative to lysine. That way the lysine becomes the limiting factor. The first diet will be 0.3 g of lysine per megajoule of digestible energy. The next will be 0.4 g/mjDE, and so on up to 0.8 g/mjDE. This will give us six diets.

We're going to have 24 0.1-ha ponds with 2000 fish in each pond so there will be four ponds devoted to each diet. All the fish are from the same hatchery batch and have been graded and distributed evenly amongst the 24 ponds. The food will be weighed to enable us to establish how much food was used to produce the ensuing increase in the weight of the fish. This will enable us to establish the food conversion ratio. The pond management will be standardised and the trial will be run over six weeks.

At the end of the trial the ponds will be drain harvested and the fish weighed again. By knowing the starting weight and the finishing weight we'll be able to measure growth rates over the period. We also processed the fish so we could measure the fat content to establish carcass quality.

The graphs will look at three qualities. Growth rates, carcass quality and food efficiency. As mentioned above, the plot points are not based on any real trial or any real species but they do bear a resemblance to what would occur under the conditions described.

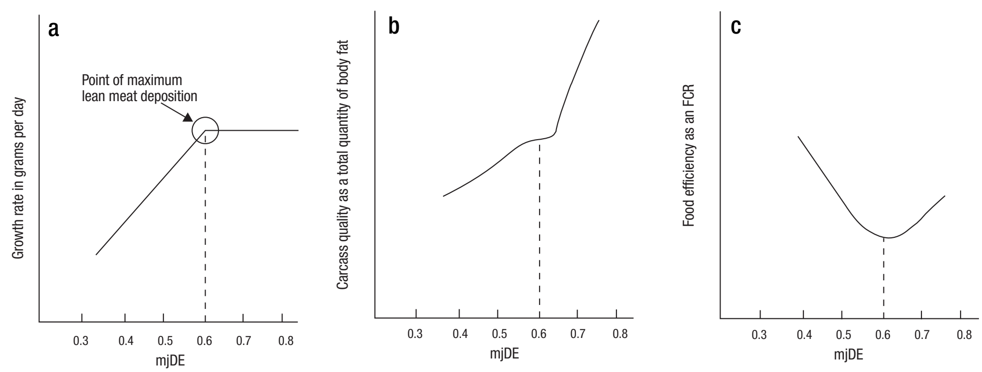


Figure 9.4. The three quantifying graphs.

What we see in Figure 9.4a, the growth rate graph measured in grams per day, is that when we have a small amount of nutrients to energy we don't get very much growth. When the nutrient density increases so does the growth rate. This is a linear response. If you put one more in you get one more back. That is until the point is reached on the graph where the graph goes horizontal. That point is called the 'point of maximum lean meat deposition'. At this point the fish can't grow any faster. That's as far as the fish can grow. After this they just lay down fat; fat that has to be trimmed off and discarded before sale to the buyer, or discounted in the price. Either way, it comes off the value of the animal to the farmer.

This point of maximum lean meat deposition represents 100% of genetic potential. If we want the fish to grow quicker we have to go back to the drawing board and work on the genetic capability of the animal to grow faster. Nutrition won't make it grow past that point.

Figure 9.4b tells us at what point we are getting the best carcass quality. There's no point in growing fish if it's unacceptable to the market. The horizontal axis is calibrated, as before, in grams of lysine per megajoule of digestible energy and the vertical axis shows the fat content. What it illustrates is that when there weren't a lot of nutrients in the diet there wasn't a lot of fat. We know from the previous graph that we didn't get a lot of growth either. If the fish aren't growing, they wouldn't be expected to get fat anyway. As the diet density increases, the fat content increases until it reaches a point where it levels out before going through the roof. This extremely rapid escalation in the quantity of fat on the carcass indicates the diet is too rich and that the extra money spent on the extra ingredients is not giving an economic return for the dollars spent.

Native fish in particular are adept at storing fat to see them through an El Niño event and any miscalculation with the diet produces an animal with huge amounts of cavity and dorsal fat. Jade perch (*Scortum barcoo*) is a species that has been downgraded by the marketplace for this very reason. As its regional name, 'Barcoo grunter', implies, the species' home water is in the channel country of Western Queensland; a part of Australia particularly vulnerable to the impact of prolonged dry spells.

The third item, and perhaps the most important, of the performance indicators we recorded, was the feed conversion efficiency. Figure 9.4c is calibrated along the bottom axis to the different diets and the vertical axis is calibrated in terms of how much food was consumed by the fish to produce 1 kg of weight.

After the food used was compared to the weight gained the graph looked a bit like Paul Keating's J curve in reverse. On the left, where the diet density in relation to energy was low, we had a poor FCR. As the density increased so did the efficiency of the diet until the FCR started to blow out again as the diet became even denser.

What does all this tell us? Several things actually. Remember, energy is the trigger for appetite. The nutrients attached to the energy make the fish and crayfish grow. In the less dense diets, in other words the diets that didn't have a lot of nutrients attached to energy, the growth rate was slow. As would be expected, the same low density diets didn't put a lot of fat on the fish either.

Strangely enough, while this lack of growth is worrying the life out of the farmer, the fish don't seem at all concerned. When the next feed comes around they consume enough to satisfy their energy requirements and leave it at that. That means they are eating about the same amount of food as normal but not producing much growth. This makes for very high FCRs and a sub-economic operation. Unless of course everybody else is feeding the same ration and the market is prepared to pay the premium required to underwrite this basic inefficiency. It sounds like defying the laws of commercial gravity, but you'd be staggered by the number of farmers who try it in the name of buying cheaper feed for their stock.

As we move across the graph we notice an increase in growth and an improvement in food efficiency. This is because density of nutrients has been increased in relation to energy. There was more of what makes the animal grow wrapped around the energy pill. The fish were using the same amount of energy each day but they were getting more nutrients. The improvement continues until the diet contained more nutrients than the fish require. Past that point the extra nutrients can't give growth beyond the genetically programmed point of maximum lean meat deposition. But the additional nutrients make extra work for the fish sorting out the nutrients, storing fat growth.

The surplus nutrients, by the way, are going straight out the back end of the animal in pretty much the same form that they went in the front end and someone has to clean up the mess. That someone is you, the production manager; otherwise the polluted water will reduce performance, endanger fish health and eventually, if not dealt with, kill the stock. We've dealt with the various options open to the production manager under these circumstances in the section on water quality management. But you should be aware of the only option open to you if you don't deal with the matter – that is to dig a big hole and bury the fish.

GWQEHN says:
You can have too much of a good thing. Nutrition is all about feeding a balanced diet.

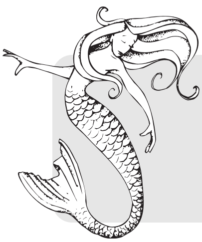
There's also another side to overfeeding. It takes 2.25 kg of protein to make 1 kg of fat. Once that protein has been converted to fat, it can't be made back into protein; it can't be used to build cells. Essentially it is lost.

On the positive side, if we drop a line down from the point of lean meat deposition in Figure 9.4a, the point of best option carcass quality in Figure 9.4b and the most efficient diet in Figure 9.4c we find that they all come down to the same point. Yes, we have established the balance of nutrients to energy we should be feeding the species we were working with under the management conditions we employed using the genotype we purchased from the hatchery. How convenient is that?

Very. It gives the grower a win, win, win, win. First, he or she is getting maximum growth to shorten the time the fish are in the production system. The second win is his or her product has the right amount of fat to give the product flavour and market acceptance. No one likes paying for a product then trimming and discarding a good proportion of it. Third, the farmer is using less feed because what he or she is using is doing the job it was designed to do: grow fish with the minimum of fuss. Fourth, the reduction in waste means less work and expense for the production manager, but equally important is the reduction in the system's BOD. This means more oxygen in the system to enable the farmer to carry more fish and get more growth.

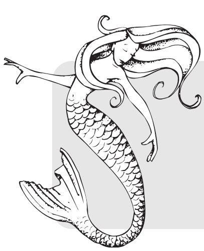
The final win is the cost saving. Never let anyone tell you otherwise, it is the efficiency of the food, not the cost, that makes feed inexpensive.

That's all very well, how do we know how close to the mark is the feed being used? The key performance indicator for this is the food conversion ratio. Care must be taken to monitor feed input and harvest weights. It's not that difficult. Some people say it's too difficult to keep tabs on it because grading and moving fish about is part of their management procedure. This actually should make it easier. The FCR doesn't have to range from fry to harvested product. The FCRs can be calculated in blocks. Weighing stock should be part of the grading procedure so one side of the ratio has been obtained. Not wanting to sound rude, but if keeping a record of the feed used is a task too onerous, then something less demanding than aquaculture should be considered.



GWQEHN says:
If you monitor nothing else relating to nutrition, let it be the FCR.

The next question should be: *But how achievable is it to produce a food with all these attributes?* The above approach is one used in the allied intensive animal production industries of pig and poultry farming. It is one of the tools that have enabled those farming sectors to become two of the major food suppliers in the modern world. In Australia before the 1960s the main meat dishes were beef and lamb. Pork and chicken were luxuries, duck was something you fattened in the backyard for Christmas and bacon was rationed to a rasher a morning with eggs and grilled tomatoes. Now they are part of the normal supermarket shopping list. This was not so much due to a change of dietary preference as a family budget issue: they had become cheap fare. They became cheap because they could be produced more efficiently. This was due in part to being able to feed the animals a balanced formulation that made them grow, which in turn was based on the information we have just been looking at.



GWQEHN says:
Not only does feeding a balanced ration increase production but at less cost. You get more for less.

How far down this track is aquaculture nutrition? A good way in some of the main-line species but sadly hardly at all as far as the authors can determine in the 'new' species. This includes Australian native species. When Atlantic salmon and barramundi diets are being fed to Murray cod it exposes the shortfall in specialised diets for some species.

On a brighter note, the information on nutritional databases enables nutritionists to design a diet that is thereabouts. While this leaves room for improvement, it does enable the farmer to feed a ration that, if the nutritionist has done his or her homework, is commercially acceptable until something better comes along.

At this point in his discussion on nutrition Bill Wiadrowski usually tells a true story of a redclaw farmer in south-eastern Queensland to illustrate his point. The owner has since subdivided the farm and moved on to something else, but at the time he was one of the largest growers in Australia. He had close to 9 ha, all netted, and, as was the wont of the industry in those days, lined with stone.

They were feeding poultry rations to their crayfish. They were using 8 tonnes of poultry feed a month, and by the economics of the redclaw industry at the time they were doing pretty well. Bill called on them to sell them some of his super-dooper crayfish pellets. To his credit, the grower didn't take long to cotton to the concept that he should be using a species-specific diet. The bloke was just about to give Bill an order when he asked how much it was going to cost. He nearly fell over when he was told it would be $950/tonne by the time he got it on the farm. He was paying something like $325/tonne delivered for turkey starter crumbles. Turkey starter crumbles were the industry choice because they had a higher protein content for the dollar. Smart thinking, eh?

Eventually Bill convinced the grower that he'd be doing himself a disservice if he didn't at least try some of the food designed specifically to feed freshwater crayfish. Being a progressive sort of bloke, which was one reason he was an industry leader, he gave it a go. Of course, when he saw the benefits he immediately became a convert to species-specific diets. What were the benefits?

The first one he noticed, following Bill's feeding instructions of feeding a set percentage of the biomass of the pond rather than just 'chuck in enough to make sure they grew', was that he was using less food. Instead of the 8 tonnes of poultry ration they were feeding 2 tonnes of crayfish diet. The monthly feed bill had dropped from $2600 a month to $1900.

Then there was the time factor. Instead of having to help the driver unload 8 tonnes a month and feed out 8 tonnes a month there were only 2 tonnes to unload and feed out. This meant less storage space was locked up holding stock food.

One of the big savings in labour came at the end of each cycle. The ponds were trapped through the growing period until it was thought they were all harvested then drained and any stragglers collected off the bottom. Then the real work began. The residue of all those turkey starter crumbles had left a knee-deep sludge in the ponds. Not only had this to be flushed out, the tyres they'd thrown into the pond as cover for the crayfish had to be removed. Fortunately they weren't far from the local university and a cheap and never-ending source of labour was available. And never-ending it had to be because this was a dreadful task, dragging the high pressure hose around these rough bottomed ponds in the broiling subtropical sun and emptying the tyres of sludge and dragging them up the bank. I think the reader would have guessed by now, that under the new feeding regime, no more sludge. Just the usual fine layer of pond waste had to be flushed out. The ponds were ready to be put back into production the same day they were harvested. This alone was a huge saving.

The redclaw also grew faster, were healthier, gave a better recovery rate and didn't have the pond staining that comes with slow growth and living in an organic-rich substrate; the same pond staining that downgrades them in the marketplace. All these gains were achieved simply by changing the food to one that had a nutrient profile relative to energy that matched, as near as the available data allowed, the animal's requirements: very simple, but very, very significant.

This was truly a win all around and while it may seem an over-the-top story by today's standards, it was nevertheless how sections of the industry functioned in the early days. And the authors would venture to say that even today, somewhere in Australia, freshwater crayfish are sitting on the bottom of their ponds dodging chook pellets and other cheaply put together rations designed by the local feed mill or the new cheap food guru to satisfy a price limitation set by buyers who haven't come to grips with the scientific and commercial reality of nutrition.

The remuneration of using a balanced diet isn't always visible.

Another example of the benefits of using a balanced diet was seen on a silver perch farm. The farmer was several hours out of Sydney and, although he sent fish in to the lucrative live fish market in the capital, he saw the future need to develop an alternative local market. He was farming not far out of an inland provincial centre so he decided to supply fresh fish to restaurants and clubs in the area. He offered two products. One was a heads-on, gilled and gutted (HOGG) fish and the other was a skin-on fillet.

He was trialling two feeds at the time. One diet was a high protein ration (42%) and the other was a lower protein (34%) but designed to meet the nutrient requirements of the species. Let's call it a balanced diet. The diets cost the same and the fish grew at the same rate. He was growing fish out to the market requirement of those days of 800 g. However, when he monitored the carcasses he found that one feed was giving him a distinct economic advantage over the other.

He was paying at the time $1000 a tonne for both feeds and getting an on-farm return of $10/kg for the fish live into Sydney. He was getting $8 per fish. At this point there appears to be no distinction between the economics of either scenario, and there isn't.

When it came to processing, which he did himself, he was getting $12.50/kg locally. That means he was getting $10 a fish. He appears to be on a par with what he was getting for live fish in Sydney. But it is here that he first noticed a difference. On weighing the fish he found that, after removing the gut, the fish fed on the balanced ration were weighing more than those on the high protein diet. There was more cavity fat in the high protein fish than those fed the balanced ration. It was quite noticeable. The waste from the high protein fish was 18% but from those fed the balanced ration it was only 15%. That meant that the high protein fish were returning him 82% against 85% from those fed the balanced ration.

In dollar terms he was getting $8.20 for the high protein fish and $8.50 for the fish fed the balanced ration. For a farm turning off 20 000 fish a year (16 tonnes @ 800 g) that would be a difference of $6000. For a farm turning off 50 000 fish, or 40 tonnes, that's a difference of $15 000 a year.

The story doesn't end there. He probed the local fillet market. Told that he would have to be competitive with the prices for fresh fillets available through the Sydney distributors who delivered to the region, he found himself selling fillets at $19.95/kg. He discovered that when he weighed the fillets from the fish fed the high protein diet he was getting a getting a 61% yield from his HOGG fish. That gave him 400 g of fillet. The fish fed the balanced ration returned 65% of the HOGG fish weight. That gave him a fillet weight of 442 g. The difference was the line of dorsal and attached cavity fat that had to be trimmed off the fillet

In dollar terms, at $19.95/kg, he was getting a return of $7.98 per fish for those fed the high protein diet and $8.82 per fish for those fed the balanced ration. That's a difference of 84c per fish, or on a 20 000 fish farm a difference of $16 800 a year. Add that to the difference on the HOGG fish and the difference becomes $22 800. On a 50 000 fish farm the difference becomes $42 000 plus $15 000, an annual saving of $57 000 for just using a balanced ration.

Table 9.3. Lean meat deposition and economic outcomes under different diets.

	High protein diet (42%) $1000/t Price per 800 g fish	Balanced diet (34%) $1000/t Price per 800 g fish
Live fish @ $10/kg	$8.00/fish	$8.00/fish
HOGG fish @ $12.50/kg	Yield – 82% – 656 g $8.20/fish	Yield – 85% – 680 g $8.50/fish
Fillets @ $19.95/kg	Yield – 61% on HOGG – 400 g $7.98/fish	Yield – 65% on HOGG – 442 g $8.82/fish

Where on the three quantifying graphs (Figures 9.5, 9.6 and 9.7) do the two diets fit?

The carcass evaluation of the fish fed the high protein has shown that it is allowing the fish to store energy and is producing an overly fat fish. The growth rate is the same

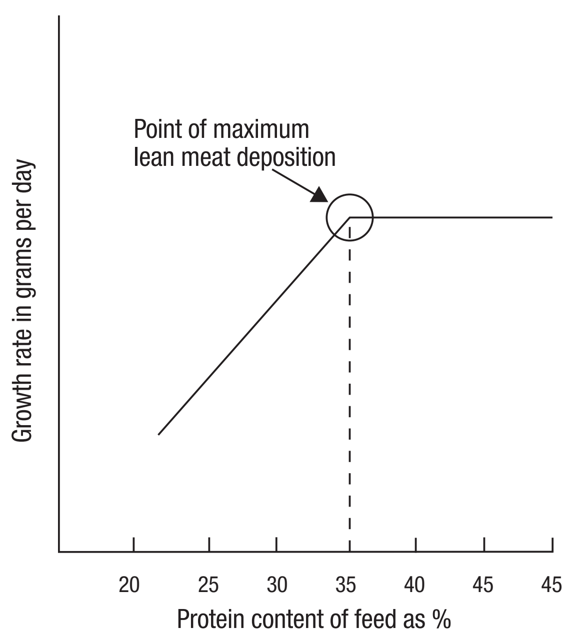


Figure 9.5. Growth rate with the horizontal axis graduated in protein levels as a per cent.

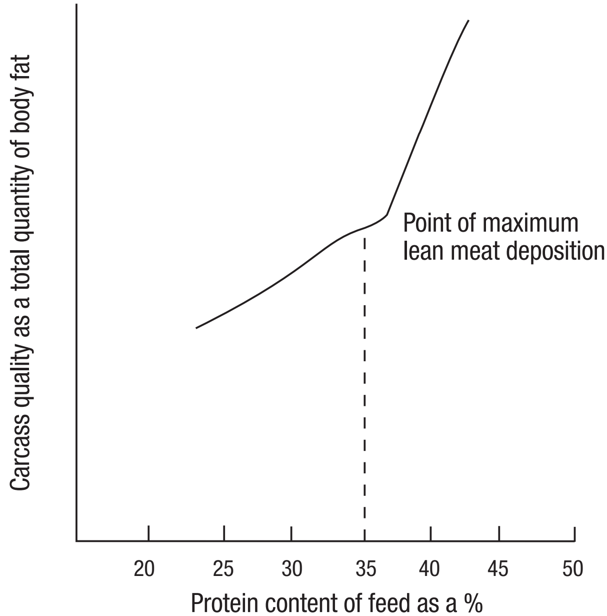


Figure 9.6. Lean meat deposition graph with the horizontal axis graduated in protein levels as a per cent.

for these fish as it is for those fed the balanced ration, so we'd have to say the point on the graph is to the right of the point of lean meat deposition: maximum growth but more protein than is necessary. The balanced diet is somewhere along the horizontal part of the graph but would be back toward the point of maximum lean meat deposition.

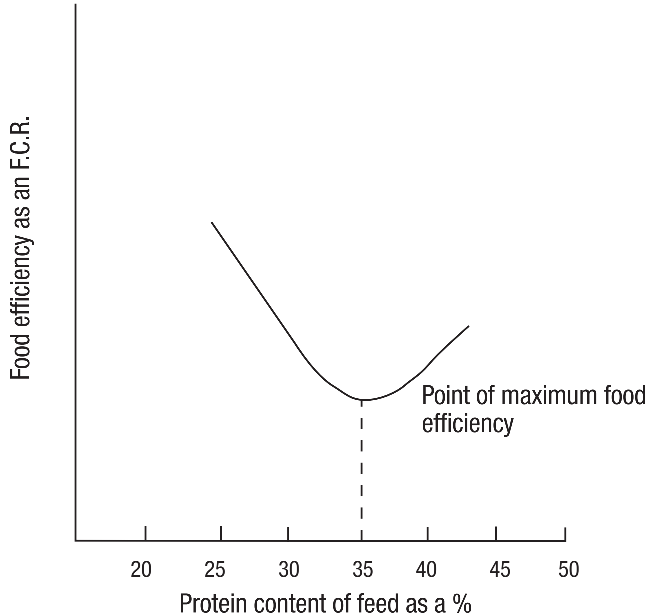


Figure 9.7. Food efficiency graph with the horizontal axis graduated in protein levels as a per cent.

Where would the points on the lean meat deposition graph (Figure 9.6) be for the two diets? The high protein diet is laying down surplus fat so it would be beyond the point of maximum lean meat deposition, or to the right-hand side of the graph. The fish fed the balanced ration would be closer to the point of maximum lean meat deposition. Maybe it is spot-on. But what's the easiest way to tell?

The easiest point for the farmer to establish is on the food efficiency graph (Figure 9.7). By carefully monitoring the food that goes into the system and the fish that comes out of the system the grower can calculate the FCR. By plotting that point on the food efficiency graph he or she can establish the point on the horizontal axis.

From the comparison of the two diets we identify another cost blowout. If the cost of the food is $1/kg and the FCR for the high protein is 1.6:1 the cost of food per kilo of fish produced is $1.60. In the case of our 800 g silver perch that means each fish cost $1.28 in food costs to produce. The food cost of the fish converting at 1.4:1 was $1.40 kilo or $1.12 per fish. That's a difference of 16c per fish. On a farm turning off 20 000 fish a year that would add $3200 to the feed bill. The farmer turning off 50 000 fish a year would have an unnecessary $8000 to his annual feed bill.

Now that doesn't sound like much and as a cost item it mightn't show up dramatically in a feed bill that could range from $24 000 and $60 000. But $3200 would be a trip to Bali and $8000 would get you over to the UK to see the Tower of London and the Crown Jewels. But as can be seen from the above example, the real costs of not using the best possible diet, in this case the balanced diet, are hidden until the grower decides to add value to his product. And let's face it, there's a limit to the number of live fish tanks in the marketplace. At some stage the industry is going to have to generate more products if it wants to expand its markets.

The other hidden cost is the cost of water quality management. If one ration is turning more of the feed into fish, then where's the surplus from the other ration going? It's going to finish up in your ponds where it will add to the load on your water quality management. Plankton blooms will be driven harder. DO levels will be under more nocturnal stress and pH will be higher during daylight hours. TAN levels will rise and fish won't feed as voraciously. All items you could do without.

GWQEHN says:
Farmers who don't make every effort to calculate the efficiency of their diets are doing themselves, their family and their bank manager a major disservice.

In this particular case the two feeds were priced competitively. This may not always be the case. The usual situation is that the price of the food is governed by the cost of the protein in it. A more likely situation is to find the high protein diet would be dearer.

Oxygen and metabolism

Oxygen is critical to the production of fish or crayfish. They cannot metabolise food without oxygen any more than a car can burn fuel without oxygen. We've already seen what a precious commodity oxygen is in an aquaculture system. As a rule of thumb, fish require 4 mg/L of oxygen just to maintain bodily function and daily activity. In a warm water system operating at 25°C that's just under 50% of saturation. To metabolise food the fish will have to have more oxygen dissolved in the water than that, otherwise the food gets digested but not turned into growth. Remember the fish is only eating to maintain energy levels.

GWQEHN says:
Oxygen + food + fish + water + management + markets = $$$$$.
Don't forget the oxygen.

It's generally accepted that it takes 1 kg of oxygen to metabolise 1 kg of food. At conversion rates of 1:1, and remember 1:1 is extremely efficient but it makes the calculations easier to do in your head, it will take 1 000 000 mg to convert 1 kg of food and produce 1 kg of fish.

Staying with our model of a 25°C water temperature with a dissolved oxygen saturation level of 8.4 mg/L you'll have 4.4 mg/L for metabolism. In other words you'll need 227 272 litres of water to produce 1 kg of fish a day, or the oxygen dissolved in nearly a megalitre to produce 4 kg of fish a day.

Fortunately it doesn't quite work like that. We've already established that water in an aquaculture production system is volatile and dynamic. Oxygen dissolves in water very readily and it can be introduced as quickly as it's used under certain circumstances. Photosynthesis will drive DO levels up to 200% of saturation level during the day. Managing the situation is the trick. Mechanical aeration can maintain DO levels after an evening feed. Oxygen can also be injected into re-circulation systems to similar levels. The high stocking densities achieved in re-circulation systems is solely due to the supersaturation levels made possible by oxygen injection.

As a rule of thumb, the authors believe DO levels should, wherever economically possible, be maintained at 85% or better. Never let them fall below 50% in a commercially driven situation where economically feasible.

There's a tendency for researchers to record and report the lower critical limit on water element parameters. While there's nothing wrong with that, in fact it's valuable information, the information tends to be taken as a minimum working figure rather than the point where fish start to die. To let you into a little secret, they can start dying before that lower level is reached in a crowded production system. And the lower limit can sneak up on you pretty darn quickly if you're not actively working to maintain DO levels as close to saturation as possible.

Even if they manage to survive, and just as often they do, particularly in open systems where stocking densities are lower, the stress levels compromise the fish's immune system.

GWQEHN says:
Don't worry about the lower limits. Keep your systems at the max. You're in this caper to make money not to operate a fish commando training course.

Growth priorities

The last, but by no means least economically significant, aspect of nutrition is growth priorities, and as fish grow these priorities alter. When the fish are young, and after maintenance of life, nutrients are used in the following sequence:

1 bone
2 muscle
3 fat.

Once they've laid down the frame upon which to hang a carcass their growth priorities change to:

1 muscle
2 bone
3 fat.

When they reach maturity the food use priorities change again, to:

1 fat
2 muscle
3 bone.

Put simply, if you're going to grow big meaty fish and grow them fast you've got to pour the right balance of food into them early, so they can grow a decent frame on which to hang some meat. Once this frame is in place you have to keep on feeding them the correct balance of nutrients in order to achieve maximum (read: genetic potential) development of muscle. Interestingly, our silver perch farmer producing the fillets in the earlier example not only gained fillet weight by the reduction of mid-line fat, but actually gained fillet yield by producing better muscled fish. If you don't feed them correctly from the start, you won't make a dollar at the end.

10

Site selection

As an aquaculturist, selecting the right site is one of the most important things you'll do so it is essential that you have a good understanding of the requirements for a viable commercial fish-growing operation. This chapter looks at:

- water requirements
- climatic and soil requirements
- infrastructure and logistic requirements – proximity to services and markets, etc
- permits and legalities
- species options
- marine farming waters.

In some cases the grower will be going into the operation cold and will be looking for a site to establish the ideal fish farming operation. In other cases the farm may be the one the farmer is already living on. The following criteria will help rate the site as an aquaculture proposition.

There are general rules common to all aquaculture sites; and there are rules that are species specific. Seeing that aquaculture is the controlled production of aquatic organisms, it wouldn't be hard to guess that water, being the item common to all aquaculture operations, is the subject of the rules common to all aquaculture sites.

Water is a precious resource in this arid wide brown land. The use of rural water is being re-assessed in the light of El Niño events, that seem to be coming through in waves, as well as the salinity problems that threaten much arable land. The triple bottom line – a balance between environmental, social and economic outcomes – is going to dominate water allocation throughout the future of our nation. It could come about that only those who are able to demonstrate multiple usage will be allowed access to water. Aquaculture is one of the uses that could be integrated with existing farming pursuits.

Sources of water and reliability of supply

You can't have aquaculture without water. The current sources of freshwater are from: bores, irrigation allocations, run-off, and in some cases temporary borrowing from rivers.

Marine farming is growing as a supplier of seafood in Australia and identifying marine farming sites presents a similar set of basic criteria. However, marine sites are crown land and there are multiple stakeholders with an interest in the use of this public space. Stakeholders could be anyone – recreational anglers and sailors, conservationists and coastal residents. A prospective fish farmer may be granted permission to farm in a particular location of his or her choosing but it's more likely that the grower will have to farm in a designated zone and be subject to a range of licence conditions.

Groundwater can be brought to the surface via a bore. Bore water is usually stable in chemical balance, flow and temperature and it usually makes excellent aquaculture water. It is the preferred option of hatchery and re-circulation system operators.

Access to bore water is often not automatic. In most states and territories, bores will need to be licenced and the volume capped at a predetermined output. Charges for the licence and the water used will vary from state to state. Check with the local water authority.

If land is being purchased with a bore on it, the word of the previous owner can generally be trusted, but it is wise to insist that the sale depends on an iron-clad assurance of the quality and quantity of water available (and it may be surprising what proof is brought forward). The vendor should produce a certificate of operation from the local water authority as to how much water can be drawn; and an analysis of the water.

Irrigation water comes from natural surface water, usually via a complex reticulation network of channels or pipes. Access to irrigation water generally is strictly controlled. An irrigation water right that goes with the property is secured by the payment of an annual fee. Additional water may be purchased from the water authority as a percentage of the water right in any given season, if surplus water is available. Local circumstances can be established by talking with the local water authority. Local farmers and stock and station agents are usually helpful in these matters.

There are some disadvantages that can be associated with irrigation water. The water can contain predators such as carp, redfin and other species of fish as well as the parasites and diseases associated with them. Predacious aquatic insects can also be introduced with irrigation water. These may prosper under aquaculture conditions, to the detriment of the aquaculturist. They can all be screened off from the water before it goes into the production system but it's something that should be taken into account.

Agricultural pollutants are a risk but the level of risk can be determined by looking at the type of farming being carried out in the district. For example: cotton croppers use insecticides by the truckload, while dairy farmers use very little, if at all.

Irrigation water can also be shut off from the grower during the winter months depending on local practice. Storing water in a reservoir to hold water for the 'dry' months, or planning the operation so that the need for fresh water coincides with the local availability of water, can soften the impact of this control.

Run-off from rain can be caught on the property and stored until needed for aquaculture during the dry period. This water is very good for aquacultural purposes and in most cases the farmer has either control of, or is familiar with the catchment, allowing him or her to avoid problems.

As water becomes an increasing disputed resource, some states are passing legislation to claim ownership of the run-off water that is stored for commercial exploitation other than stock and domestic use.

Rainfall, however, is still subject to El Niño events and the vagaries of the weather. The storage should hold twice as much water as the operation requires, in case the district suffers a dry year. Local knowledge will provide a pattern of droughts and wet years but there is no restriction on the timing or the nature of the usage.

Water can be temporarily borrowed and then put back. In some cases water can be diverted from a river system, through raceways and back into the river system. Most freshwater trout farms are run on this method.

In the ideal situation, the user pays only for the water not returned to the river system. It is getting harder to procure divergence licences but there's no harm in asking the local water authority what the chances are.

Water quality

If you can get water, you want that water to be good. The first thing you should do is to take a sample of the water you intend to use and have it analysed. The local farm advisory service should know where to have this done.

The next step is to get the analysis interpreted to see how it relates to fish farming. The local Fisheries Extension Officer should be able to assist with this, or one of the training providers.

Toxic factors

The first matter to be determined is: 'Will the chosen aquaculture species live in this water?' If the answer is 'No', then it is a potential show-stopper and you'll have to find out why. It unusual to run into this situation but it does happen occasionally and is generally associated with highly mineralised bore water. If the situation is not manageable, there's no point continuing with the evaluation of site.

Bore water has been associated with what has become known as 'hole-in-the-head syndrome' or more correctly chronic erosive dermatopathy (CED) syndrome in Murray cod grown in re-circulation or flow-through systems. At the time of writing Dr Brett Ingram of the Marine and Freshwater Research Institute (MaFRI) based at Snobs Creek, Victoria, has indicated that they haven't been able to find any directly related pathogen connected with outbreaks and that he suspected a number of water quality parameters working in a symbiotic relationship causes the breakdown in the cods' immune system (personal communications, 2003).

Other potentially serious pollutants that may be found in the water are agricultural and industrial chemicals. Because their presence can be of a seasonal nature, particularly in rural areas, it would pay to inspect the upstream conditions of the water source. Persistent insecticides and herbicides may be present in the soil, so seek a written assurance that there is no chance of their presence in the soil if you're purchasing the property and check the land's history if you already own it.

If nutrient levels are found to be unusually high in the water during a pre-purchase inspection, it would pay to determine the cause of this, as it may mask an inherent problem of an unmanageable nature.

Manageable factors

Fortunately, many problems with water quality are manageable. Dissolved oxygen and pH are two measures that, although vitally important to aquaculture, will vary greatly during the daily operation of the ponds depending on the level of plankton production and the levels of carbonate and bicarbonate in the water. These parameters can be managed (see chapter 6). Unless pH is over the roof, indicating highly alkaline water, or extremely acidic, indicating imbalance in the other direction, there should be no reason to be concerned about oxygen and pH levels in the water

Bore water will usually be devoid of oxygen when it first comes out of the ground, and it may contain other constituents such as carbon dioxide. Bore water should be thoroughly aerated prior to use in aquaculture to gas-off the unwanted elements and oxygenate the water.

Low carbonate hardness and general hardness levels can be adjusted by adding limestone, but if it's already in the water that's a bonus.

Be wary of the highly mineralised water that often accompanies high hardness levels. Sometimes they can become a dominating factor that is unmanageable. In open ponds, evaporation will increase the level of mineral salt in the water. For instance, should a 2 m deep pond with a general hardness level of 300 ppm lose 2 m of water through evaporation over the season, and be topped up with water from the same source, the mineral salt levels will have doubled by the end of the season. Take a more extreme case. Let's say you've conditioned silver perch to tolerate a salinity level of four parts per thousand (4 ppt) at the beginning of the season. Under the same evaporation and replacement regime, the water by the end of the growing season will have reached a salinity of 8 ppt. That's getting close to their tolerance levels under commercial circumstances.

When it comes to general hardness, which is mainly calcium, magnesium and potassium salts, a guide can be taken from the aquarium fish industry where they tend to keep their native fish at around 150 ppm to 200 ppm. General hardness is not as critical to a fish pond as carbonate hardness as it has no influence on pH. However, it does have an impact on the fishes' osmoregulation. The addition of fish food, fertiliser, and particularly limestone, builds up general hardness over a period of time. The salts left in water that remains after evaporation will also add to the general hardness build-up. Hardness is easy to add if you feel you need it, but difficult to remove from your ponds once it's there.

Evaporation is not such an issue in re-circulation units, so these concerns aren't as much of a problem. However, highly mineralised water can create electrolysis in stainless steel tanks and brass fittings releasing heavy metals such as cadmium and nickel in the former and copper and zinc in the latter.

Calcium levels (general hardness) can be raised by using gypsum; and carbonate hardness can be lifted by liming; but if the readings are too high, say above 300 mg/L, there is little you can do to change things outside mixing the water in question with softer water. Problems with hard water are generally found in bore water and catchment water stored or collected in country with a very low or very high soil pH. The take-home message is that water with a high to very high carbonate and general hardness may have other factors affecting its aquacultural suitability and indicates that deeper investigation should be undertaken.

Saline, or brackish water may be suitable for some freshwater species, but it is a complex area, so don't look for problems. Salinity levels will quite often mask the total alkalinity and total hardness of the water relative to aquaculture. The use of inland saline water for aquaculture is debated around the world and unless you have a firm grasp of what drives aquaculture and water chemistry it might be an area to steer clear of.

If plankton production is going to be a major source of the food supply then the water should be relatively clear, as light penetration will determine the pond's ability to produce plankton. Most of the detrimental turbidity in water in Australia is caused by colloidal clay particles suspended in the water and these can be flocculated out of the water (see chapter 6).

Alum (Aluminium sulphate) will clear water but it will also drop the pH and kill just about everything in it at the time. It's reasonable to hold some reservations about its use from a fish health and cost point of view and its effect (by lowering the acidity of the water dramatically during the flocculation process) on pH levels. Again there is no need to create unnecessary problems so alum is something to use with caution.

The presence of heavy metals should be considered – these are most commonly found when using bore water. Iron is the metal most frequently found in water and it is not difficult to remove it by aerating the water and allowing the iron to precipitate out. Copper, zinc, mercury, lead, nickel and cadmium are others that may be present in trace proportions. Some tolerance levels are shown in the table below.

The figures in the table are from the authors' personal research from a wide range of data on the topic.

Table 10.1 Fish tolerance to metals in water.

Metal	Tolerance level (ppm)	Metal	Tolerance level (ppm)
Arsenic	>0.05	Manganese	0.001 to 0.01
Boron	0.05 to 1	Mercury	0.001 to 0.002
Cadmium	0.0002 to 0.005	Molybdenum	a trace
Carbon dioxide	1 to 10	Nickel	0.0 to 0.15
Chromium	0.002 to 0.02	Phosphate	0.005 to 0.2
Copper	0.002 to 0.006	Silicate	2 to 20
Iron	0.5 to 1.0	Sulphate	5 to 100
Lead	0.001 to 0.02	Zinc	0.002 to 0.05

Tolerances may vary from species to species, but it goes without saying that stressed fish are more vulnerable to disease. Short periods of exposure to heavy metals shouldn't be a problem (other than the risk of a residual effect should the periods be on a regular basis). Prolonged exposure is to be avoided.

Different kinds of operations may have different standards for water. Hatchery water has to be the best available. There are no short cuts in this regard. Most hatchery operators look for the stability of bore water for their water supply. Many re-circulation system operators take the same view and look for bore water with aquaculture qualities. The low water usage from these systems encourages some operators to use town water.

Water quantity

The item most overlooked when assessing a potential aquaculture site is the amount of suitable water available.

The amount of water needed can be, and should be, calculated before a farm is established. The requirement should be checked against the availability of water. This calculation is one of the most important components of establishing the feasibility of an aquaculture proposal.

There are a few traps for beginners in this regard, and they relate to the kind of aquaculture proposed.

Outdoors, there is likely to be some water loss due to evaporation or leakage from the ponds or reticulation channels. For outdoor applications, the following pointers will help you evaluate the aquacultural capacity of the water supply on the property:

- 1 ha of pond surface area will require 10 megalitres of water to fill it to the depth of 1 m;
- 1 m of evaporation per year will consume 10 megalitres of water for every 1 ha of pondage;
- a total water replacement for 1 ha of pondage, necessitated by a major water quality collapse, to the depth of 1 m would require 10 megalitres of fresh water;
- it is likely that there will be a water seepage factor of some measure during water movement along earthen channels.

Make sure the water volume requirements of the species you're thinking about farming are well understood so you don't leave yourself short in this regard.

Re-circulation systems are promoted as frugal water users, but in practice they seem to use more than the miserly figures quoted by their suppliers. The flushing of the organics in suspension separated by the mechanical filter can use a surprising amount of water. A unit using the apparently low volume of 3% a day to flush the screens will be using 21% of the volume of the tanks a week. Five per cent a day would see 35% of the volume of the tanks going out of the system. Reading the articles in *Austasia Aquaculture*, it would appear that some of the high stocking density units exchange 10% of their water capacity a day. It may not seem like a lot but when you also take into account the water pulled out of the system during grading, harvesting and other management procedures, such as disease control, it may come as a surprise at the end of the year just how much water is consumed during the operation of a commercial re-circulation system.

The price of water and the cost of moving it

It can cost money to obtain water. It can also cost money to shift it to where you want it. These costs are an essential component of any feasibility study.

Water shouldn't be a big ticket item but, if you're buying-in a water allocation, it could run into tens of thousands of dollars. Calculate the cost of water at the farm gate if it has to be purchased from an authority, and the cost at the bore head if it has to be pumped.

Moving water can be a substantial cost on a fish farm and even though it will spend a lot of its time running downhill you will still face the original cost of lifting it above the pond systems. Consider the topography of the site with this in mind. Some trout farms and prawn farms have pumping as a major cost item. It can be significant.

Water disposal

Water that leaves a farm becomes effluent. If it is enriched by nutrients from fish wastes and uneaten food, or silt from pond walls, some authorities regard it as polluted effluent.

Around the country, the various Environment Protection Agencies (EPAs) are looking more closely at discharges from fish farms and regulations are constantly changing as water quality management increasingly becomes a public issue. The relevant agencies in the various state and territory jurisdictions have guidelines covering water disposal from aquaculture pondage into public waters. 'Public waters' can mean anything outside the farmer's boundary lines.

Smart farmers will be trying to work on ways to conserve or re-use water from aquaculture but, in cases where this is not possible, the attitude of the EPAs to the disposal of water from the proposed operation should be sought. For more detail, see chapter 21 on the law.

Farmers using pond effluent on their own land are exempt from EPA restrictions and the principle is the basis of integrated agri-aquaculture. Where this is the case, any aquaculture system should have first use of the water on the farm (where the highest water quality is paramount) and any waste water should be directed to the irrigation of crops or pasture, which can obtain the benefit of added nutrients.

Soil

The first requirement of the soil, if you are contemplating building ponds, is that it be able to hold water. Look for a good clay base under the topsoil. The local earth-moving contractor is the best person to see about these conditions but a poke around with a shovel will give you a preliminary idea of the soil's ability to hold water.

The second requirement of soil is that it not be exceedingly acid or alkaline. Acidity can be adjusted by the addition of agricultural limestone; and it is possible to lift a calcium level that is too low in relation to the carbonate hardness by adding gypsum. However, the reverse case is harder to deal with: it is not feasible to adjust extremely high readings of alkalinity or hardness. In practice, this normally should not be a major concern because excessively alkaline soil will probably be bordering on pure limestone and consequently too porous to hold water anyway. As a rule of thumb, you generally find soil that makes for good general farm land is pretty well balanced in acidity and alkalinity.

Rich alluvial soil contains lots of nutrients and if it is in a pond, the water will produce more plankton than if the pond was dug in poor sandy soil. However nutrients and organic tilth can be added to the pond at an acceptable cost so it doesn't present much of an issue one way or another.

Topography

The lie of the land is an important feature in site selection. The construction of ponds and the engineering involved in moving the water is one of the largest capital outlays the farmer will face. The ponds also need to be user-friendly, and that basically means simple to operate and be easily accessible in all but the worst weather.

From a cost of construction point of view, the ideal country is that which falls gently and evenly toward the low point on the farm, but it is not necessary to have land that is as flat as a billiard table; nor is it imperative to have all the ponds laid out in a row. Remember: it is more important that the ponds be functional to grow fish or crustaceans than they are of any particular shape or in any particular position on the farm.

Geographic area

Having discussed what to look for in the way of aquacultural advantages on a property, we'll now look for where that property should be geographically or more to the point, *climatically*.

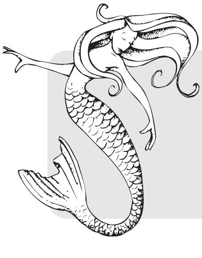
Macro-climate

The climatic conditions prevailing in the district must be compatible with those in the optimum range of the target aquaculture species. Optimum water temperature should be able to be maintained for at least six months of the year.

Micro-climate

In a given region, some properties will have a better climate than others because of local influences on the weather. Frost, for instance, settles on the low country first; and country that has early exposure to the sun disperses the frost and warms up quicker than country in the shade until mid-morning.

If water is to be harvested from run-off, local rain shadows should be considered (and avoided).



GWQEHN says:
If you get site selection and system design wrong, you're beaten before you start.

Infrastructure

Infrastructure can be divided into two areas: regional and on-farm facilities.

From an aquacultural point of view, some of the regional features that may affect the judgement of the farmer in relation to site selection are:

- the access to all-weather, year-round roads;
- proximity or access to markets;
- proximity to transport services;
- availability of reticulated electricity;
- proximity to social and family support systems;
- availability of a skilled and semi-skilled workforce; and
- availability of potable water should processing be contemplated.

On-farm facilities

On-farm facilities are sheds, power, roads and housing. Inside a property, power connection and reticulation can be a huge cost (if access to a power grid is available). The amount of electricity used on any commercial fish or crustacean farm will warrant 3-phase power and this should be a prime consideration when evaluating a site, whether it be for an open system or a re-circulation unit.

Purchasing a property is a real estate transaction. The likelihood of capital appreciation should always be taken into account. The financial wisdom of selection of any location, regardless of whether it is for aquaculture or any other purpose, is governed by the three cardinal rules of real estate: position, position, position.

Permits and licences

Each state or territory will have an agency responsible for issuing permits or licences to undertake aquaculture. Usually it is the 'fisheries' agency. Contact the relevant agency in your area and find out what you can and can't do, and how much it's going to cost you to do it.

Farmers in some states complain about the complicated and seeming irrelevant forms that have to be filled out before a licence is issued. The authors come from both sides of the fence in this case, yet both agree that if the application is approached with common sense the process runs relatively smoothly. The important outcome is to get permits with the minimum of hassle and in the shortest time, not who wins or loses a particular debate.

The aquaculture industry is governed by legislation, regulations and government policy. In some cases key legislation limiting what you might or might not do is set not in the fisheries or aquaculture acts, but in environmental protection acts designed to protect the environment; or fauna and flora acts designed to protect genetic diversity or habitat integrity. Those parameters control the way aquaculture is run in that particular state or territory. Learn to live with it or move to another state.

Species options

Aquaculture species have an optimum range of environmental conditions, (see chapters 4, 7 and 23). Borders between the natural ranges of species often overlap and it may be tempting to grow a high value species in a region that would otherwise be considered marginal. The attempts to grow redclaw in northern NSW was one such failed adventure. The tropical species couldn't survive the cold winters along the mid-north and north coast regions and attempts to culture them in these regions have all but died out. The irony is that the climate is ideal for growing yabbies. The prospective fish farmer should weigh carefully the pros and cons of trying to grow a species in an area with environmental conditions that do not match the optimum conditions. The cost of working against the climate could well drain the operator of capital and energy; not to mention that vital ingredient that keeps us all going in the face of adversity – enthusiasm.

With the advent of re-circulation technology it has become possible, and even fashionable, to grow species outside their natural range. Artificial heating allows tropical species to be grown close to southern markets. At the time of writing, South Australia, with the help of very warm artesian water and an established re-circulation sector, is the nation's second largest barramundi farming state. (However, barramundi production in the Northern Territory and Western Australia is increasing by leaps and bounds and South Australia could soon lose its mantle.) A word of warning: fighting the environment (for example heating in cool climates or cooling in hot) costs money and extends the break-even point. As regional and international transport links become even more efficient and cheaper, the advantages of proximity will be marginalised when compared to cheaper production costs.

Marine farming waters

If you're looking at marine farming, any decision on site selection may already be out of your hands. Don't think that because a patch of sea is apparently unused that it will automatically become available to a bright young person with a good idea.

In most cases, mariculture production zones have been allocated, and all a prospective mariculturist can do is apply to the controlling agency (usually the state fisheries agency, but sometimes 'lands' agency). If the fisheries agency doesn't control the matter, they will know which agency does.

In some places in Australia, for example the Northern Territory, people pressure is low and there is more room, so it still may be possible to obtain a patch of un-alienated seawater, but the process is slow, and requires a significant amount of public consultation, which is slower.

11

System design

This chapter outlines the outcomes you require from your fish farm from an aquacultural point of view. It covers:

- pond systems
- floating cages
- flow-through systems
- re-circulation system design.

Aquaculture is difficult enough without having the handicap of an inadequate production system. It is one of those key areas, along with site selection, that if you get it wrong you're beaten before you start. Sadly, all too often the authors see fish farmers in such a hurry to get fish in the water that they rush into an inappropriately designed and structured production system hoping to learn on the job. The sad reality is that they spend so much time trying to make the system do what it should be doing that they don't get around to farming fish; nor do they learn much about farming fish from the experience. Ponds, cages, raceways or re-circulation systems that are poorly designed and poorly built will create problems in just about every area of aquacultural production. Water quality management and consequently husbandry are affected; harvesting becomes a nightmare with unnecessary stress placed on the stock and the farmer; and tight management goes out the window as timetables fall hopelessly behind schedule.

The following sections will look at the four main methods used to produce finfish in Australia and how they function. The authors have taken the 'one size fits all' approach with each production method. Rather than support any one particular configuration of each method, the authors feel that the best thing they can do is to list the functions they should perform and let the prospective fish farmer use them as a guide to designing or purchasing his or her system.

Ponds

The attributes of a pond-based fish farm are essentially the same wherever you are or whatever species is being grown. There may be differences in the dimensions of the pond but the fundamental requirements will be the same.

Layout and design

Before you draw up any plans for the pond or move any earth, you should take the levels of the land intended to be used for the ponds and its relationship to the water take-off point and drainage basin. The ponds should be sited in relation to the shape of

Figure 11.1. The inland farm shown here is set up to make maximum use of water. Drainage is used on the homestead garden, a native wood-lot and surrounding irrigated pasture.

the entire property to allow for future expansion and other water use downstream from the ponds. You should also consider moving the water by gravitation wherever possible.

Fish and crayfish ponds should get first use of the water. If the farm is producing both fish and crayfish, ideally the fish ponds should get first use of the water. The nutrient-enriched water can then be used in the crayfish ponds to feed the detrital food web. In a fully integrated water use system the water is used in an irrigation operation after it has been through the aquaculture set-up.

Ponds are designed to accommodate the management demands of the operator and the only dimension to be considered in regard to the stock is the depth.

Certain design requirements should be incorporated in an aquaculture production pond. The absence of any one of them will render the pond inefficient. This means you will not be able to carry out many of the production measures that will allow you to manage your water quality and take good care of your stock.

Bottom draining ponds

The pond must be able to be drained from the bottom for two reasons. At the end of each production cycle the pond should be drained and dried, maybe limed, and maybe cleaned out if an unmanageable layer of sludge has built up. The drying helps break pathogen cycles and allows you to do any maintenance such as liming, fertilising and laying out hay for a detrital food bed. In NSW, Fisheries have taken a positive step in this direction and made it mandatory that ponds used for commercial aquaculture must be bottom drained.

The other reason is that should the pond's drainage system require maintenance, it's a lot easier to work in a dry environment than to be slip-sliding around in a half-full pond.

Pumping or syphoning the pond is not the same as having a bottom draining pond, especially when you're trying to remove the last part of the water and keep the pond dry should there be a bit of rain about.

Pond bottom access

It is important that the grower can get machinery into the pond during the fallow period to lime, fertilise, remove sludge or carry out any mechanical maintenance. At least one pond bank should have a gradient to allow easy access for the equipment that will be used for these tasks.

Pond bottom design for quick draining/refilling and to eliminate habitat preferences

If something goes dramatically wrong with the pond water, being able to exchange it with good quality water will go a long way to solving the problem.

To drain harvest a pond you will want to get the water out of the pond quickly. If the draining process is slow it could leave the fish in a shallow pond when the weather is hot and the fish stressed by the high stocking densities of a half-full, over-heated pond. The ensuing stress shows up in the purging system or the flavour of the flesh if they are being sent off fresh chilled.

You may be harvesting to grade or treat fish for some ailment or other. The fish will be stressed, particularly those that are already weakened by pathogens. A slow drainage system will only aggravate the problem.

Being able to fill a pond in 12 hours should be sufficient to cope with most contingencies but six hours would be better.

The floor of the pond should be built so that the last of the water drains quickly and totally without having a gradient that would give the fish noticeable habitat choices from one part of the pond to another. Nothing flatter than 1:250 should be enough. That's a fall of 1 m over 250 m. In a 1 ha pond measuring 150 m x 80 m that's a fall of half a metre. There's no point in going to extremes.

Extreme variation offers habit choices to the fish, which in turn leads to hierarchical behaviour as fish compete for preferred positions. This is something we should aim to reduce in our production systems.

Ideally, the pond bottom should slope toward the drainage end and from the sides to the middle, but certainly towards the drainage point.

Total exchange of water

The ponds must be constructed so as to ensure that the water is exchanged totally without leaving pockets of 'dead' water behind. This is particularly important if your method of production relies on a high rate of water exchange. You'd be surprised how easy it is to create dead pockets where 'dirty' water can build up.

Tyres in the bottom of many crayfish ponds are traps for dirty water and the authors don't encourage their use.

Gully dams used as aquaculture production systems can also have dead pockets that trap water and debris. While in the normal course of events these dead pockets may not be a problem when the gully dam is used as a recreational or ornamental fish habitat, they can become death traps should commercial feeding rates be introduced.

The same can be said of ornamental lakes. Introduce fish by all means and you can even feed them, but most of the production and remedial procedures outlined in these pages will be denied you. Proceed with caution. Before we have GWQEHN popping up with one of her homilies, make that *extreme* caution.

Vehicle access to the headlands

The headlands between the ponds should be constructed to allow the passage of the vehicles delivering the food to the fish and those taking the harvested fish to the processing shed. Quite often the banks are used as work sites when grading or other measures. Make sure they are wide enough to do what has to be done around the ponds. They are not just there to separate the water.

The headlands should also have an all-weather surface. The fish don't like being told there's no food today because of the 100 mm of rain you had three days ago, any more than your marketer will put up with you telling him he'll have to wait until the banks dry out before you can harvest again.

Kikuyu and couch grass planted on the pond banks will help consolidate them and provide a good top as well. Livestock or geese can be used to trim the grass if you can't be bothered mowing it. If you have access to good gravel the banks can be topped should you feel that would be an advantage.

Figure 11.2. The headlands are used as worksites and roadways around the farm. Make sure they are solid enough to cope with the traffic that will be using them.

Predator control

The pond must have adequate predator control. This is considered to be of such vital importance it is dealt with in a chapter of its own (see chapter 16).

Water level regulation

There may be times when the grower will want to regulate the level of the water. It could be to dose the pond with a prophylactic to remove pathogens or it could be to reduce the volume of water during a harvest. There are several options. The three most common are the monk, the stand pipe and the chimney pipe.

The monk

The monk is widely used in flow-through systems. It can be either set in to the bank or out from the bank. Naturally it is situated at the deep end of the pond. In the case of the monk set off the bank it consists of a casting of concrete, which in plan looks like a 'U'. The open side of the 'U' faces into the pond and at the back end a drainage pipe takes the water through the pond bank into the drainage system. The internal walls of the 'U' have grooves in them that take boards. The board nearest the back of the monk will regulate the water level. The water level can only rise to the height of the 'backboard'. The one at the front of the monk will be higher, but it will set off the bottom of the monk to allow water to flow under it, thus removing the 'dirty' water from the bottom of the pond. The authors would strongly recommend that the flow of water through the outlet pipe be controlled by an external valve. Aquaculture is a belt and braces operation.

Figure 11.3. Innovation is the name of the game. Here is a monk made from the mould of a road culvert supplied after negotiation with the local concrete company. The boards weren't installed at the time of the photograph. Note also the concrete steps coming down into the pond and the concrete apron around the internal sump. This particular pond was a fry pond at a marine hatchery.

Figure 11.4. A simple in-bank monk that can be installed at the same time the pond is built.

Having the monk set out in the pond provides a convenient place to lay a ramp out over the water. This provides the farmer with a handy viewing platform. Hours can be spent lying on the ramp in the sun observing the fish. It's an excellent way to learn, not to mention relaxing. But don't let it keep you from the other chores around the farm that have to be done.

The monk can also be set in the bank of the pond. The water regulation and drainage arrangement remain the same, but it leaves the pond clear of encumbrances should you want to net the entire pond. It's also handy for a partial harvest. Fish can be crowded toward the monk and the valve opened. When you've got enough fish the valve can be closed, the net removed and the fish will swim away without being stressed too much. This is particularly good for fry production or nursery ponds where the fish are small.

Grooved neoprene strips and sheet metal, as used in irrigation channel gates, can be substituted for the monk boards.

The stand pipe

The stand pipe water level regulation method is quite simple. The drainage pipe runs through the bank level with the bottom of the ponds, as in the monk drainage system. The rate of water flow is determined by the in-line valve between the outer pond bank and the level is regulated by the stand pipe. The stand pipe is connected to the drainage pipe by a sealed PVC right angle bend. Care should be taken to ensure that the stand pipe is secure from being knocked over accidentally. This method of water regulation is commonly used in indoor situations such as hatcheries and fish rooms. The upright stand pipe can be laid over to determine the level of water in the pond or tank.

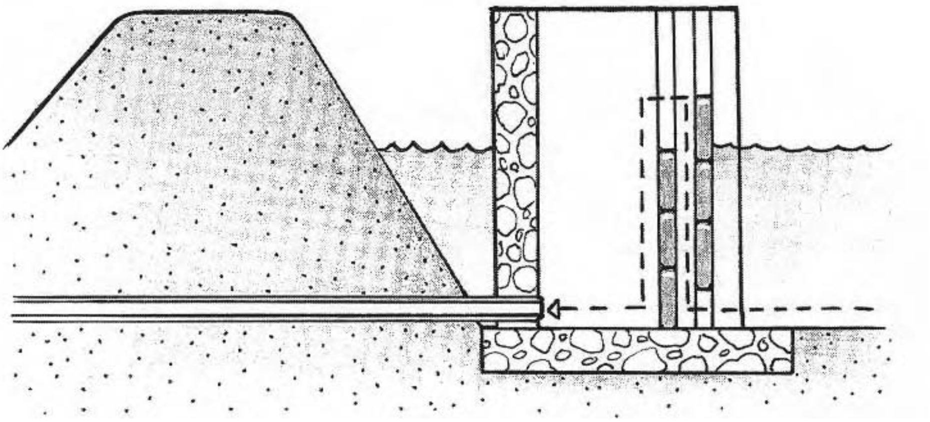


Figure 11.5. The principle of the monk is to establish a pond depth while at the same time remove the bottom water from the pond. More commonly found in flow-through systems.

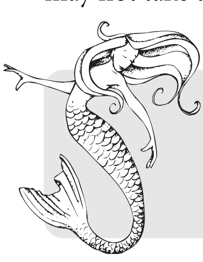
The chimney pipe

The chimney pipe is more often found in crayfish ponds where the water levels are shallower than fish ponds as the farmer will have to enter the water to adjust them. The principle is simple. This method is best done in PVC pipe because the fittings are readily available off-the-shelf. The pipe runs through the bank as usual with a control valve on the outside. At the end of the drainage pipe on the inside of the pond connect a 90° elbow. Into the elbow fit a pipe cut so that, when fitted into the elbow, it will be approximately half the depth of the pond. Use a flanged end so that another section can be fitted to bring the pipe up to the full depth. To draw the water off the bottom of the pond an oversized pipe is placed over the stand pipe rising from the elbow. This oversized pipe, or chimney pipe, is slotted at the bottom or sat on bricks. This will allow the pond water to be drawn off the bottom, up the space between the two pipes and over the rim of the inner pipe and down into the drainage pipe.

Aeration

Aeration is an important production tool and if it has been decided to use electricity, and this has proven over the years to be the most efficient power source, provision should be made to lay cables during the planning stage.

When considering the aeration system, keep in mind that any internal combustion engine employed near the ponds increases the risk of pollution from fuel or lubricant. It's also very noisy, and as most aeration is done in the wee small hours the neighbours may not take too kindly to it.



GWQEHN says:
It is not practical to operate a commercial aquaculture pond without mechanical aeration.

External sump

Harvesting is one of the backbreaking tasks on a fish farm. The job should be made as simple and easy as possible. Many ponds have an internal sump into which they drain the vestiges of the production water, and with it the fish. This is fine when the 100 000, 1 g fry you are harvesting from a plankton pond only have a total weight of 100 kg. When the crop consists of 10 000 fish weighing between 500 g and a kilogram the job becomes a real killer.

Figure 11.6. The external sump at Wartook Native Fish Culture. All the fry production ponds drain to this one 'fish-out' sump. Note the flat all-weather working area surrounding the sump.

Ideally the pond should have an external sump – an area into which the pond can be drained and the fish separated from the pond water. This can be done by having the water flow into a cage set in the drainage channel taking the water away from the pond. The fish stay in the cage and the water passes through. When full, the cage can be lifted out of the channel and placed in a tank of water on a trailer or a truck and taken to the purging or processing room. A jib of some sort would make the job even easier.

In the case of crayfish, a large sock made of shadecloth-type material, can replace the cage attached to the external end of the drainage pipe.

Permeability and batter

Use expert advice wherever possible. The knowledge and experience of the local earth-moving contractor is a valuable resource to draw on in these circumstances. No one knows the soil better. It goes without saying that the soil should be able to retain water.

Liners can be used but, generally speaking, they are too expensive for the economics of most situations.

Figure 11.7. Wave action from aeration and wind will erode the banks until they form a natural batter of 1:3, so why not start at that point?

Water will erode most soils so that the batter finishes up 1:3. It is best to start at that point rather than have the banks cut away by normal fish farming activities over time. This batter also allows easy access to the ponds. There's no reason to have steep banks.

Flow-through raceways are a different matter and concrete walls are often built around their edges to consolidate the banks.

Don't skimp on the banks of the ponds, as they will also be the roadways around your farm.

If you are concerned about leaking walls and bottoms, you can mix some bentonite into the soil at the time of construction. If you discover that you have a leak in the wall or bottom of your pond, you can mix it into the soil around the leak on the inside of the pond during the period of pond maintenance. (Bentonite is a powdered material, which swells many times its size when wet, which should close off the leaking area. It's available from most farm supply stores.)

Siting, size and depth

Ponds can be built in the ground or above it, but in flood-prone country common sense would suggest that above-ground ponds to be the most practical. State fisheries regulations will probable include a clause in the licence conditions that stipulate the height of the pond banks in relation to flood levels, or even the siting of the pond.

The size of your pond is a management decision. As a rule of thumb, smaller ponds are easier to manage than larger ponds. However, larger ponds are cheaper to build: less earth to move for a given area, less plumbing overall and other economies of scale. Four or five to the hectare are regarded as a cost-efficient management compromise in warm water aquaculture while prawn ponds can be more than a hectare. In the USA the catfish and crawfish ponds can be as large as 20 ha, but it is interesting to note the sizes of the ponds in new operations are scaling back to just a few hectares including some experiments with ponds down to a hectare and less. Attitudes to pond sizes are continually changing and it would be advisable to have a good look around the particular sector you're thinking of joining to see what the latest ideas are.

The depth of the ponds is set to accommodate the species being farmed and, to a certain extent, the vagaries of the local climate.

For instance, a water depth for yabbies could be as shallow as 50 cm in a well-aerated pond, but during a summer heat wave the shallow water could quickly become too hot for good production. In winter months the 50 cm pond could become too cold and would be no good for over-wintering broodstock.

Generally speaking, the water depth for freshwater crayfish is between 50 cm and 1.5 m depending on the species. Yabby ponds tend to be shallower and marron ponds tend to be deeper. For prawns the depth is 1.5 m to 2 m. Finfish ponds generally range from 1.5 m to 2.5 m. Where floating cages are used in ponds the water depth tends to be over 3 m.

Testing and seasoning a pond

It is always a wise move to give your system a trial run to make sure everything's working properly. Fill the pond slowly to allow the freshly moved soil to take up, especially around inlet and outlet pipes set into the bank.

It is also a good time to practice water quality management before the valuable stock arrive. No one ever does, so feel free to join the vast army of aquaculture soldiers who practice on live fish. Newly filled ponds will produce plankton within a few days providing there are sufficient nutrients and sunlight for photosynthesis.

Flood the pond slowly to a depth of 30 cm and let it stand until you're sure that the subsoil is thoroughly soaked, say a couple of days, then raise the level, again slowly, to its maximum. Leave it there for at least another week to test the banks. Play around with the plankton bloom for as long as you like but when you let the water go, do it slowly so as to allow the drainage end of the system to take up.

GWQEHN says:
Open and close ball valves slowly. Water will build up quite a momentum and sudden braking can put pressure on your walls at the drainage pipe the same way in which sudden braking can shift the load on a lorry.

Let the pond dry out for as long as it takes. This will have the effect of compacting the soil on the pond's bottom. If you intend to grow a cereal or grass crop in the dry pond as part of the production method, now is the time to do it.

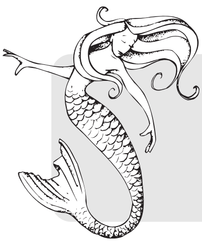
Adequate plumbing

Avoid at all costs the temptation to save money by skimping on pipe diameter. Plastic plumbing is as good as any and it is light to manipulate into position but it comes in several grades. Speak to suppliers and make sure the grade of pipe is robust enough for your job.

At any given time you are going to have to move water quickly, so don't skimp on pipe diameter. It may seem a costly exercise when you first do your calculations but if having adequate plumbing only saves one crop of fish it will pay for itself.

By doubling the diameter of the pipe you will increase the water flow four times.

Use baffles or weep flanges on the pipes going through the banks to prevent water soakage or crayfish burrowing along the pipe. In steel pipes the baffles can be welded onto the pipes. Plastic irrigation pipes can also have baffles welded onto them.



GWQEHN says:
See a hypnotist and have 90 mm stormwater pipe erased from your memory bank. It has a purpose but not around fish ponds.

Drainage/harvesting choices

Decide at this point how you are going to harvest your stock. Harvesting by drag net is still a preferred method on many farms. However, if you're going to employ a built-in system such as an external sump, now's the time to consider it in the design. Once the ponds are built it can be the devil's own job altering them. It also runs the risk of destabilising the earth works.

Everyone's situation will be different, but the features required of pond design will generally fit into the above production demands.

Calculating flow

Having warned that there will be times when you're going to have to move fresh water into the ponds, the authors have included some calculations to give you some idea of what is meant by adequate plumbing. Again all situations are likely to have peculiarities of their own so they advise that you run your pond design past an expert in this area.

Several factors have a bearing on the final result, factors such as pipe diameter, the length of the pipe, in-line impediments, such as bends and the head of the water in the case of a flow situation, and the volume of the pump where water is being moved mechanically.

Just to provide some idea of what you'll be looking at, the following data might help you get a broad idea of what will be required in the way of pipe sizes.

- Pipe with a diameter of 150 mm that is 10 m long with a fall of 1 m will flow water at about 50 litres a second, or approximately 4.3 megalitres a day. If the fall, or head, is increased to 2 m the flow will be about 80 litres a second, or approximately 6.9 megalitres over 24 hours.
  This is fine as long as the head remains constant, as it would if you were pushing replacement water in at the same time. But if the exercise is to empty the pond, naturally, as the pond drains the water loses head and the flow slows.

- Extra pipe length has a reducing effect. The same 150 mm diameter pipe at 100 m with a 1 m head will flow at about 10 litres a second, or approximately 0.9 megalitres over 24 hours. With a 2 m head the flow will increase to approximately 24 litres a second, or around 2.1 megalitres a day.
- If the pipe's diameter is increased to 225 mm its water carrying capacity will be around 55 litres a second with a 1 m head, or approximately 12.1 megalitres a day. At a 2 m head the same 225 mm x 10 m long pipe will deliver around 90 litres a second, or approximately 17.3 megalitres a day.
- A 150 mm pipe should be sufficient for a 0.2 ha pond.

Remember, your ponds are your fish farm. They have to be right or they won't work. Too many times the authors see people putting in systems that just don't allow the operator to farm fish. As usual we'll let GWQEHN have the final word on the matter.

GWQEHN says:
It's better to spend your budget on one pond that will work than on 10 that won't. That way, even if you have a bad year, you'll at least learn something.

Floating cages

Floating cages are used to grow three of the nation's largest aquaculture products: southern bluefin tuna, Atlantic salmon and barramundi.

The process is simple. The fish are held in floating pens or cages and the tide and current provide the water exchange. Fresh oxygen-rich water is brought into the growing site and the water from which the fish have used some of the dissolved oxygen is pushed out of the pen to be re-oxygenated by the natural environment. The metabolic by-products of carbon dioxide, phosphorus and ammonia nitrogen are also removed from the water by the natural biochemistry that keeps the oceans clean. Actually it finishes up fuelling the phytoplankton bloom that drives the ocean's ecosystem. This is a simple but sustainable and efficient way of producing fish.

Water temperature is a major factor in the productivity of floating pens. While those sited in oceanic situations tend to be relatively stable, those sited in bays and estuaries can have a wide temperature range. The trade-off between a sheltered easy access site and the more temperature stable oceanic site is one of the economic considerations for this type of farming.

The development of ocean cages has been dramatic. From the early cages that were anchored in the sheltered fiords and estuaries have evolved the ocean-going pens of today. This improvement in the seaworthiness of the fish pen will see more and more of our seafood being cultured than caught.

Barramundi are a very farmable fish able to be reared in salt or freshwater and can be produced in all four systems under review in this chapter. As well as marine fish pens, they are produced in floating mesh cages in inland ponds.

The method is simply a very primitive form of re-circulation system. The ponds are square and the mesh nets are hung from a jetty extended out into the pond. The water is rotated around the pond and through the cages. The ponds act as the bio- and mechanical filter and management is carried out from the jetty.

The holding nets can be any size you like. A popular size is 2 m x 2 m x 2 m. The ponds need to be deeper than the cages but 3 m to 4 m is sufficient depth. The floating cages can be any size you want them to be.

Management includes the usual monitoring of health, growth feeding and defouling the nets. Covering the cages with netting easily controls aerial predation but water rats can still be a problem.

Note that floating cages in ponds require predator netting as well as lids to keep birds out. Diving birds, water rats and tortoises will all attempt to take fish below the waterline through the netting. The first two have been known to drive to the fish to one side of the cage while a partner(s) tackles the crowded crop from the blind side. Even if they don't make a killing, they can do damage to stock and gear.

The ponds are aerated continuously to keep the water moving and the sludge finishes up in the middle of the pond. This can be drained off as needed by adding fresh water to the system. Aeration and water exchange are key elements in this method. It is not possible to operate commercially without them.

As the industry develops there will be innovations. One such innovation that was being trialled at the time of writing was a floating system that offered the flexibility of the floating cage and the benefits of the flow-through system. It consists of a floating plastic raceway that uses an airlift pump to bring water from the dam or pond up into the raceway. The water is then pushed along the raceway past the fish and out the other end through a restraining grill. The nutrients in the raceway water are then neutralised as they are in the pond or dam housing the floating cages.

Flow-through systems

This is a proven method of producing fish and is the basis of the inland trout industry. Rainbow trout are another proven aquaculture species, in both the 'ocean' trout sector in Tasmania and Victoria's inland system. It is utilised around the world and Denmark would have to be regarded as world leaders in the commercial development of this method. Flow-through systems could best be described as the inland version of the marine fish pen. The water is diverted from a flowing waterway through the ponds and back into the waterway. The incoming water brings dissolved oxygen and removes the phosphorus, carbon dioxide and ammonia nitrogen. These elements are removed from the water downstream as aquatic plants, including phytoplankton, feed on them. They in turn form part of the ecosystem of the river.

The flow is continuous and the water temperature must be within the critical range for the species being cultured. Ideally the temperature should be within the optimum range to maximise growth. Inland systems are subject to wide fluctuations and this has to be taken into account when choosing a site.

Water is a precious commodity in Australia and recent El Niño events have brought home to Australians just how precious it is. Both federal and state governments are reviewing the allocation of their natural resources and diversion to flow-through fish farming systems is not high on the agenda. However, this attitude could change once the benefits of the triple bottom line of environmental sustainability, economic viability and social responsibility have been demonstrated.

For instance, flow-through systems could be integrated into existing irrigation farms. Ideally the water could be run through a finfish pond before the nutrient-enriched water was used in a crayfish set-up. The water could then be allowed to continue on its way to the cotton, rice or other crop that it was originally destined for. But we don't live in an ideal world. The proviso here of course is for the water to be flowing at a steady rate all year round, or at least during the aquaculture production period.

The other dominating factor is the water temperature. Inland systems, particularly in Australia, have a wide fluctuation and the length of the growing season has to be considered on an economic basis. Crayfish, with their shorter growing season, may be the best option for this method of farming in the warmer sections of Australia, while trout, where sites are suitable and accessible, present the best opportunity for flow-through systems in Australia. However, wherever a continuous flow of water is available and the temperature straddles the preferred range of the species, just about any finfish can be grown in a flow-through system.

The actual production capacity from any given flow-through system will depend on several factors such as the number of days the water is in the fish-growing temperature band for the target species. A simple rule of thumb Victorian trout growers use is that for every megalitre of water they have running through the farm a day they can hold a tonne of fish and produce three tonnes over the year from the system.

Different species will have different characteristics and they should be established before potential fish farmers get too excited over a particular site that lends itself to a flow-through system. The parameters of the site over the whole season should be established as well as the variations from season to season.

Some trout growers find they have to use mechanical aeration during high temperature periods caused by an El Niño event to enable them to carry their stock through until seasonal conditions improve.

Re-circulation systems

The range of re-circulation systems available on the market, along with the bells and whistles that have one manufacturer claiming theirs is better than anyone else's, can be quite confusing at times. We've looked at the advantages and disadvantages of using a re-circulation system to produce fish. In this section we'll look at the workings of what is also called a re-circulating aquaculture system (RAS) and the engineering that empowers these fish production systems.

Re-circulation technology is fish production taken to the nth degree and can be likened to hydroponics in horticulture. Two features drive their use: extremely high stocking densities can be carried; and (because optimum conditions can be maintained around the clock), year-round maximum production is a reality. What makes the former achievable are the supersaturated dissolved oxygen levels that are possible under the conditions created in the RAS and the latter comes about from being able to maintain optimum water quality and temperature conditions on a 24-hour basis. Sounds good on paper, but the design of the system is crucial to the operation being a financial success. Before we look at the functions of the technology, let's look at an aspect of it that is often overlooked in the excitement of plumbing the system and getting it going.

Some of the major benefits of re-circulation technology are the side benefits it brings into the operation. For example, apart from the obvious ones of year-round optimum production parameters such as water temperature and quality, there's no need for predator-control netting. The shed provides that, including protection against poaching. Quarantine protocols are easy to install, but more to the point they should be. So the first item on our list is quarantine.

Quarantine

There are three aspects to quarantine: water, fish and inputs. Any water coming onto the farm to be used in the re-circulation system will have to have at least one or more things done to it. It has to be sterilised, aerated and/or de-chlorinated. There are four sources of water likely to be used in a re-circulation system: bore water, town water, rainwater and dam/irrigation water.

Quarantine for water

This simply means holding what you feel would be a safe buffer of exchange water for the system in a reserve tank isolated from the main system. It should be sterilised, aerated and de-chlorinated before it goes into the production system. There's no point in spending a fortune on a you-beaut re-circulation system only to find that one of the main advantages has been compromised because pathogens have been introduced via the exchange water. However, should some of the sterilising agent remain in the water, usually chlorine, then this will mix with the production water and become dangerous to the fish but more importantly it has the potential to damage the bacteria colony in the bio-filter. Should ammonia be present in the water, the chlorine will combine with it forming highly toxic chloramines. Chlorine can be aerated out of the water or removed by treating the water with a water purifier.

Bore water

Some re-circulation system manufacturers will insist that their systems have only bore water used in them. That is because of the general stable nature of bore water. Of course, some bore water may be totally unsuitable for use in aquaculture for one reason or another. For example, water that is highly mineralised would be unsuitable. This includes water with a calcium and carbonate imbalance or high salinity. But one thing is certain – it will need to be aerated. Bore water is generally devoid of oxygen. This is not a problem. It should be reasonably clean but thorough tests and analysis should be carried out before any other investment is made.

Saline water is not seawater. It is water carrying mineral salt loads that make it unsuitable for use in agriculture. Just because the water is salty doesn't mean it carries the same properties as seawater and it doesn't automatically follow that water from saline basins will grow oysters and snapper. Seek professional advice should you find yourself in control of an inland saline water resource, and follow up some of the many attempts to rear fish in inland saline basins to find out how they turned out. The Fisheries Research and Development Corporation (FRDC) website (www.frdc.com.au) would be a good starting point.

Town water

Town water is expensive compared to rural water. It is sold by the kilolitre (1000 L) whereas rural water is sold by the megalitre (1 000 000 L). Town water will certainly be treated. It is not uncommon, particularly in rural regions, for the local water authority to 'over-dose' the water should there be concerns about a particular climatic event, such as an algal bloom generated by a run of sunny days or a storm run-off event that may carry high animal manure and other forest floor detritus loads into the storage. You wouldn't be the first re-circulation farmer to be caught short under these circumstances if you didn't build a buffer supply for your system and you probably wouldn't be the last, but the authors would like to think you will heed this warning.

Rainwater

Rainwater is fine but it does leave you subject to seasonal factors. Another aspect of rainwater is the surface from which is collected. Galvanised iron roofing and holding tanks will certainly leach zinc into the water. If you do decide on collecting roof run-off as a source of water then it would be wise to check out any material that may come in contact with the water.

Dam/irrigation water

Dam or irrigation water is cheap, but it does have a downside. It is in contact with the elements and will have to be thoroughly sterilised to prevent any contamination getting into your system. Some operators view using this sort of compromised water in their re-circulation system as being akin to using sump oil in a Rolls Royce. That doesn't mean it can't be sterilised to meet re-circulation technology standards; it just means to remove all risks associated with using this low security water you'll have to be extra thorough about sterilising it. Once you get an unwanted life-form, particularly a persistant microbe, in the system it can be the Devil's own job getting rid of it.

Quarantine for fish

All fish that come into the system should undergo quarantine just as the water should, and for the same reasons: once you get a pathogen in the system it can be very difficult getting rid of it. Unless you're absolutely certain of the health status of the incoming fish the re-circulation system should have a separate system to quarantine them.

Passive Solid Removal (PSR)

The first thing a re-circulating aquaculture system should be able to do is passively remove as much organic material in suspension as possible, as a rule of thumb >95%. Passive removal means the solids have to be removed before they go through one of the many pumps pushing the water around the system. If they are put under any pressure they will fragment into fine particles that pass through the mechanical system and will be more difficult, read 'costly', to remove from the water later. Some may even be emulsified. If they aren't removed they will have to be neutralised, biodegraded or oxidised if you like, within the system. This will take oxygen away from other crucial processes with a resultant drop in production capacity.

There is also a risk factor involved. Should some of the organic material get trapped in a pocket in the labyrinth of pipes and encased areas in the system they can use so much oxygen from the water in the vicinity that the aerobic bacteria will 'borrow' oxygen molecules from the relatively harmless nitrate. By utilising one of the nitrate's (NO_3) oxygen molecules it produces nitrite (NO_2), which is toxic to fish.

The influence of nitrite can be reduced by running salt in the system. Most freshwater fish can tolerate small levels of salinity quite comfortably, although this doesn't mean that the production systems should be run at that level. Murray–Darling species for instance handle levels up to five parts per thousand (5 ppt).

Nitrite causes a disease known as 'brown blood' disease. Haemoglobin joins with nitrite to form methaemoglobin. This prevents the blood from transporting oxygen, not unlike carbon monoxide toxicity in humans. Fish can usually cope with nitrite levels up to 1 ppm or 2 ppm, however nitrite and chloride are taken up by the same mechanisms in the fishes' system. Professor Claude Boyd, who is recognised as a world leader in warm water aquaculture, says if you get a lot of chloride relative to nitrite it blocks the uptake of nitrite. USA catfish farmers will add salt to the ponds to prevent 'brown blood' disease by maintaining six times as much chloride as nitrite. As the nitrite is measured in parts per million you wouldn't need a great amount of salt, unless of course you have a great amount of nitrite.

The authors aren't sure how this would be regarded in our salt-degraded inland, but it is possible in re-circulation systems, especially where the exchanged water is not going to be used in hydroponics or horticulture. You may even have small amount of sodium chloride in the water if you are farming in a saline basin. However, before anyone suggests that some of our saline basins would have an advantage in this area, it would be best to consider all the factors impacting on aquaculture production before investing in an inland salt lake on that basis alone.

The methods of passively removing organic solids in suspension are:

- drum filters
- screen filters
- settlement tanks
- swirl filters
- sand filters
- disc filters.

Drum filters

Drum filters consist of a mesh drum of a very fine screen size, usually between 35 μm and 75 μm. The water from the production tanks gravitates to the inside of the drum where the solids are separated. The water passes back into the system for further treatment and the solids are flushed off the screen and out of the system on a pre-set

Figure 11.8. A pair of drum filters in a re-circulation system. The organic solids in suspension are removed and the water is returned to the system.

mechanism or triggered by a rheostat that measures the amount of light obstruction by the material on the screen. This is a very efficient and probably the most commonly used method of PSR.

Screen filters
Screen filters are a static screen and pads, or series of screens and pads, that allow the water to run through them. Unlike the drum filter, they have to be removed and cleaned manually as part of the regular maintenance of the system. Anyone who has operated a system relying on filter pads or screens for PSR will know what the warning 'wrong way go back' means.

Settlement tanks
Settlement tanks are very good but they have to be large enough to slow the water almost to a standstill so as to allow the finest particles to settle. In a large system installed in a purpose-built shed it's practical to have a large settlement tank under the production system. The sludge will have to be drawn off and flushed from the system as in the case of the drum filter.

Swirl filters
Swirl filters, as the name implies, are circular tanks into which the production water enters (under gravity) at an acute angle to the side of the tank so as to 'spin' the water in the swirl tank. As the water swirls, the particulate matter is drawn by a vortex movement to the centre of the tank where the particles settle lower in the water column and congregate at the base in the centre of the swirl filter. The cleaner water is drawn off at the upper level at a point close to but behind (in relation to the water flow) the entry point. Particulate wastes can be then removed via an outlet in the centre of the base of the swirl filter tank. This can be set to open at regular intervals or operated manually on an as-needs basis.

While some question the overall effectiveness of the swirl tank, its low installation, maintenance and operating cost makes it a cost-effective, in-line passive solid waste removal mechanism.

The authors are grateful to Lindsay Hopper of Aquasonic for the data on a swirl filter model they designed and manufactured at their Wauchope (NSW) Research Centre. Lindsay said that, to work effectively, the water in their 1m^3 swirl filter should flow at no more than 60 000 L/hr and no less than 20 000 L/hr. The bottom of the Aquasonic swirl filter has a concave slope of 5° to the centre with a 50 mm outlet point. The particle size the swirl filter is capable of removing varies depending on the particle density. Lindsay has found that particles as small as 50–100 μm can be collected, but this is not a nominal filter and is most likely to pick up larger-sized particles more effectively.

Sand filters

Sand filters are cheap to buy through the various trading magazines, but the authors would question their efficiency as a primary PSR mechanism. It is very easy to under-estimate the sheer volume of solid waste coming out of a fish production system and sand filters would either have to be very large and/or back flushed continuously, usually something they're not designed for.

Disc filters

Disc filters are similar to sand filters in that they may well be efficient at removing the few bits of dregs in a spray irrigation line but are hopelessly under-geared for the role they would have to play in a frontline PSR system.

Note: that as most of the water exchange is associated with the removal of the sludge separated from the production water, and presuming the incoming water reflects the seasonal ambience of the climate, any incoming water will have to be raised or lowered to the optimum temperature being run in the system. If the range is wide, this can be a cost consideration.

The final polish

There will be fine particles that elude your primary defences. Some operators may decide their water is clean enough at this stage and send it on to the next stage after primary PSR. While this may be OK within the operating parameters of a grow-out system, if the water is to pass over an ultraviolet (UV) light it should be devoid of any organic material in suspension to ensure maximum efficiency. There are several options by which they can be collected and removed from the system.

They are:

- up-welling filters
- sand filters
- screen filters
- disc filters.

Up-welling filters

An up-welling filter is a compartment filled with material such as bio-blocks or other medium that allows water flow but will collect fine particles that settle like dust on such material.

The water that has been through the primary PSR is introduced to the up-welling chamber from the bottom and taken off from the top. By the time it slowly rises to the top it has shed the remaining fine remnants of particulate material in suspension in the water. The chamber is back flushed when necessary, or as a part of the regular maintenance program.

Not all the water goes through the up-welling filter. The usual diversion is around 20% but it can be increased should the particular operation, such as a hatchery, require a cleaner water supply.

Sand filters

Sand filters come into their own as a secondary PSR device. The flushing intervals become manageable under the greatly reduced load and they are very efficient at removing fine particles.

Screen filters

Screen filters are either a very fine screen or fibreglass pad through which the water passes after primary PSR. While they can manage the reduced load they still have to be cleaned and the idea of a re-circulation system, or any form of aquaculture, is to reduce the labour input.

Disc filters

Disc filters will remove fine particles but unless they can be cleaned automatically they will present the operator with the task of manually checking and maintaining their efficiency.

Potential toxins in solution

The next contaminants that should be removed are the ions in solution. These are the by-products of metabolism that we have discussed earlier: carbon dioxide (CO_2) and total ammonia nitrogen (TAN). In a high stocking density situation, potential toxins can build up quite rapidly in a re-circulation system. We discussed in chapter 6 the impact they have on the biochemistry of water. The operator of a re-circulation system is saved the effort of managing plankton blooms because his production unit is enclosed and not influenced by photosynthesis. However, he will still have to monitor and manage the other side effects of producing fish.

Carbon dioxide (CO_2)

CO_2 has an adverse impact on fish in that it makes them lethargic, and lethargic fish are not productive fish. However, carbon and oxygen are both used by the nitrifying bacteria to oxidise the ammonia and their presence in the water could be seen as part of the natural process. At high levels CO_2 can be toxic but this should not happen in a well-designed system.

The usual procedure is to de-gas the CO_2 by a combination of agitation and utilisation. The same action will allow oxygen (O_2) to be dissolved in the water thus combining two operations in the one process. The most common way of achieving this result is by trickling the water over a medium such as bio-balls or bio-blocks in a tower or compartment of some kind. These devices are called de-gassing chambers or towers.

Nitrifying bacteria will grow naturally on the medium in the de-gassing chamber thus utilising the CO_2 as well as the ammonia.

The ammonia that isn't removed from the water during the de-gassing process is removed in the bio-filtration process. Some systems will run what appear to be identical towers, calling one the de-gassing tower and the other the bio-filter. The processes are so similar it doesn't really matter so let's not get hung up here on semantics. The actuality of the situation is different, as we shall see.

Probably the most important thing to consider in the bio-filtration process is the need for maximum oxygen levels. The bacteria are oxidising the ammonia nitrogen so that it becomes nitrite (NO_2) and nitrate (NO_3). This takes oxygen from the water. So much so that some operators actually oxygenate the water before it enters the bio-filter or even in the bio-filtration chamber. In this regard, the de-gassing allows the water to dissolve more oxygen, and even though it's acting as a bio-filter, the de-gassing chamber is only a preliminary step to the final nitrification process.

Ammonia

Growers use a rule of thumb that says it takes 100 m^2 of bio-filter surface area to remove the ammonia produced by 1 kg of fish food. For instance: if the system held 1000 kg of fish and they were being fed 1% of their body weight a day the system would be receiving 10 kg of food a day. Therefore the bio-filter medium would have to have 1000 m^2 of surface area to cope with the load.

There are qualifications to this rule of thumb. It presumes that the amount of oxygen and carbon that is present at the interface of the ammonia and the bacteria is sufficient for maximising the nitrifying efficiency of the bio-filter. To enable the bacteria to work at their maximum capacity there has to be some space between the medium to allow the free passage of the water. That space is called the void. A lot depends on the design of the material but generally speaking a void of 75% or better is regarded as good. A void of 90% is very good, but the bigger the void, the bigger the space required to house the medium, and in re-circulation technology space is generally insulated and comes at a premium.

Ammonia nitrogen in water is consumed by the nitrifying bacteria (autotrophic bacteria) and in doing so creates nitrite nitrogen and nitrate nitrogen. The nitrogenous oxygen demand (NOD) will draw on the system's oxygen supply. For every gram of ammonia converted to nitrate, the nitrifying bacteria will consume 4.57 g of oxygen.

Two points should be driven home from this observation. First, the nitrifying bacteria are living organisms and will have to be treated as such; not some mechanical device buried deep in your system that strips ammonia from the water. Second, they will consume oxygen from the system just as the fish do, and as such will have to be considered as part of the contribution to production. The oxygen uptake that occurs as part of the NOD works in conjunction with the oxygen uptake of the fish as part of the normal activities and metabolism, or BOD.

The above rule of thumb may sound like a lot of surface area and in one sense it is, but one of the properties of commercial bio-filtration material is its compactness. Bio-balls range from 400 to 500 m^2/m^3 and bio-blocks are around the 200 m^2/m^3 mark. Generally speaking, the smaller the medium the greater the surface area that can be crammed into a given area. Beads for instance will give around 1000 m^2/m^3 making them even more space efficient. Fluid bed filters would leave any of them for dead. They have by far the most economical surface area to volume ratio systems delivering a massive 21 000 m^2/m^3.

These are options you will have to evaluate when it comes to costs versus space versus efficiency. For instance, if you have ready access to river stones or road gravel the space you would need for a bio-filter may be as big as a house but the water will have to be kept warm, oxygenated and pumped around the bio-filter to ensure an even distribution of the water across the medium. That could turn out to be impractical. Engineering will dominate the efficiency, and consequently the cost of operating the re-circulation system. Do your sums thoroughly and weigh up all the options.

There are formulae that allow for more precise calculations. For instance Claude Boyd, in his book *Water Quality in Ponds for Aquaculture*, says, 'The major source of ammonia in (aquaculture) water is a direct excretion of ammonia by fish (Tucker and Boyd, 1985) and crustaceans (Chin and Chen, 1987)' (p. 156). The amount of ammonia can be estimated from the net protein utilisation (weight protein gain by fish – weight protein in feed) and the percentage of protein in the feed. The formula Boyd offers is:

Ammonia-nitrogen (g/kg feed) = (1.0 – NPU)
(protein divided by 6.25)(1000)

Where NPU = net protein utilisation
Protein = decimal fraction of protein in feed
6.25 = average ratio of protein to nitrogen

Values of net protein utilisation often are about 0.4 for high quality diets. Thus, for feed with a crude protein content of 28%, the ammonia-nitrogen excreted would be:

Ammonia-nitrogen excreted = (1.0 – 0.4)(0.28 divided by 6.25)(1000)

Therefore in a 10 000 m^3 system receiving 50 kg/day of 28% crude protein feed, the total amount of ammonia-nitrogen excreted daily would be 1345 g (1.345 kg).

Boyd concludes by saying: 'As long as the net protein utilisation remains constant, the ammonia production will increase in direct proportion to the feeding rate – double the feeding rate would double the ammonia excretion' (p. 156).

Fluid bed bio-filter

This device is extremely economical in space and is super efficient. It consists of a sealed tube containing very fine silica sand. Water and air are introduced into the bottom of the tube. The huge surface area of the sand provides an excellent medium for nitrifying bacteria and the air provides the oxygen to feed the oxidisation of the ammonia into nitrate. The level of the sand should allow a space at the top of the chamber from where the cleansed water can be taken off. Pure oxygen can be used to supersaturate the water in the chamber should more O_2 be needed than can be supplied by the atmospheric air.

Other contaminants in solution 1

The water being used for fish production will contain other contaminants. Many of the ingredients used in aquaculture diets will have pigments that leach into the water.

Unmetabolised proteins will also dissolve in the water. Proteins in solution, while not directly harmful to the fish in themselves, can help cultivate water-borne bacteria. The colouration is also not directly harmful to the fish and some growers claim it helps the fish to be in a murky environment. Others feel that since they've spent so much money on building a system to give them maximum control over their stock, they would be better able to monitor the impact of that control if they could see what was going on in the tanks.

If you're having trouble making up your mind about this, consider that most species grow in relatively clear water. While many of our inland rivers look turbid now, the diaries of the early settlers along the Darling talked of being able to see the cod moving around on the bottom of the river in 12 ft of water (5.75 m). Even our native inland fish evolved in clear water. The environment can always be darkened if it is felt the fish are intimidated by being crowded together.

Foam fractionator

Protein and pigments in solution are removed by a foam fractionator, or as it is sometimes called, a 'protein skimmer'. To borrow from the excellent publication *Aquatic Systems Engineering: Devices And How They Function* by P.R. Escobal: 'A protein skimmer is a hollow tube through which water is introduced while air is pumped into the bottom of the tube. The bubbles collide with the water and bombard the water droplets with a mechanical and chemical action. This action generates foam, which is collected at the top of the skimmer and discarded. The foam carries out dissolved organics and pollutants.' (p. 6.)

You may have seen nature doing the same thing on a windy day along the beach. The brown spume blown up onto the sandhills is protein skimmed from the oceans and helps nourish the coastal vegetation.

The foam fractionator works better in saline water but the authors have used them in fresh water systems to great effect. If using a particularly oily food, such as an eel grow-out diet, there will be times straight after feeding when efficiency will be compromised but they soon get back on track. Should they not be working as well as they should, they can be helped along with a harmless foaming agent available from most aquarium suppliers.

Ozone can be introduced to foam fractionators instead of air, which makes them even more effective water-cleaning devices.

A warning

The atmosphere in a re-circulation shed is by nature humid. Drawing the air from inside the shed to supply oxygen concentrators or ozone generators can cause damage to these pieces of equipment.

Other contaminants in solution 2

Unless you go to extraordinary lengths to quarantine your system, water-borne bacteria will be present. It's unavoidable but not necessarily a problem. In fact the bacteria in your bio-filtration system will be working for you.

In high density operations stress is always just a system malfunction away. It's when fish become stressed that bacteria are most dangerous. In mild doses their immune system can cope with normal bacteria loads but these normal loads can build up very quickly in the hothouse environment of a re-circulation system.

Viruses are also an omnipresent organism and under favourable conditions can wipe a grower out almost overnight once they get hold. There are medications to handle some of the common varieties of these threats but by far the easiest way is prevention. GWQEHN would tell you an ounce of prevention is worth a pound of cure.

Production water can be purified by using ozone (O_3) or running it over an ultra-violet (UV) light.

UV Steriliser

A UV steriliser looks like a florescent tube, except that it emits ultraviolet light. Avoid looking at it while it is switched on unless you're wearing protective eyewear as recommended by the manufacturer. The water runs across the UV tube and the bacteria and the viruses get zapped. However, different microbes have different levels of vigour therefore the exposure time must be long enough to destroy the target organism. The manufacturer should be able to help in this area.

Ozone

Ozone is a powerful disinfectant and will provide a suite of advantages to the grower, however, care should be taken when using it. Where it is used in a reactor any surplus ozone that is bled off the water purification chamber (reactor) should be passed through carbon. The return water should be diluted by at least 10:1 before it is returned to the fish tanks. You'll know when you're putting too much ozone into the system as the fish room will smell like your local indoor swimming pool.

Some of the benefits resulting from responsible ozone use are:

- control of aquatic parasites
- control of ammonia, nitrite and nitrate
- control of bacterial diseases
- control of algae.

Remember that the secret to aquaculture is maximising the control you have over the balance and stability of your production system. All these controls will make water quality management that much easier

The above advantages make fish healthier and happier. This is essential to aquacultural production. The use of ozone in a production system will:

- greatly improve water clarity
- improve the biological capacity of the water
- increase carrying capacity
- increase the oxidation-reduction potential.

GWQEHN says:
If you don't have the best interests of your fish at heart you shouldn't expect them to take any interest in your best interests.

Ozone generators

Without going into too much detail, ozone is manufactured from extracting oxygen molecules from the air using ultraviolet light in a sealed chamber. Ozone is a commonly used commercial disinfectant and ozone generators can be purchased with outputs to suit most aquaculture requirements. Just remember to read the instructions and warnings about its manufacture and use.

Oxygen injection

So far we've talked about removing elements from the production water; elements that are negative influences on fish production. Now we get to the point where we start adding something to the water, something beneficial.

There's not much more we can do to make the water safer for our fish, but there is something you can do to make it more productive. Remember GWQEHN said 'Oxygen + food + fish + water + management + markets = $$$$$. Don't forget the oxygen?' Well, we can add extra oxygen to the water to gain extra growth. Technically you don't gain extra growth, you gain the same growth but you get it quicker; so you're really increasing the growth rate. Oxygen can be concentrated from the atmosphere we breathe. It's present in air at a level of 21%. By isolating this 21% we can produce oxygen that is nearly 100% pure. This can then be introduced to production water to raise the dissolved oxygen (DO) levels to supersaturated levels of 200% and more.

How is this done? In Europe and the US the low cost of bottled oxygen makes it an option but here in Australia we generate our own. The generated oxygen is stored and injected into the water in a pressurised container as required. The super-saturated water is then introduced to the production tanks where the fish are being held at densities of up to and over 200 kg/m^3. Once back at normal atmospheric pressure, the supersaturated oxygen escapes from the water, but not before the fish can use it.

The authors would like to offer a warning at this point. To carry fish at extremely high stocking densities is one way of making the high capital cost of re-circulation technology work, but it is also a high risk strategy and demands good fish husbandry skills to ensure that it has any sort of chance of succeeding.

Oxygen injection should not be confused with mechanical aeration. Oxygen injection is the only way DO levels can be artificially raised beyond saturation, and that fish can be produced at densities higher than 40 kg/m^3.

Comments on re-circulation technology

Bedding in

The system, once installed, should be bedded in. There are two aspects to this. First, the plumbing side of the construction. Are all the pipes properly joined? Does the water flow at the rate it is supposed to? Do all the mechanical and electronic parts work? The other aspect of bedding in is to remove any potential toxins or pollutants from the system left behind after construction.

Fill the system with water and run it for 48 hours. Empty it and repeat the process, this time for 24 hours. Re-fill it a third time and this time put some cheap fish in it to make sure there isn't any toxic residue from manufacture or assembly left in the system.

There shouldn't be but this is a belt and braces operation. For what it's worth, young fish are more sensitive to toxins and pollutants than older fish.

Temperature control

There are many options. Do you heat the water or the air? Can you strip the energy from the operation of the system to maintain optimum temperature? Should I look for a thermal bore or similar source of water?

First, it's cheaper to warm the water than it is to warm the air. Having said that, warming the water tends to cause condensation in the shed and for that reason, where economically viable, such as in small areas like as a crayfish hatchery, it may be preferable to warm the air.

Yes, energy can be stripped from the operation of the pumps moving the water to warm it. The fish themselves will generate a surprising amount of energy, as will the bio-filtration system.

Thermal bore water or cooling water from a power station is a cheap source of energy but care should be taken to ensure that, if it's to be used in direct contact with the fish, it doesn't contain elements that would compromise water quality. Having access to thermal water is not a reason to build a fish farm. There are other economic and technical factors that are far more crucial. Heating the water is a minor cost in the overall picture. You'll be surprised how much heat you trap in a well-insulated shed from the machinery, the fish burning energy and the action of the bacteria in the bio-filter.

Finally, don't even think about operating a re-circulation system in an uninsulated shed. It's under these circumstances that the cost of maintaining a stable temperature can ruin you. If you are in the tropics and have the moderating influence of an oceanic climate you could give it a go, but the whole purpose of re-circulation technology is to ensure the balance and stability of the system.

Does it work?

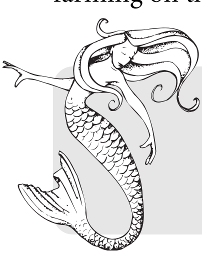
It would be fair to say that a good percentage of the people reading this book would have a strong leaning toward re-circulation technology. With that in mind, the authors feel obliged to stress that there are two aspects to it: the technical side of it and the economic side of it. First, the technical side.

The technical side is not an issue. Re-circulation technology works. It's been used to remove impurities from human waste for as long as anyone reading these pages can remember. It works in fish farms. The secret is to have enough engineering to remove all the impurities and to remember that you are cultivating two organisms in the system: the fish and the bacteria in the bio-filtration plant.

They are often called 'closed systems' and in a sense they are. Everything you do, everything you add and everything you remove from the system will have an impact. For instance, should you double the weight of fish in the system, you'll double the load on the bio-filter. That means, in simple terms, you'll have to double the bacteria in the bio-filter. That won't happen instantly. You'll have to wait for the bacteria to build up. There may not be sufficient filter medium to cope with the extra load. The same thing happens in a pond system but it happens that much faster in a re-circulation system. This form of aquaculture is even more about balance and stability.

Figure 11.9. With a life span of 20 to 30 minutes for your fish, should the power go down, emergency generation capacity is essential in re-circulation systems, or any aspect of aquaculture that is reliant on power for its aeration.

Having said that it works, the authors would like to qualify that by pointing out that *it doesn't work automatically*. There's a temptation to believe all the bells and whistles take the work out of fish farming. Assemble and just add water, fish and food. Sorry to disillusion you, it doesn't work like that. You'll still have to keep an eye on your fish as you would in a pond-based system. You'll still have to keep an eye on your water quality parameters. You'll still have to keep an eye on your moving parts and all those shiny extras associated with your you-beaut re-circulation system, including maintaining your emergency alarm and back-up system and generator. Make no mistakes; this is fish farming on the high wire. Make sure the safety net is secure.



GWQEHN says:
Everything you put in your fish production system will have a reaction. Managing that reaction is the art of fish farming.

Getting the bacteria going

Once the system is in place the next task is to get the bacteria established. Everyone seems to have their own method. Some buy bacteria cultures in a jar from system suppliers, others introduce a few fish and start to feed them. Some just put some food in the water on the premise that the bacteria are omnipresent and once fed some ammonia they will fire themselves up.

One method the authors have used successfully has been to take a clean filter pad or other form of sterile material around to someone who has a bio-filter working; someone whom you can trust to have a 'clean' environment. Leave the filter pad or material in their system for a few days so that it becomes impregnated with the nitrifying bacteria. Once the bacteria are established the pad or material can be introduced to the new system so your own colony can be started.

Another way was suggested by a student at one of the Victorian TAFE courses run by John Mosig. The student worked at a nearby sewerage treatment plant. As part of the course they had to set up a new re-circulation system. To introduce the bacteria the student suggested they take some fresh animal manure, and dilute it in a bucket of water from the system. Then they should strain the spent fibrous material from the mixture and pour the remaining solution into the tanks. It was crude but effective. Nitrification began within two days.

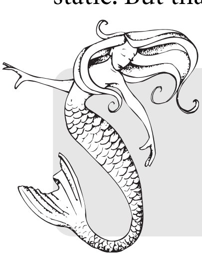
Once established the bacteria will increase in potency over the next two to three months as they colonise every available innate surface of the system.

The importance of a good quality feed

It is pointless having the best re-circulating system in the world only to clog it up with poor quality feed. Sludge costs money to remove from water as we've discussed in chapter 9. It costs money to separate, remove and dispose of. While it's in the system it costs oxygen to neutralise. On top of all that, you've got to store and handle feed that's not being turned into fish, so in that sense the exercise is a waste of time.

The economics of re-circulation technology

This is the big question everyone asks. There are so many factors involved in economic success that it's impossible to answer with any degree of accuracy. Naturally, if you're able to get substantially more for your fish than it costs to produce them, it stands to reason you're going to make a substantial profit. The cost of production is far easier to determine than the price you're going to get for your fish. On top of that the price of fish is not going to remain static any more than production costs are going to remain static. But that's farming.



GWQEHN says:
Making money out of farming is difficult enough. Farming under water is no box of birds.

The authors would like to relate two stories. Both concern visiting re-circulation technology specialists. A visitor from Europe was the principal of a major re-circulation manufacturer and supplier. He was addressing a group of potential indoor fish farmers in the mid-1990s and at the end of his talk on the workings of the technology he offered some sound advice: you should only grow a species of fish in a re-circulation system for which you can get $10/kg live weight at the farm gate. That narrows the field down a bit in today's seafood markets.

The other visiting re-circulation technology expert was from an American university specialising in this field. At the end of his discourse he threw the meeting open to discussion. One of the questions asked was: From his observations in the USA, was he able to cite any success stories? His answer was probably more revealing than it might have been at home. He said the only people he saw making money out of re-circulation technology were those folk who picked up their systems for 10c in the dollar at a fire sale.

From this it would appear that you should have assured markets, a professionally designed system with a manufacturer's guarantee and enough expertise to keep the fish alive and growing at their maximum rate.

Having said that, the authors see a role for re-circulation technology in certain areas. Hatchery systems would benefit from the pristine quality of the water and when fish are young and growing fast, as they do in the nursery stage, the growth rate would warrant the higher than normal operating costs.

Being able to grow fish out of season is the most obvious benefit and salmon growers in the Northern and Southern Hemispheres use re-circulation technology to get a jump on the season. New species, such as Murray cod, usually have a high value, but experience with new species has shown that the honeymoon market doesn't last beyond the early stages of production. Once everybody gets onto it the market soon softens. Endangered species, especially universal staples such as Atlantic cod, will have a following for a while. But once they are grown using the more economical production methods, such as cage culture, the price will come back as it did with Atlantic salmon.

Before you get too far down the track with any investment in this field, you would be well advised to talk with someone who has been operating a system for more than three years, longer if possible. This is the best source of knowledge on re-circulation technology you'll find, or on any form of aquaculture for that matter. Weigh the encouragement you receive from the local growers' association president and the Fisheries Department Development Officer against the sound advice you'll get from a practicing fish farmer on a ratio of 100:1.

GWQEHN says:
Anyone trying to sell you something, no matter how well-meaning they may seem, is a salesperson.

The technology used in re-circulation systems technology is evolving all the time. Systems are built to accommodate the husbandry of particular species. For instance an eel system might be totally different in tank design from say a jade perch system. But the real evolution is in engineering efficiencies. New water treatment technology is being developed for all sorts of applications and this can be used, where appropriate, in aquaculture.

Space is crucial in re-circulation systems technology. Insulated sheds cost money to build and money to heat, if that is deemed to be necessary. Remember that the nitrification process works better at 25°C and most of the fish available for indoor systems in Australia grow better at >25°C. Space could also become a design factor when the site is chosen. If the operator chooses to build close to a capital city market he may find the cost of factory floor space a decisive cost issue.

Many of the early systems were designed by sewerage treatment engineers whose background hadn't trained them for the very narrow cost window the seafood production industry had to squeeze its product through. Not a few of them were supported by development grants or tariff-protected markets. Less power consumptive systems are being designed and 'smart' systems that aren't over-engineered are being built. Re-circulation technology is here to stay. How we use it will determine the economics of it.

If you want to see the evolution of an idea, invite yourself into the office of a well-established trucking operation and have a look at the first truck the managing director drove with a 12 tonne payload from Melbourne to Sydney on a Hume Highway that was a two-lane death trap and then have a look out in the yard at the rigs that move 40 tonnes of goods at a time. There's no reason this evolutionary process isn't happening right now with re-circulation systems technology. You'll just have to decide where it is and where you want to join the process.

Building your own system

Among the readers of this book, there'll be some of you who want to build your own system. To build a commercial system is an enormous project, no less complex than building a car in many ways, and the authors hope that the above will be of some help. However, there's another aspect to the economics of re-circulation technology, and that's the engineering.

Everything must be in balance. Water flows are crucial in exposure time to each process. For instance the PSR and the bio-filtration are the basis of the operation. The rotation time, the time the whole volume of the system goes through the mechanical and de-nitrification process, is crucial. Every drop in the system will have to undergo these procedures as often as is necessary in relation to the stocking density and the amount and quality of the food being fed. Some systems exchange their entire water volume every hour. It certainly shouldn't be any more than every two hours at commercial stocking rates. The other procedures, such as up-welling filtering and UV treatment might only cleanse 10% of the water in the same base period. There are too many variables to deal with in the context of this book and the authors suggest that anyone going into building a commercial system should arm themselves with a source that divulges the formulae that govern each process.

GWQEHN says:
Whether you build a string of open ponds or a re-circulation system, it's imperative that you get the design right. If you don't, you're beaten before you start.

12

Aquaculture hardware and infrastructure

In this chapter we'll be discussing what kind of equipment fish farmers need for a successful aquaculture operation. The main topics will cover:

- essential equipment
- beneficial equipment
- harvesting and fish handling equipment
- essential infrastructure
- aerators, feeders and fish graders
- transport
- data handling.

Hardware is the equipment used on a fish farm to assist the operator to produce a crop. It can be divided into two categories. Into the first falls the equipment growers can't do without; and into the second falls the equipment that they could do without, but the immediate and manifold benefits provided by its use should lead them to consider its incorporation.

Infrastructure is the shedding, transport and holding/purging systems used on the farm. In most cases they are an integral part of the farm's operation and growers don't have a lot of choice in what they can do without and what they can acquire later. If you've tried to run a grazing property without a set of yards, you'll know what I'm talking about.

Hardware the farmer can't do without

Water quality measuring equipment

Equipment is needed to measure water quality. No one can tell you the invisible qualities of water without a meter or reagent test kit. After a while you'll be able to take an intelligent guess, but you'll still need something to verify the guess. Operating a fish farm without water testing equipment or a microscope is the equivalent of driving our imaginary aquaculture vehicle up the Birdsville track without gauges and instruments. If you don't have a temperature gauge, you won't know you've broken a fan belt until the motor seizes.

Equipment used to determine water quality is simple to use once you've used it enough. You should practice with the equipment until it becomes second nature to you.

Test kits

Test kits are generally not too complicated. The farmer mixes a sample of water with a reagent, and watches for a colour change in the mixture. Most people are familiar with a litmus test, in which a treated strip of paper is inserted into the fluid being tested. If the paper turns orange to red the pH of the water is low (acidic). If the liquid is alkaline the litmus paper turns blue. In aquaculture testing the same principle applies and the degree of colour change after mixing the chemicals with the water is measured against a colour chart to give a reading. There are test kits specifically designed to measure most of the compounds in water that a farmer is interested in.

Test kit reagents are made up of chemical compounds, some of which may not be stable over a long period of exposure to extremes of temperature (for example living on the back ledge of the ute all summer or on the shelf in the corrugated iron pumphouse). The usual storage obligations apply: keep your testing chemicals in a cool dry place out of the sun. You can just about test for the presence of any chemical by titration but the parameters we're looking at in aquaculture are:

- TAN
- nitrite
- nitrate
- carbonate hardness
- general hardness
- phosphate
- iron
- calcium.

Meters and probes

Other elements crucial to aquaculture production are pH and DO. Both can be tested by titration, but it is far easier and in the long run less expensive to monitor these parameters with calibrated instruments. They consist of a meter connected to an electronic probe that measures to resistance of the particular element being monitored. The meter translates the impulse to a reading on the face of the probe, either analog or digital. As long as the probes are maintained and the meter regularly calibrated as per the manufacturer's instructions, the instruments will provide an accurate and instant reading of the pH and DO in the system.

Some meters are constructed to give multiple values. For instance, one popular maker offers a pH meter that also provides electronic conductivity (EC), total dissolved solids (TDS) and temperature. It sells for more than twice the cost of the standard model that reads pH only. You will have to assess what you really need before investing in meters because, a bit like walking into a camera, computer or fishing tackle shop, you get seduced by the power of technology and often walk out having spent more than you wanted, or, more to the point, needed to. Assess the real value before you rush into multi-value meters.

There are probes that report their impulse to a remote control panel that will trigger an automatic reaction to a parameter outside the optimum range. For instance: should the oxidation-reduction potential (ORP) fall below a pre-determined level, the ozone generator will switch on. The message, with the wonder of modern electronics, can also be connected to a terminal so several sites can be monitored and controlled from a remote workstation.

Generally, meters outlast the probes. Probes may eventually pack up and will have to be replaced. They wear out, just like tyres on your car. Should they become unstable, return them for testing and if they've had it, order a replacement.

The life of the probe will vary from manufacturer to manufacturer. Mistreatment shortens their working life. For instance: you should always keep the probe of your pH meter moist (they tell you this in the instructions if you bother to read them). Manufacturers will provide you with an airtight cap to go over the probe but moisture will dry out if the probe is stored for long periods.

One thing that should be remembered is that, although your scientific instruments are your tools of trade, they are still sensitive scientific instruments and require care. Get yourself a carrying case of some sort and pad it with sponge rubber to absorb any shock. The box and sponge will also insulate against extremes of temperature.

As their purpose is to be used around water, meters are usually moisture-proof. This doesn't mean waterproof, although some of them are so well sealed that they may survive a quick dunking. However, play it safe and don't let them fall in water.

TAN can also be measured by an electronic impulse, but the cost of the meter is beyond the budget or need of a normal fish farm and it is rarely seen outside the laboratories of training or research establishments.

A maximum–minimum thermometer is another scientific instrument that will allow you to monitor the range of water temperature in the system over any given period.

Some measuring equipment, like a plankton net and a Secchi disc, are dead simple nuts-and-bolts or sheet metal affairs. Their simplicity generally means they are robust, but like any useful tool, they should not be abused.

Cost of testing equipment

The cost of equipment can be off-putting at times. Many people starting up put off the purchase of these intricate parts of the fish farm 'until I get a bit of money out of it'. The harsh reality is that they never 'get a bit of money out of it' because they don't have the equipment. You wouldn't buy a car without instruments (nor is it legal to operate one without at least a speedometer). So why would you cut costs on your aquaculture venture?

A basic set of water-testing kits including a 20/40 power binocular microscope can cost around $1000 to $1500. A more sophisticated set shouldn't cost more than $5000 including $1500 for a 100 power microscope.

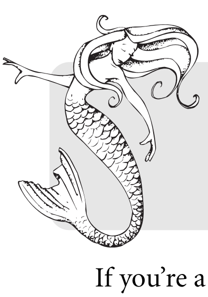
It could be argued that you could use the $1500 to buy 7500 fry at 20 cents each and that maybe the money is better spent on livestock. Trouble is, you can lose the fry too easily if you don't invest in water and fish health monitoring equipment. If you have 7500 dead fish, you have to spend the money again to replace them: if you spend the money on equipment, you have the hardware for as long as you take good care of it. It's a small investment to protect your stock and increase your productivity.

Interpretation
There's no point in taking all these readings if you don't interpret what they mean to you in terms of fish safety and production outcomes. Plot the readings and use the results to compare outcomes under differing circumstances and differing husbandry and nutritional regimes.

Care and maintenance
One of the biggest shortcomings seen amongst new fish farmers is their lack of confidence in their apparatus. Meters and test kits can be sensitive pieces of equipment and a full understanding of their handling and servicing requirements should be obtained from the supplier. *Read the instructions.* Rocket science isn't required to calibrate any of the instruments used in aquaculture but for some reason people don't seem to persevere. It's tempting fate not to be able to know the DO, pH and TAN readings at any given time. Your system might be running on four out of six cylinders without you knowing it! The fish could be living under low or even medium stress levels with the consequential loss of production unless you're able to monitor the water quality parameters.

How do you become confident in using your instruments? Familiarise yourself with their use by reading the instructions and practising. Sounds familiar? If, after your orientation program, you are still unsure of a particular instrument call the supplier and have a chat about your problem. A good supplier will be only too glad to back their product with some after-sales service.

A little bit of local knowledge might help at this point. Water chemistry changes in fish and crayfish ponds follow a loose pattern rather than a fixed one, and many people become uncertain about their readings because at times they can be all over the place, and vary from one pond to another, or even one tank to another, depending on stock densities and water flow. The variation is why you're taking the readings in the first place. Develop confidence in your ability to calibrate, maintain and operate your instruments so you have confidence in what they're telling you about your water quality parameters. You might like to take the instruments with you when you visit other growers, so the two of you can compare readings and instruments. It's all good practice.



GWQEHN says:
It is not necessary for the water in two adjacent ponds to behave in the same manner even though they have been operated in an identical manner.

If you're a member of an association there'll be other growers who have had the same experience as you in learning to know and love their pH and DO meters. You may even suggest a workshop and invite the local Extension Officer along to add their experience.

Growers who have been in the industry for a while will also have a good idea of the more robust and stable brands on the market.

Whatever you do, persevere. You have to be able to operate scientific instruments if you are going to successfully manage an aquaculture system. Using instruments is even more crucial if you're running fish in a re-circulation unit where stocking densities will be much higher than in a pond and things will happen more rapidly, and with much more at stake.

You might have the flashest meters in the world, and they might look real good on the mantlepiece, but they only have value in so far as they enable you to measure key water quality parameters. In practice, farmers use a mix of meters, test kits and mechanical aids. What they opt to use is determined by the relative importance of the water quality parameter, the scale of the operation and, to some degree, personal preference.

Dissolved oxygen

Oxygen is life, yet we as air-breathers have almost no natural way of telling how much oxygen is present in water.

Almost everybody measuring dissolved oxygen uses an electronic DO meter with probe. The DO meter measures the amount of DO in the water, which will tell the operator how much oxygen is available to the pond's biomass at any given time.

With a DO meter, choose a reliable supplier and a warranty-backed brand. As for most things in life, you get what you pay for.

pH

The acid/base balance of water, like the DO, will vary considerably with pond conditions. Under the circumstance of a rich plankton bloom, the pH can be extremely high during the middle of the day only to fall dangerously low during the hours of darkness.

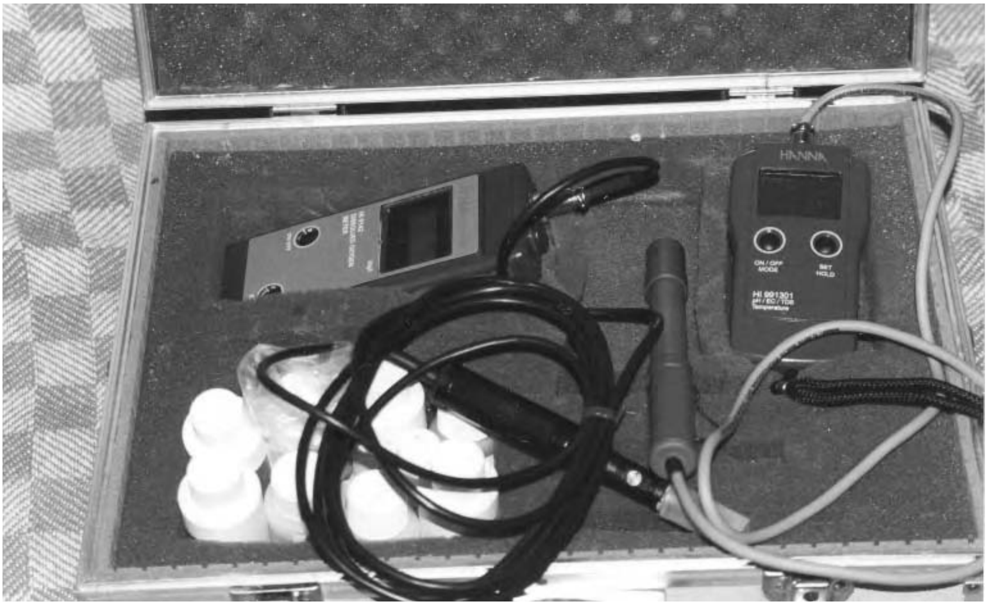


Figure 12.1. DO and pH meters are essential parameter measuring aids that will pay for themselves a thousand times the first time they save a crop.

This will influence the amount of toxic ammonia that is present in the pond. For this reason alone pH should be monitored.

Aquarium shops sell test kits, usually complete with jar and colour reference sheet. These are cheap and convenient, but the small size of the bottles and a propensity of reagents to go off after a while make them impractical for long-term use in commercial aquaculture.

In serious aquaculture, almost all measurement of pH is undertaken with a dedicated pH meter, and the reading obtained will tell the operator to what degree his water is acid or alkaline.

Ammonia, nitrite and nitrate

Overstocking or insufficient water quality management and/or engineering will lead to a build-up of ammonia in systems and, although sound management procedures should eliminate the need for concern in this area, ammonia, nitrite and nitrate testing will quickly identify any shortcomings.

Meters that measure the concentration of ammonia, nitrite and nitrate in the water are terribly expensive. Few farmers make the outlay.

A farmer can measure ammonia nitrite and nitrate by means of a test kit. The kits can range from the simple test kits on offer at the local aquarium suppliers, which are inexpensive and simple to use. More expensive kits can be obtained from aquaculture suppliers.

Another alternative is to opt for one of the more sophisticated electronic photometers. They are far more expensive but give readings of laboratory accuracy. As is the case with scientific instruments, you get what you pay for.

Hardness and carbonate hardness

Hardness testing will give you the total hardness of the water: mainly calcium, magnesium and sodium. Carbonate hardness testing will give you the alkalinity of the water; or more importantly its acid-binding capacity, the water's ability to buffer against pH swings.

Most farmers opt for test kits to measure hardness and carbonate hardness.

Phosphate, iron and calcium

There aren't too many elements that can't be identified in water, however, there's the time spent testing for these elements as well as the materials used that add to the cost. Phosphate will build up in ponds being driven hard for plankton and detritus production. Iron and calcium are only a problem under certain regions.

Again, most farmers opt for test kits.

Secchi disc

Turbidity (lack of clarity) can give us an idea of the extent of a plankton bloom. (The plankton can be masked by inorganic turbidity, that is suspended silt, and this has to be considered in the calculations).

The favoured instrument for measuring turbidity is a Secchi disc, which can be made on the farm with scrap materials. A Secchi disc is a plate divided into black and white sectors attached to a rod calibrated in centimetres. It is lowered into the water

Figure 12.2. A simple farm-made Secchi disc.

until the disc disappears from view. The depth at which this occurs is the Secchi disc reading.

Plankton net

Plankton sampling is an essential part of any operation that relies on natural food.

Sampling plankton requires another nuts-and-bolts piece of equipment. A plankton net is used to collect samples for analysis. The size of the mesh in the net will determine the minimum size of the plankton collected.

These nets can be the simple hand-held aquarium model or the more sophisticated air-sock variety that can be thrown and towed back to shore. The hand-held variety can only be used to collect samples at the edge of the pond, from a boat or by wading through shallow ponds such as crayfish ponds. The air-sock type can be used off the bank or from a boat.

Plankton analysis

Plankton monitoring can be taken a step further by separating the plankton by size. This will also make species identification and breeding virility easier if you find it necessary to do so to improve productivity. By straining the sample through a series of sieves of ever-decreasing mesh size, the plankton can be broken down into size cohorts. The series of nesting sieves are called an Endacott sieve. It's not something you'd do on an everyday basis unless you were monitoring food for fish larvae. The mesh is measured in microns (thousandths of a millimetre). (See section on plankton production in chapter 8.)

Figure 12.3. Bruce McInnes of Wartook Native Fish Culture demonstrates plankton sampling to students from the University of Ballarat course in one of his fry production ponds with an 'air-sock' type plankton net.

Microscope

A microscope is an essential piece of equipment. It allows you to study micro-organisms that are in your system and on your stock. It is not possible to farm scientifically without a microscope. While husbandry may be an art form, fish farming is most successful when methodology is supported by scientific evidence.

A 20 to 40 power microscope should be powerful enough to cover most eventualities but sometimes you may find you need to go up to 100 power. (The power of a microscope is the number of times the item being viewed is magnified.) 20/40 power microscopes are binocular, which means they have two eyepieces. They come with removable eyepieces of 10 power magnification, that can be replaced with a higher power should the magnification need to be increased. The bottom part of the instrument has a rotating barrel with a 2 power lense and a 4 power lense. The area to be examined is normally top and bottom lit. That means you can look at the object from the top or have it silhouetted from the bottom: a bit like an x-ray.

Notebook and diary

Don't laugh. This is an essential piece of equipment and the best money you will spend. The reality is, if you don't write it down, you don't remember! Everyone should carry a notebook to record events and observations. Information should then be transposed to the relative diary: the pond diary, the fish room diary, and so on. There is no way you can run an operation without accurate and meaningful records.

Harvest and fish handling

Harvesting equipment

Let's face it: you're not going to make a penny until you get the little blighters out of the water. We'll be talking about the application of harvesting gear later, but we'll just mention it in passing here. Nets and traps are an essential part of any fish farming operation and their cost can be a surprise when the grower sends out the dimensions required for a quote. Don't leave it out of budget calculations.

Fish handling gear
While it shouldn't be, one of the biggest costs in aquaculture can be labour. Anything that reduces the cost of labour is a valuable asset on the farm. Harvesting is a big cost area and we'll be looking at that in chapter 17. As well as nets and traps for harvesting you'll need containers to handle the fish during and after the harvest. Their cost will set you back a bit too. Make sure you allow for them.

Prawn crates
Prawn crates have become a standard piece of handling equipment on crayfish farms. They have several advantages. They conveniently weigh a kilo, so crayfish can be weighed and the weight of the containers easily deducted from the gross weight, or the scales pre-set to allow for the tare of the containers. They are made of an open plastic material that allows a good flow of water in either a spray room or in a tank of aerated or flow-through water. They nest for storage and have become standardised throughout the industry so they are interchangeable with other crayfish growers.

Oval meat tubs
Oval meat tubs are a handy carrying container for small fish in water such as larvae, fry and fingerlings. They are also handy for handling broodstock. They are robust and have carrying handles. Other sorts of tubs can be used, many of which may be less expensive than the oval meat tub, but for all-round value and convenience it's difficult to go past the old standby. In fact one of the authors still uses one of the original bins he bought 20 years ago to keep the drinks cold at family BBQs.

Fish bins
The standard container for fresh, chilled fish is the fish bin. They have drainage slots at the corners to allow thawed ice to drain out. They, too, are robust and universal.

Pumps

There is no way you can do without pumps in an aquaculture situation. You can find any number of suppliers, all with performance charts and power loadings. Look for volume not pressure, and don't overlook cost efficiency, especially if you're looking at pumping water continuously as you would in a re-circulation system.

Infrastructure the farmer can't do without

Infrastructure is the shedding, transport and holding/purging systems used on the farm. People thinking about the aquaculture industry don't generally look at shedding as part of the farm, but it's as much a part of your fish farm as your ponds or re-circulation system. It really shouldn't be left till later.

Feed storage room

Aquaculture feed is expensive. On a properly run farm it will be the single biggest expense incurred in the production of the stock. It is also a key driver of the efficiency of the farm: poor quality feed will give poor results. It is important that feed be kept as stable as possible in a cool, dark, dry place free of vermin. Aquaculture feed has a strong aroma and will attract unwanted guests from all over the district. Excessive heat will also hasten the breakdown of vital nutrients. Some of the farmers in the tropics find it necessary to hold their feed in cool rooms, and maintaining stability is a cost they just have to bear.

If you are planning to store large parcels of feed, you would be advised to consider a silo.

Stock handling room

The stock handling room is the pivotal point of the fish farm, a point that should be considered when planning the layout of the farm. It is here that the fish are purged, quarantined, graded and inspected. The floor plan will vary to suit the species being farmed, the management style, and the scale and resources of the operation.

Crayfish purging room

Also called the 'drip room', 'spray room' or 'wet room'. This is really essential to a crayfish farm as it allows the grower to be in charge of quality control and to time his market entry to some degree. When the crayfish come in from harvest they should be salt dipped and held for purging (to empty their guts) for at least a few days before they go out. This room has to be efficient.

Some growers favour a room in which the water sprays over the prawn trays full of crayfish before it is recycled. Others favour holding the crayfish in trays in tanks of water that is either recycled or flows through to some other use on the farm.

Crayfish handling area

Crayfish don't like bright light, being exposed to excessive temperatures or being in windy situations. Avoid grading on the pond bank if possible, especially in the heat of the day. The crayfish may not complain but deep down inside they are distraught. The ideal working area would be sheltered floor space right next to the purging room to create a comfortable area in which to wash, grade and pack stock. This usually involves a dry area with tables and benches. There are some excellent examples around the industry and you should come across at least one as you move about on your aquaculture journey. Getting to see this sort of facility is another good reason for joining a growers' association.

Finfish handling area

The finfish handling area is the place where stock are graded, purged, weaned and inspected. Finfish can't be held out of water the way crayfish can so the fish handling area will need to have tanks, water and aeration. Ideally the room will be relatively temperature-stable but it's not essential, as long as the water's not exposed to extreme temperature swings. Above ground tanks are more susceptible to ambient temperature changes.

As with crayfish handling set-ups, there are many good examples around the industry from which to draw inspiration.

Equipment the farmer can do without, but would be beneficial

There is a fine line between essential equipment and equipment that the farmer would gain an immediate benefit from but can get by without.

Aeration

The first handy set of equipment that springs to mind is aeration gear. While it is possible to operate a fish pond without aeration, it is very difficult to operate intensive cultivation or achieve commercial yields. The rule of thumb figure used in the US catfish aquaculture as the absolute maximum amount of food that can be introduced to an un-aerated pond per day is 40 kg/ha. Even in that case, feeding is undertaken under experienced and watchful management. If the food conversion ratio (FCR) of the fish were an inefficient 2:1, which without aeration it could be, and the specific growth rate (SGR) is 1%, then the greatest amount of fish that could be safely maintained per hectare would be 2000 kg/ha. Even at an FCR of 1:1 the amount of fish a hectare can carry only rises to 4000 kilograms. Silver perch have been raised at the NSW Fisheries Research Station at Grafton at nearly 12 000 kg/ha, which tells us that if you don't have aeration, there is a lot of potential bio-space to have in a system (which costs the same to build regardless of the amount of stock it holds).

We've discussed how vitally important dissolved oxygen is to aquaculture production. The closer to saturation you can get the DO levels, the nearer to maximum production you will be able to operate the system. High DO levels can be maintained by rotating the water in the system, as in re-circulation technology, or by aerating the water in the system, as is the normal practice in open pond systems; or by a combination of both.

Aeration serves five main purposes. It:

- oxygenates the water;
- de-stratifies the thermal layers that will otherwise build up in the system;
- de-gasses unwanted compounds such as carbon dioxide;
- creates a current in the system, eliminating dead spots (it has been found that fish, especially native species, are more active in water with a bit of current in it);
- brings fresh oxygen, in the case of pond-based farms, to the substrate where all the rotting organics, such as dead fish, dead plankton, uneaten food and faeces, settle. This will ensure the bacteria cleaning up the substrate have plenty of oxygen to drive their non-stop effort.

The rule of thumb for aeration on commercial ponds is to have 10 horsepower per hectare.

All commercial aerators are electrically driven. However, water and electricity don't mix and care should be taken when installing, operating and particularly when maintaining them.

There are as many aeration devices as there are manufacturers who have turned their hand to making them. The volume of water aerated and moved is determined by the amount of horsepower available, coupled to sound engineering. Manufacturers will have performance graphs outlining the benefits of their particular product, such as how

Figure 12.4. Aerator manufacturers compete for buyers' attention at an aquaculture conference and trade show in south-east Queensland. In the foreground can be seen a propeller-driven water lifter while in the background an air injector is at work.

much dissolved oxygen their model will put in the water each hour. The usual rules apply: you get what you pay for. Check around to get an idea of the reliability of the aerator and the supplier.

Aerators utilise a variety of principles to get air into water. Let's look at some of the options.

Paddlewheel aerators

Paddlewheel aerators are regarded as the most cost-effective method of getting oxygen into the water while, at the same time, ensuring the other four targets listed above are met. As the name implies, a paddlewheel aerator has a set of paddlewheels mounted on floats and driven by an electric motor. Their output is designated in horsepower. All things being equal, a 2 hp paddlewheel aerator should generate twice as much oxygen as a 1 hp paddlewheel aerator.

Oxygen is dissolved in water very easily up to its saturation point. All that needs to be done is to break the water tension at the surface. By throwing a spray of water into the air, the paddlewheel breaks the water surface of the pond into trillions of drops. These drops increase the exposure of water in the pond to the oxygen in the air. Imagine the surface area of a drop of water compared to its mass.

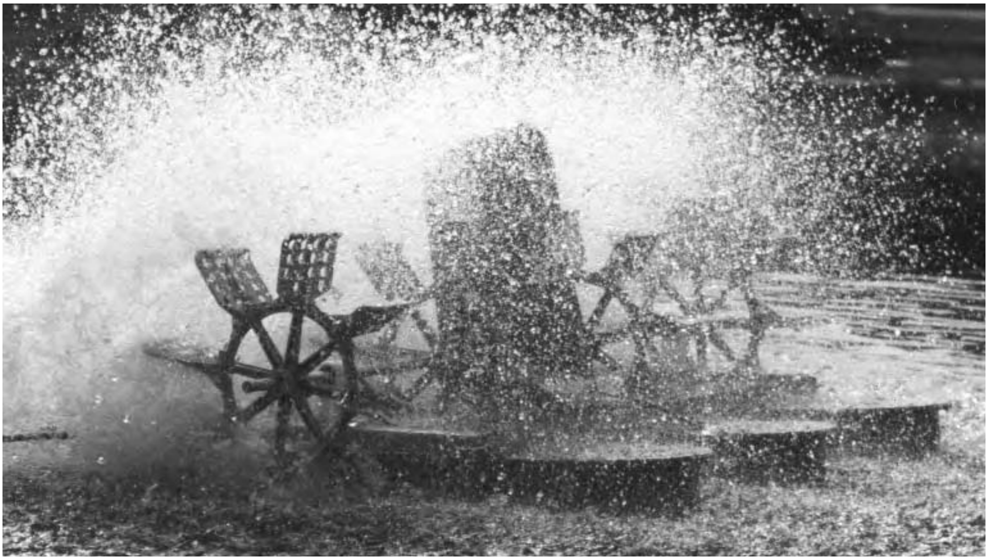


Figure 12.5. Paddlewheel aerators throw a continuous spray of small water particles into the air where the droplets interface with the atmosphere. This process allows the water to expel carbon dioxide and take on oxygen up to saturation level.

Air blowers and air injectors

Air blowers or air injectors, not to be confused with oxygen injectors, are set on floats and anchored in the pond just like a paddlewheel aerator. They are driven by a motor connected to a shaft with a flange mounted at the bottom end of the shaft. The shaft is set in a tube, and is shaped not unlike a grain auger. The shaft and tube sit well down in the water at an angle. As the motor spins the shaft, water is pushed away from the tube

Figure 12.6. Simple farm-built devices are just as effective and will be a lot cheaper to build. However, a warning: it's not that water and electricity are bad mixers; the trouble is that they are very good mixers. Any electrical short that finds its way into the water will electrify the water which can be fatal to humans.

and air is drawn in through the top. This forms a lot of fine bubbles that are pushed down into the water column.

Air blowers look impressive but test have shown them not to be as efficient as the paddlewheel aerator in keeping DO levels up during the night. There's not much in it, but the air blower moves more water and in this role they are more efficient than paddlewheels. Some growers, prawn farmers for instance, will use both types using the air blower to stir the water in order to keep organic particles in suspension during water exchanges.

Air diffusers

Air diffusers pump air along a polypipe into a pond where it escapes along a porous hose of extruded material. You may have seen the porous hose at your local hardware supplier labelled 'leaky hose'. Some growers spend time drilling fine holes in polypipe then connect the drilled pipe to the polypipe delivery line. If you've got a lot of ponds to cover it can be a laborious job.

The rising air bubbles create an upward movement in the water and this creates a current as water moves in from the side to replace the rising water. The air bubbles exchange oxygen and break the water tension at the surface where de-gassing occurs. It is by far the least efficient of the aeration options but has one advantage: the power source and the pump can be some distance from the ponds and the pressurised air can be piped to the ponds over the intervening distance. This can be much cheaper than reticulating electricity. The downside is that when air diffusers are not in use, the porous hose tends to be colonised by bacteria and algae, which clog up all the holes.

Oxygen injection

At the high-tech end of the scale is direct injection of pure oxygen. It can be injected under pressure, with the result that the water is supersaturated with the gas.

Oxygen injection is used in very intensive aquaculture, such as intensive re-circulation systems or hatcheries. It is amazing the density of fish that can be held in water with oxygen injected into it. Sometimes it looks as if there are more fish than water!

Having a source of oxygen may have other benefits. The following spin-off is not an established medical fact, but one of the authors has noticed that a short snort of oxygen seems to do wonders for a hangover.

Water-lifters

These devices lift water from the bottom of the pond and bring it tumultuously to the surface. In some cases the lifting mechanism is air. Air is pumped down a pipe and released in a spray of bubbles at the bottom. As the air bubbles rise they bring the water in the pipe with them to the surface; hence the name 'water-lifter'.

Air-driven water-lifters can be built on the farm using everyday materials like black poly and PVC pipe. The advantage of water-lifters over air diffusers is that you don't have to lay down lines of porous hose along the bottom of the pond five or ten metres apart. Water-lifters are an inefficient way to maintain DO levels and achieve the other benefits of aeration but they do have some distinct advantages, not the least being the low cost of installation. These kinds of devices are generally used in small areas, for example in a crayfish nursery pond under an igloo, where the violence of the more efficient paddlewheel and air blowers would be too severe.

Another form of water-lifter is a submersible motor set in a float. At the top of the submersible motor is a propeller that sits just below the surface. When the motor is switched on, the propeller spins and draws water from the bottom, flicks it into the air, from where it tumbles back into the pond. The exchange generated by the propeller is far greater than an air-lift, but is not as severe in action as the paddlewheel and the air blower.

These propeller-driven devices are used to provide aeration in small areas such as in channels delivering water that is being recycled to the ponds. Farmers employing a flow-through system may use the water for more than one pond and, as it travels from one to the next, the water is rejuvenated in the channel by aeration. This is used where the cheaper approach of creating a waterfall is not an option due to insufficient fall of the land or to increase the carrying capacity of the farm. It is also used when conditions are stressful to the fish, such as temperatures nearing or beyond the critical limits, particularly during an El Niño event.

Outboard motors

Outboard motors were the old standby of the pioneer fish farmers. When the DO levels got low the duck punt would be floated on the pond and nosed into the bank with the outboard running. The outboard propeller would move water around the pond. This approach was crude, but effective in an emergency, however, you would need a duck punt and motor for every pond!

P.T.O. attached paddlewheels

P.T.O. attached paddlewheels can be built to fit on a tractor. When the DO levels get low the tractor can be backed up to the ponds and the power take-off engaged. You can drive a very large paddlewheel with a 100 hp tractor, but again you'll need one for each pond if you have plankton blooms in each pond at the same time.

Feeders

Feeding out equipment

The simplest way to feed is to do it by hand. Feeding by hand has three major advantages: the equipment required is cheap; it gives the farmers the chance to observe their stock; and it is extremely restful to the operator. On the downside: it takes time; and it can get boring if you've got one of those minds that doesn't allow you to stop and smell the roses. It may also be that the labour-unit cost of handfeeding is too high, and a more efficient method of getting the feed to the fish would benefit the overall management of the farm.

The mechanical options are to deliver the feed from a mobile mechanical feeder such as a feed blower, or to place automatic feeders on the ponds or tanks.

Feed blowers

There are trailing or linkage mounted spreaders or blowers that you can whistle around the ponds with in next to no time. You can make one or look at the proprietary lines that are available, or if you are mechanically minded you could convert an old fertiliser spreader.

Automatic feeders
Another mechanical feeding option is to have automatic feeders set over the ponds, cages or tanks. These can be timed to deliver a given amount of feed at set times. Some species will learn to trigger a release lever that will enable them to feed on demand and there are self-feeders designed and built for this purpose, although these systems fell out of favour when it was found that some fish triggered the feed release lever to relieve boredom, rather than to get something to eat.

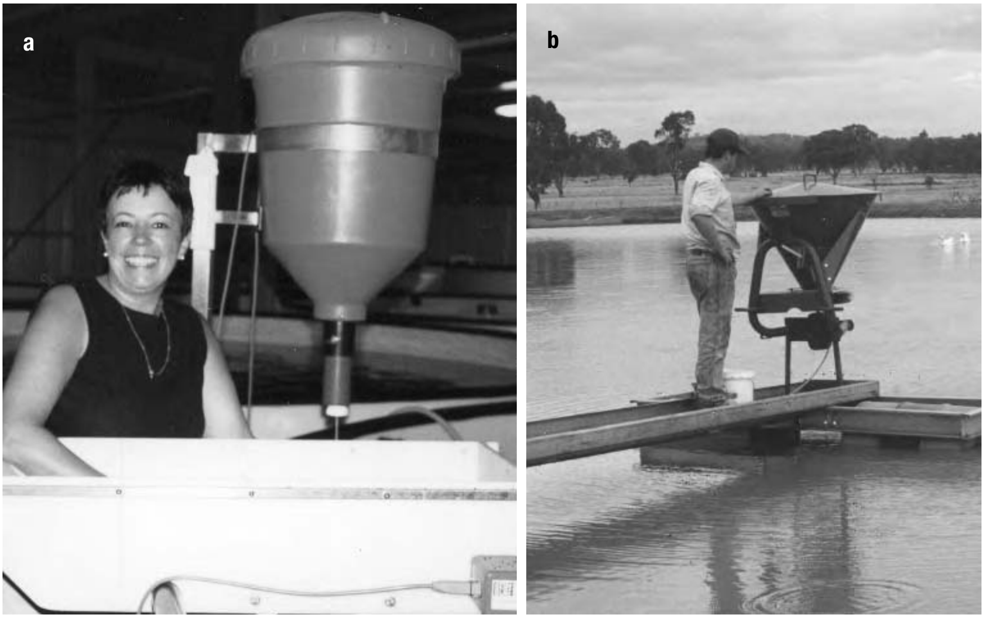


Figure 12.7. (a) Automatic feeders are popular in indoor situations away from the elements. (b) Automatic feeders can be used on open ponds and can be manufactured on site with the usual amount of farming ingenuity.

Automatic feeders have had a mixed reception. They have worked well indoors on re-circulation units but have been found to clog up in an open pond situation. The timing of when to deliver food is also crucial and must be set to match the feeding habits of the species being grown, as well as the feed requirement of the biomass in the pond. If the feed input doesn't match the biomass in the pond, the result will be under or overfeeding. Underfeeding will see a loss of production as the dominant fish will hog the food and the others will fall away. Overfeeding will load the water column with excess nutrients, degrading water quality.

Fish graders

Fish graders are devices that automatically sort fish into predetermined size groups. Graders range from a box-like arrangement with slats that can be adjusted to grade fry and fingerlings, costing a few dollars, to large contraptions for sorting 2 kg and 3 kg fish, that are so big they have to be wheeled around the farm behind a tractor. A state-of-the-art model with everything that opens and shuts can cost tens of thousands of dollars.

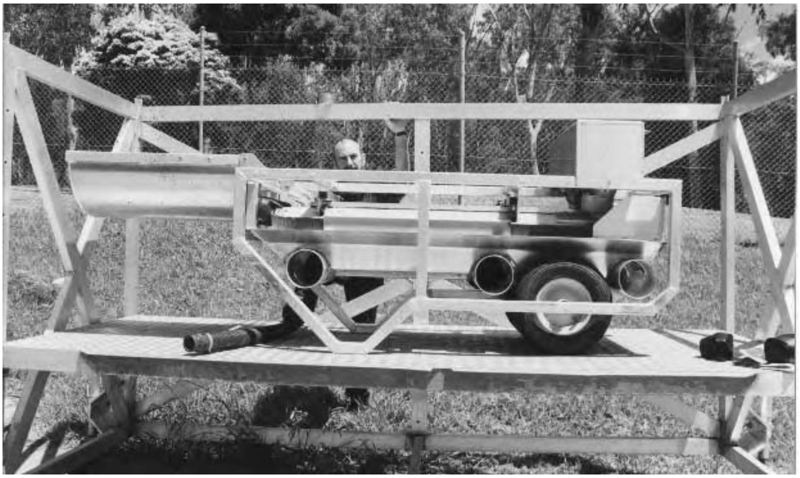


Figure 12.8. Fish graders come in all shapes and sizes. This one can grade three sizes.

Fish graders make the task of sorting fish or crayfish by size so much easier. Even with mechanical assistance, grading is a big task and it can be as stressful on the fish as on the operator.

Crayfish grader

Crayfish grading can be done by hand and a good operator can do 100 kg per hour. Sorting by hand is good because it gets you handling crayfish and makes you more familiar with your stock, but it can be a boring and a grader will make things easier. Crayfish graders work on the same principle as finfish graders: stock are put through a series of sieves (usually parallel bars). Crayfish tend to hang on to each other but if the grader has a spray of water running over it, and the operator doesn't startle the animals, they will go through the grading bars without much trouble. Having several graders working at the same time hastens the job. They can be made on the farm.

Transport

All-weather vehicle

This is one of those items that could have just as easily been listed as essential. By not having 24-hour vehicle access to the ponds you could be placing a lot of pressure on staff and operators who have to slog around pond banks too wet and slippery for a conventional vehicle; or losing a market advantage by being kept indoors waiting for the ground to dry when other growers are busy harvesting for market. If you distribute your feed by vehicle you would also be losing production.

Regardless of the weather, fish have to be fed, monitored and harvested; equipment has to be checked and maintained; water quality management continued. It may not be feasible to do it all on foot. If that is the case, and the farm is in an exceedingly wet region, an all-weather vehicle would be an advantage.

When considering an all-weather vehicle it should be remembered that the head-lands being used as roadways are also the banks of the ponds and any degradation of the roadway will be a degradation of the pond's bank. A tractor is an all-weather vehicle but it may be too heavy for the banks.

Data handling

Data loggers

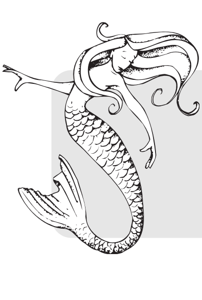
Data loggers assist farmers to record what is happening in their ponds and read the data in a form that might be more easily analysed later. They have their uses in all kinds of production systems, be they pond, cage or tank. Data loggers are very useful in allowing farmers to read their pond parameters by switching on a monitor in their office for a real-time profile of water quality as well as for taking and storing records over a period of time. The most common value collected by data loggers is temperature, however, other values can be recorded.

Data loggers and other sensors can be tied into automatic responses. For example, if the DO falls below a trigger level, power can be automatically switched on to aerators. This is particularly useful if aeration commonly needs to be initiated in the wee small hours. The alternative is the farmer getting out of bed at very awkward intervals, or adopting a precautionary attitude: turning on aerators early enough to provide a safe margin, but wearing the extra power costs.

Computers and computer programs

Successful fish farmers analyse measurements so they know what is happening to the water in their system, how fast the stock are growing and can forecast the need to order food and market dates. They are also businesspeople, who have to keep records of costs and returns. Records can be collected and recorded manually but in this day and age we have computers to help us. Computers are extremely empowering and will make the job of recording, collating and more importantly, analysing data much easier.

There are two types of software programs available for aquaculture and it is important to know the difference between them. One lot comprises simple financial programs that are helpful to tell the farmer what the economic outcome will be if the fish behave in a particular way. They are handy for obtaining a financial profile of a proposed venture under a fixed set of inputs. The second, and more expensive type of software, are management programs attached to an economic model. They tell farmers what is actually happening on their farm up to the point of the last data entry. If farmers have an understanding of the key performance indicators they'll be able to make predictions as to the physical circumstances of the farm at a given point in the future. The former won't help you run your farm but the latter will. Be aware of the difference.



GWQEHN says:
Running an aquaculture system without instruments is like driving a car without a dashboard. You're relying on the knocking piston to tell you you've blown a radiator hose.

13

Stocking and handling seedstock

In this chapter we'll talk about actually handling fish, including seedstock and issues associated with stocking ponds. We will cover:

- selecting seedstock
- handling stock on arrival
- checking stock quality
- quarantine
- identifying problems
- weaning
- stocking the pond.

Stock handling is one of the most crucial moments in a fish farmer's routine, and one of the most traumatic for the stock. Care should be employed at all times when handling fish to avoid stress and physical damage.

Stock handling is required often in the growing stage of the stock: harvesting, treating for disease, grading, quarantine and breeding (if you're running a hatchery). The general rules relating to handling fish are the same regardless of size. However, younger fish are more sensitive to the factors influencing stress and disease and need extra care.

Poor handling techniques will stress the fish, which in turn will cause lost production at best and lead to the introduction of disease at worst. It is not always possible to handle large volumes of fish with kid gloves but the trauma to the fish can be reduced to a minimum by using appropriate gear for the particular task, such as knotless netting during harvesting, and ensuring that handling systems function smoothly.

GWQEHN says:
Seedstock supply is one of the bookends that hold up aquaculture. If you don't have a reliable supply of quality seedstock you don't have an aquaculture industry.

Seedstock

Seedstock means the raw material to which value is added by on-growing. They are the stock with which you are going to commence a new cycle in that particular pond or tank. Although the term 'seedstock' usually refers to juveniles of the species being grown, it doesn't necessarily mean very small fish as production systems can be seeded with fish of any size. They can be juvenile stock of less than a gram in weight; they can have come from your own ponds as under-finished stock or from someone else's farm at the same stage. All sizes of seedstock benefit from being handled with care.

Sourcing seedstock

Seedstock can be divided into two categories: stock that have been purchased and brought in and those that come from your own farm that you've grown yourself.

Purchased stock

Stock purchased from other growers, or from a hatchery, will need to be held to ensure that no disease comes with them onto the farm. Without knowing their history you need to be able to assess whether or not you have got value for money. You also need to be able to identify and head-off any potential problems that might occur.

Stock from your own farm

If the seedstock are from your own farm you ought to know their history and that it is probable they have already been exposed to any enzootic (parasitic) diseases on the farm.

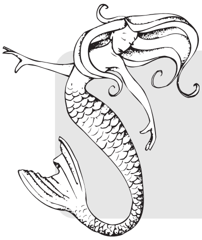
Many growers find it advantageous to take the opportunity at this stage to give their stock a salt bath to get rid of any protozoan parasites that may have built up. If parasite loads are high it will be essential. We'll be talking about these pests and how to handle them in chapter 15.

Dealing with the supplier

Getting the right stock will prevent many husbandry problems. Larvae with full yolk sacs start off life well. Stock free of parasites and pathogens grow faster and provide a better return. Stock that are certified to be specific pathogen free (SPF) will command a better price in the marketplace, and in increasing cases, due to the translocation policy of a particular jurisdiction, may be sold into a wider geographic area if they are to be sold live as a finished product.

Another important factor is reliability: getting what you want, when you want it. It is very frustrating to prepare a large area of ponds, with all the trouble and costs that may involve, only to find that the supplier didn't have all the seedstock they thought they had, or that it might be some weeks before they can deliver your full order. In many cases, reliability of supply is far more important to your final bottom line than the price of the seedstock.

To get good seedstock, when you want it, it helps to have a good working relationship with a reliable supplier. The relationship you have with your seedstock supplier is one of the key strategic alliances you will have in aquaculture. It's the hatchery operator who determines the genetic make-up of the stock you will have in your ponds. It could come about that the best way to secure quality seedstock is to do it yourself. At least one prawn farmer of the authors' acquaintance noticed a marked improvement in his stock as soon as he set up his own breeding program. Putting that aside for the time being, choosing a seedstock supplier is a critical decision. Make it based on quality and service and not on price.



GWQEHN says:
Quality control begins with seedstock. Get that wrong and you'll be battling right through to the time you sell the produce.

To start with, most hatchery operators have a wealth of knowledge and will be able to offer support during your learning phase. Spend the off-season looking around to find someone you're happy with. This may take some time but it will be worth it in the long run. Seek the views of people in the industry.

Obtaining this background will enable you to develop a shortlist. Visit those on the list to develop a better relationship than that which comes with just an order over the phone. If the hatchery operator sees that you've gone to that much trouble he or she'll know you're serious about the caper and are likely to become a long-term customer. A good hatchery operator will also appreciate the trouble you've gone to, that you've taken the courtesy of making an appointment, and visiting during the off-season.

Once you've decided on a hatchery to supply your seedstock, establish the terms of the relationship. For instance, agree on how the seedstock are to be counted. If you've only got one or two thousand to count it won't take all that long by hand and this is quite common: *one; two; three; four... 2621; 2622…* It can take a long time if you drift off thinking about the cricket while you are doing it. Hatchery operators get a bit stroppy if you spring the idea of re-counting 100 000 fish on them by hand when they arrive with the stock.

Without prior arrangements, it is amazing how easy it is to develop a misunderstanding. Do your best to ensure that all possible contentious points have been thrashed out before the season gets under way because once the season starts there's a lot of pressure on the hatchery operator and he or she won't appreciate having to negotiate the finer points of the deal when they're in a screaming hurry to get back to the hatchery to pick up the next delivery.

Arrange the payment terms and the description of the fish. For example: *100 000 snapper to be delivered to XYZ Fish Farm at ABC Wharf, JKL Island between November and December at 20c per tail; minimum size to be 25 mm; average size to be 30 mm; the fish to be in sound condition and free of parasites. Count by weight.*

Confirm the arrangement in writing. Ask about assurances. Suggest a deposit to clinch the deal if the hatchery operator has a solid reputation. The deposit might be declined but it shows your good faith. It also formalises the contract between you, as does a letter of confirmation.

One thing that should be discussed before the seedstock are delivered is that they will be held in quarantine. Holding them in quarantine is not, or at least it should not be, the problem. The contention is likely to revolve around the capacity of the quarantine system itself. If the supplier feels that there's a real risk the quarantine system is underpowered for the number of fish, he or she may feel that you are going to kill some, that you will blame them for it, and seek financial restitution. With this in mind they may remove any warranty offered. A more reasonable supplier might pass on their concerns and work through some arrangement to sort out the situation. It is best to have this clear in everyone's mind before you are up to your armpits in fingerlings.

The count

You have just purchased a whole batch of seedstock and parted with hard-earned cash. You want to be sure that you are getting your fair number of stock. The count is the greatest cause of friction between growers and breeders.

Counting out thousands of fish fry is not easy. The buggers move. The original way the industry determined the number of fish was by volume. A number of equal measures, say a tea strainer or larger, are taken of the fish in question. The number of fish in the scoops are counted and the average is taken as the standard measure for that batch. The number of scoops are counted and multiplied by the average for that batch. Some people swore by it, others swore at it.

The industry has swung over to counting by weight. Several random samples of around 500 or 1000 fry or fingerlings, depending on the size of the order, from the batch are counted and weighed. The average weight becomes the measure and the number of fish are estimated in this manner. This method is quicker and easier on the fish than the tea-strainer approach. Since the advent of re-circulation technology it has been easier to keep track of fish numbers and the weighing method seems to work out pretty well. As there's not much difference in the scientific application in the two methods it would be safe to presume the old method was as accurate as the newer.

There are automated fish counters available, but they cost an arm and a leg. You might be able to hire or borrow one but they are a sensitive piece of equipment and people are reluctant to let them out of their sight; and there aren't all that many around. As the industry grows and more money is flowing through it, you may find them in common use but at the moment they are generally only found in government research stations and sometimes in the more mature sectors such as prawns and salmonids. The author who has worked in a government research station suggests that while these pieces of equipment have all the shiny gadgetry, and give an authoritative number at the end of the process, they are probably not all that much more accurate than hand counting, but they are a lot easier and quicker to use.

The fish will be stirred up by the stress of transport and will swim frantically around the holding tank for a while. Give them plenty of aeration and put a lid over the tank to keep them in the dark and prevent them jumping out. Give them an hour or two to settle down. Keep an eye on them to make sure they're not dying. Check at the bottom of the tank for any corpses.

Fry can be sedated during counting to reduce stress. Anaesthetising fish is covered in chapter 15.

Holding density will depend entirely on the efficiency of the system and the degree of shock loading you're prepared to trust it with. Somewhere between 10 kg of fish per cubic metre and 20 kg of fish per cubic metre should be OK in a professionally designed system. Systems with oxygen injection could go much higher, but err on the side of caution. Young fish, particularly when stressed, will have a higher metabolic rate than the equivalent weight of mature fish, sometimes up to four or five times the rate. Confidence born of experience will allow you to judge the upper critical limit for different species and circumstances.

Keep records of the pH, DO and ammonia levels in the quarantine water to ensure that they are within the fishes' comfort zone and, in case you have to trace the beginnings of a disease or dispute, the condition of the fish on arrival. If you are insured, a policy condition will be the keeping of accurate records.

Counting crayfish

The most common method of counting crayfish hatchlings is to count a given number, say 1000, and weigh them. You can do this several times to strike an average if you like. Counting of hatchling yabbies by the tail is a formidable task. It is very likely that as the industry matures it will start selling yabby juveniles by weight, although the growers will still need an idea of the count to establish stocking densities.

Advanced crayfish can be anything from post-hatchlings of 25 mm to 35 g underfinished animals that require one more doubling to make them a saleable product. The smaller crayfish might still be sold by the tail but larger animals are sold by the kilogram.

Counting prawns

Prawns are counted several ways but they all come down to averaging. This is done by averaging a volume of post-larval (PL) prawns from a known volume of water and the average extrapolated. For instance: if a 40 L tub is aerated and the PL prawns thoroughly mixed, several one litre samples will be averaged and the mean figure used to calculate the number of prawns in the 40 L container.

Counting molluscs

Again, averaging is the preferred method employed in the industry. Several samples of a given weight (say 10 g) of graded shellfish, such as oysters or scallops, will be counted and the average used to determine the larger volume. Sometimes, especially with spat under 2.5 mm, the average weight of the shellfish will be determined by counting and weighing several samples. The displacement weight is used to establish the count of the entire batch.

You can count molluscs by electronic counter but this is an expensive item. As the industry grows, they are being incorporated where they are proven to be cost effective.

Mussel larvae settle on collector ropes hung in the water when the mussels are spawning naturally and are sold as a seeded spat rope. This can also happen when they are spawned in a hatchery and the ropes are left in the spawning tanks with the free-swimming larvae to settle on. Again the spat are sold as seeded ropes. The spat are stripped when they reach the desired size, graded and socked onto grow-out ropes.

In the case of seeded pearl oysters, each oyster is a valuable commodity. They are stored in panels. The value means that each oyster is counted and counted carefully, so there is unlikely to be any debate on the number being exchanged.

Quarantine

New arrivals should be put in quarantine. That is, they should be isolated from the farm to prevent transmission of any diseases, and not removed from this isolation until they are deemed to be free of disease.

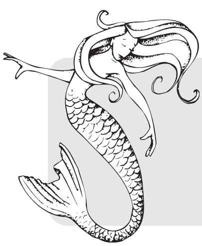
Quarantine is important. There should be no need to explain the importance, but the authors keep hearing horror stories of newly introduced stock bringing parasites into a system with costly consequences. It's not just the parasites carried on the fish or crayfish that can cause a problem: the transport water can have free-swimming parasites in it as well.

GWQEHN says:
Don't think about quarantine. Just do it.

If you want an example of the consequences of not quarantining fish, look no further than the re-circulation system operator who brought in a ciliate protozoan to his system on some barramundi seedstock. It was a fully commercial operation. He was turning off nearly a tonne of barramundi a week and had built up a regular clientele; no mean feat in a competitive market. The ciliates prospered in the hothouse conditions of the re-circulation system and gave the barramundi a very hard time. The barramundi became so loaded with parasites they lost condition and the grower lost production. What was worse, he also lost clients when his supply targets weren't met. He was between a rock and a hard place. He couldn't drain the system as he had stock in every tank and had built up his numbers so that stock were coming through to market size at a steady rate, if by now in irregular quantities. Treating the parasites in the tanks with formalin knocked their numbers back, but didn't wipe them out. The treatment, however, had an adverse impact on the bacteria in the bio-filter and the farmer had to wait until the bio-filter recovered enough to allow him to pour the feed into the system again, otherwise the holding water would be swamped by ammonia. In the end the farmer had to bite the bullet and do what, in hindsight, he probably should have done in the first place: remove the stock, destroy the ciliates, drain and dry the system, and start again.

We can provide another example of a disaster caused by not quarantining crayfish in an open pond system.

In this case, the yabby grower had taken every precaution as far as predators were concerned, right down to screening the incoming water to 500 microns. Not a fish, bird, water rat or crayfish could get into the pond area unless formally invited. All the ponds but one were stocked with hatchling yabbies of 20 milligrams and they grew well. The most noticeable thing about the yabbies was that they were very clean and free of Temnocephalids (little white leech-like parasites that live on freshwater crayfish and lay their adhesive eggs on the tail plate, detracting from their market value). Lo and behold there was one pond left to stock and the hatchery operator said he was 'out of hatchlings', but he had 'some advanced juveniles of 10 g to 15 g' that he would supply the grower instead. It turned out that this mixed parcel of seedstock was made up of yabbies that had come out of farm dams. After stocking the advanced juveniles, the first thing that happened was some started dying. After the initial deaths the yabbies seemed to settle in all right, but they were covered in Temnocephalids and as the yabbies grew, they displayed the tell-tale eggs that downgrade the finished product. The yabbies from the other ponds had been as clean as a whistle, but within a very short time, all the ponds became infected. The entire production of the farm dropped in value. Who knows, the parasites may have found their way into the other ponds eventually by some natural means. However, the reality is that after going to all the trouble to do everything right, the yabby farmer had one little lapse in quarantine and his stock became infested with the livestock version of lice.



GWQEHN says:
If you don't quarantine every fish or crayfish that comes onto your farm, it's only a matter of time before it costs you, and costs you big time.

The principle behind quarantine is to isolate all new stock and the water in which they come. The water is sterilised or disposed of in a place where it cannot convey infection. The stock are observed for a while to see if disease or parasite infestation breaks out. If it does, the stock are either treated until the infection/infestation is removed, or they are returned or destroyed.

It is impossible to have stock completely 'free of disease'. If a disease is already present in the general water supply in an area, quarantine is only able to keep out those pathogens that need a carrier to transport them into the system. Quarantine can't stop water-borne parasites unless the incoming water is sterilised. This is not always practical outside the confines of a re-circulation system because of the volumes involved. The farmer must focus on management to keep the stock healthy and resistant to full-blown infection.

To test the disease status of the seedstock, you may even put a small sample 'under the hammer' in the fish room by putting them in a separate tank and stressing them by raising the water temperature slowly to put them under some stress to see how they react. If they have a bug, the stress will give it a chance to express itself. There's no need to dramatically exceed the highest temperatures you'd find in your own system.

Quarantine procedures will vary according to the kind of stock farmed.

Freshwater finfish

For freshwater finfish seedstock on an owner-operator scale farm, the quarantine procedure entails isolating them for anything from five to 10 days before putting them into the on-growing system. It could be longer or shorter depending on the circumstances. The exact number of days will depend on how sure you are that the fish are free of disease and how long it takes to wean the stock across to the diet they're going to be fed in the ponds. Different pathogens will have different incubation times. Check with your veterinary adviser or aquaculture Extension Officer as to the incubation period of any of the pathogens you expect to find in your stock. Ectoparasites will probably show up immediately under a microscope unless they are in a resting stage.

The quarantine system should be separated from the farm's normal water discharge system to prevent the spread of any infection that may be present.

Some growers use their purging tanks for quarantine when stock arrive then sterilise them after the process is completed. Others have a flow-through system attached to a bore, with the water going out to irrigation after it's been through the tanks. Whatever way you go about it, keep effluent separate. Water used to on-grow stock has to be free of access to pathogens, otherwise it defeats the whole purpose of quarantine.

One point to consider is that the fish will be held for quarantine at much higher densities than they would experience in a normal pond or in all but the most powerful re-circulation systems, therefore you will need to maintain the highest possible water quality during quarantine. Maximum aeration should be maintained at all times.

If you find you have to treat the fish in a re-circulation system, be conscious of the fact that what you are putting in the water to kill a parasitic, bacterial or fungal infection is very likely going to have an adverse effect on the bacteria in the bio-filter. Formalin and methylene blue are two chemicals that can destroy bio-filter populations if strong doses are used. Even diluted doses will give the filters a headache, and remember: the doses have to be strong enough to kill the pathogens.

Sea cages

If finfish seedstock, such as barramundi and salmon, are to be liberated into sea cages, it is a little difficult to hold them in quarantine on-site. In this case, strict precautions must be taken to ensure that stock are free of disease before they come to the farm site.

Crayfish

Crayfish have their own quarantine requirements, which vary depending on the life stage of the stock.

Quarantine for hatchling crayfish can be a little difficult as they will be moulting continuously, and if quarantine involves keeping them in close confinement, the hard-shelled crayfish tend to eat their moulting siblings under stressful conditions. In most working circumstances, hatcheries with high hygiene standards will have already quarantined hatchlings, and if you're sure of the procedures and protocols of the seller, you can put them straight out for on-growing. In fact they are more likely to survive and do well if spaced out in a nutrient-rich pond at say $10/m^2$ than confined in a holding or nursery system.

Advanced crayfish differ from hatchlings in that they are more likely to have come from an aquaculture pond, a farm dam or natural wetland. In all cases they have been exposed to pathogens and must be quarantined. Ten to 15 days should be enough time to show up any problems. Some operators quarantine crayfish in the drip room, but if cross-contamination is considered to be a health risk to be avoided then isolation should be complete. Quarantine can be made more secure in an area dedicated to the purpose.

The most likely problems with advanced crayfish you'll be able to pick with the naked eye are parasites and a particularly nasty disease called *Thelohania* (upon which we'll have plenty to say in chapter 15).

Bacterial infections are a lot harder to pick up with the naked eye. Crayfish ponds by nature carry high detritus loads that provide a prime environment for bacteria. Even though crayfish have evolved to live in these organically rich habitats they are still vulnerable to opportunistic invasion in the gut and muscle tissues from bacteria. Jay V. Huner in his excellent publication *Freshwater Crayfish Aquaculture*, states: 'increased bacterial levels may affect survival and quality of crayfish during transportation, storage and handling after harvest, especially when placed in intensive systems' (pp. 121–122).

Quite often the mortality in crayfish starts overnight when you get them and continues unabated for a few days until your quarantine system looks a bit like the Black Hole of Calcutta. If you put crayfish out in the ponds without quarantine the first sign you could have that something is wrong will be dead crayfish washed up on the banks, and that could only be a percentage of the mortalities. Advanced crayfish, especially if you're not sure of their origins, must be held in quarantine until you're sure they're not going to die.

The best place to quarantine crayfish is in a similar structure to the one you would use for purging. Some people even argue that there's not a lot of health problems a crayfish can bring into the purging system (that it's not already exposed to) and use the same system to quarantine their incoming advanced seedstock. (*The Australian Yabby Farmer* describes the workings of a purging room.) The crayfish purging/quarantine system is based on the same principle as the fish purging system and can be either a flow-through or re-circulated water system. The main thing is that the crayfish get a good salt bath to clean them up as soon as they come onto the farm. After the 'gill flush', as the process is sometimes called, some growers hold the crayfish in trays, spraying water so that it drips down over the animals, while others hold the crayfish in vigorously aerated tanks during the quarantine period.

The temperature of the quarantine water can range from 8°C to 18°C. Some growers like to slow down the activity of the crayfish with cold water, others argue that the cold water inhibits the activity of bacteria and consequently masks its presence. They reason that the darkness of the holding room and the tightness of their containment still keeps them quiet. Check daily for any mortalities.

The tropical redclaw crayfish should be held toward the upper end of the scale anyway as temperatures below 14°C would tend to stress them.

Crayfish, like abalone, will be quite messy when they first come into your system. You could use the same system you use to hold crayfish for market but if you're buying in a lot of advanced animals you might set up a quarantine room apart from the purging/holding room. This will also allow the high ammonia levels associated with stressed crayfish and those still purging their alimentary canals to be isolated from the main body of stock being purged for sale.

Prawns

The practice in the prawn industry is a little different. Prawns come in one of two ways: as nauplii or as post-larvae (PLs). If they come as 'naups' they are really only just hatched, and a complete nursery process has to be instigated. People with nursery facilities usually have the wherewithal to do the hatching as well, so acquiring prawn nauplii as seedstock is not a common practice in the Australian industry. Nauplii are tiny and can't take too much stress, so dipping or other preventive actions are not taken on arrival (although antibiotics are sometimes used in the nursery stage). The nursery process itself acts as a quarantine stage.

Similarly with PLs, preventative actions are rarely taken. It is possible to view them on arrival, check for mortality and to note if they appear listless. They are liberated into the ponds as quickly as possible, and for the immediate future at least, it is hard to tell how they fare.

Oysters

Pearl oysters are bivalve molluscs. The pearl industry is well established and has had decades to develop procedures. In decades gone by, nobody bothered to hatch their own pearl oysters: they fished them from the wild and then took the shell to the growing site. This had a very poor level of quarantine, especially since oysters may be moved very long distances. In recent years there is an increasing reliance on hatchery-bred pearl oysters, and having stock in a controlled environment more or less applies a level of quarantine.

Quarantine of oysters along the NSW coast has been on an industry wide scale. The big concern with shifting edible oyster seedstock collected from the wild in estuaries is that juveniles of the exotic Pacific oyster may be transported with Sydney rock oysters. As the Sydney rock oyster is marketed at a premium, growers, supported by conservationists who regarded the Pacific oyster as undesirable, have so far managed to restrict the farming of Pacific oysters to designated estuaries.

Regions in which there have been outbreaks of the oyster disease QX have been quarantined to isolate the outbreak.

Translocation has become a national issue and each state will have a policy in place in regard to stock movement. Contact your local Fisheries Extension Officer to find out what you're allowed to do in this regard.

Finally on quarantine

As the aquaculture industry matures and deals with issues confronting it, codes of practice are being developed by each sector so participants have guidelines by which they are expected to operate. As a stakeholder in the environment, the aquaculture industry has a responsibility to protect it from degradation. Sound quarantine practices are part of the protocol that prevents the transfer of disease as well as protects the wellbeing of other growers.

Handling stock on arrival

To deal with your stock, to move it into quarantine, liberate it, or anything else you want to do, means you are going to have to handle it. Handling can cause stress and trauma. The nature of the stress and trauma depends a lot on the nature of the beast you are handling. If you have an idea of the vulnerabilities of your stock you can minimise harm.

Finfish are slimy. They have a coating of slime that acts as a protective layer. Just as our skin acts as an outer barrier against infection, the fish's slime has a similar role. Fish live in water and an additional role of the slime layer is that it controls the passage of fluid from the skin and into the body via the process of osmosis. Any damage to this slime layer interferes with the process and opens the way for fungal and bacterial infection. The acid in a dry human hand can 'burn' the slime layer, so either use gloves or ensure that your hands are wet so they have a coating of water over them when handling fish.

Stress will reduce the efficiency of the fishes' immune system, allowing access for any pathogens or parasites that may be present. Since we're talking about stocking we'll presume that most of the time we're talking about young fish, but the rules apply equally to advanced fish being stocked in a new pond or tank on the farm or any fish coming onto the farm for the first time at any size. Stressed fish will cost production time while they recover from the trauma, and lost production time is lost money. You never get it back.

Gills are the most sensitive, most critical and vulnerable part of a fish's anatomy. It is through the gills that fish take in the oxygen needed to drive their metabolic functions. Any reduction in the fishes' ability to take up oxygen will compromise the fishes' ability to utilise food efficiently. Gills can be damaged by abnormally high or low pH of the surrounding water: below 5.5 or above 10 are considered dangerous and any readings approaching these levels should initiate prompt action. Excessive ammonia in the water will also damage the fishes' gills.

It should go without saying that fish will bruise during rough handling; not only do they bruise easily, the bruising can take weeks, and in some cases, months to go away. Gill-net marks are notorious for this. The market value of bruised fish is diminished, as is any spoiled merchandise.

The fins are made up of a fine membrane supported by spines. The membranes are easily damaged and apart from being unsightly, breaks can present a convenient site for infection. One of the first things an experienced fish farmer will look at is the condition of the tail for signs of rough handling, or damage caused by other fish, most likely due to stress or overcrowding.

Salt dip

After transport, freshwater finfish species benefit from a saltwater bath. The purpose of the salt dip is to bathe any external damage done to the fingerlings during harvest, transport and unloading. The salt will reduce the risk of fungal and bacterial infection and will also remove any external parasites such as *Costia* and *Chilodonella* that may have come through from the hatchery.

Most likely juvenile freshwater finfish will have had a salt bath at the hatchery before consignment. Some farmers even transport their stock in a 5 ppt saline solution. (Freshwater species generally can be held in a saline solution of up to 7 ppt without causing any undue stress.)

Some growers do their salt dipping as soon as the stock arrive, but some allow the fish to settle down first. If the stock has had a long trip give them a rest.

There's an argument at this point for taking a sample of the transport water. Obviously you can't do it in hindsight so it will have to be done when the fish arrive. It will also have to be done with the knowledge of the person delivering the fish. Your skills at diplomacy will be tested here, as well as your relationship with the hatchery operator. Asking to check the pH and temperature of the transport water to make sure it matches the quarantine water shouldn't create any stir. A good operator will have some way of aerating the transport water in transit, usually a cylinder of oxygen bleeding into the tank, so DO shouldn't be an issue but it doesn't take long to swirl a DO probe around the transport tank to see what the reading is. Checking the ammonia takes a few minutes but it could be done while you have a cuppa and a chat.

The salt dip comes in two stages. First there's the 'hot' dip. This is a 20 ppt solution of salt in clean water. Leave the fingerlings in this brew with heaps of oxygen for 10 minutes, or until they show signs of stress.

The second stage is a bath at 10 ppt to 15 ppt for 20 to 30 minutes, or until the fish show signs of stress. A simple way to do this is to fill the tank to 33% of capacity for the 'hot' dip. At the end of the 'hot' dip period, just bring the tank up to 66% full with fresh water and the solution will be diluted from 20 ppt to 15 ppt.

It is often the practice, particularly in the case of native freshwater species, to salt holding water during purging or quarantine. By topping up the tank with freshwater the above bath becomes holding water at around 7 ppt.

Dissolving salt can be a slow process and the finer the salt the easier it is to dissolve. The most readily available product is coarse salt but ask for iodine-free butter salt, which is finer and will dissolve more easily. Salt will dissolve quicker in warm water.

Crayfish

Redclaw and marron are usually reared in ponds and are either harvested as they grow large enough to market, or are collected as advanced juveniles from hatchery ponds and re-stocked in the grow-out ponds. Unless the grower is just starting up, home-grown seedstock is used. Yabbies are also grown the same way but in the cooler winters of the south, hatcheries play an important role in producing seedstock early, ready for a flying start when the weather warms up.

Although crayfish look armour-plated, they are as sensitive to stress as any animal and have vulnerable zones that require consideration during handling and transport. It's not always immediately obvious when some of these vulnerable areas are compromised.

Crayfish can survive quite a while out of water, but their gills require irrigation to operate at peak ability. If they are left dry too long, or are kept in corrosive water, their gills can suffer. This is not immediately visible to the casual observer, but can reduce the animal's ability to withstand other stresses.

The ectoparasites found on freshwater crayfish are easily removed by a salt bath, just as for freshwater finfish. The salt bath will also help clean out the gill cavities and generally clean up the carapace and around the tail.

Prawns

Prawn seedstock at the nauplii stage go into special nursery facilities, and the detail of rearing them is beyond the scope of this book. Suffice it to say that, at that very early age, naups are quite sensitive to less than perfect living conditions and the presence of potential infections. Skill and care are needed for successful rearing.

Prawns are liberated into ponds at an early stage in their life cycles. Post-larvae (PL) prawns have left the larval stage, but only just. They are somewhat similar to crayfish, except they are not as heavily armoured and are adapted to salinities in the high teen range.

It is not normal practice to dip PLs but to get them into the ponds with minimal stress.

Molluscs

In most cases, molluscs have a strong and thick shell to protect them. Also, in most cases, they have the ability to seal themselves off for some time. Bivalve molluscs such as oysters and mussels can close their shells. Many of the spiral shelled species (gastropods) have a little door at the opening of their shell which they can close after withdrawing their bodies.

The ability of these animals to 'close the door' as it were, means they can be subjected to treatments which will remove anything living on the outsides of their shells, but it also means that whatever has found its way to the inside, is more or less protected from the treatment.

Some species, like abalone, do not have the ability to seal themselves off from the surrounding water. They have to wear whatever comes their way. Treatments for these species have to be kinder, or the cure will be worse than the disease.

The other key feature of gastropod molluscs (relatives of snails) is they generally crawl to get around and they have a strong muscular and slimy foot. Surfaces that have been immersed for some time develop bio-films. These slimy films often contain some real nasty bacteria. A cut in the foot, or some other damage, may provide access to the internal parts of the gastropod for disease.

Checking stock quality

Now that you have got the stock, you want to keep them in peak condition and prevent problems developing. You can get a fair idea of the stock's condition by having a good look at them. It can be difficult at times to observe behaviour and appearance in a crowded tank, so some growers set up an aquarium with the same density of fish in it as the tank and observe them in there as well as keeping an eye on the tank.

GWQEHN says:
Follow the quarantine procedures: there are no short cuts in aquaculture.

There is no simple, one-off approach to maintaining health. Of course there's nothing stopping you going for the doctor and treating the stock for every possibility as a precautionary measure. However, some pathogens aren't treatable unless in a clinical state so the 'shotgun' approach provides no guarantee. It's also important to know the condition in which the fish have arrived in case you have to trace a later outbreak. There are behaviours exhibited by finfish that indicate something is not quite right.

Erratic behaviour

If the fish are swimming in an erratic manner it's time to get them out for a closer look. One of the authors remembers starting his working life in an aquarium shop. The older gentleman (polite term for 'old bastard') who owned the shop only had only one eye, but he could use that eye with devastating effect. He only had to walk past the front door of the shop and would turn around and say, 'That tank down the back, the neons are swimming wrong. Get them out of that water and into something better.' At the time, the fish just looked the same to an unpractised eye, but experience told the boss that a stress was being reflected in erratic behaviour.

Sometimes it is just a case of applying common sense. Fish that are too cold will hang in close around a water heater.

Some finfish, when they are not feeling well, will prop on the bottom with a twist in their spine and their fins spread to support them. If fish that normally are free-swimming start to adopt this stance, it's time to look at the water quality and check on fish health. Goldfish with white spot sit on the bottom of the tank too, but they pull their fins in.

If you see something you recognise as strange, but you're not experienced in this area call the hatchery operator and discuss the behaviour. If they can't suggest anything, seek professional advice.

Flashing

If the fish have parasites they will turn on their sides to try to brush them off against the bottom of the tank. When the light hits their sides they 'flash' and that is the term given to this activity. Flashing is not restricted to aquaculture; one of the authors has occasionally observed fish flashing in the wild.

Flashing may not necessarily reflect the presence of ectoparasites; skin sensitivity caused by exposure to high or low pH and/or ammonia levels can have operators scratching their heads as they peer intensely down the eye pieces of their microscopes in search of the villain causing their charges to flash.

The most common external parasites are *Costia*, *Chilodonella*, *Trichodina* and flukes. We'll be dealing with these parasites in more detail in chapter 15, but in brief they can be removed by dipping. In some cases the main problem is the secondary infection, such as fungal and bacterial disease they set off by their abrasion of the fishes' outer tissues and gills.

Fish gasping for air at the surface

This is a sign in finfish that they aren't getting enough oxygen. The cause could be that the aeration system is inadequate; or it could indicate gill damage.

Gill damage, which reduces respiratory efficiency, is generally caused by external parasites and/or poor quality water. The poor water quality could be home grown, but damage could also have been done at the hatchery or during shipment. Poor quality transport water can cause a lot of damage that shows up after the fish have been delivered (and generally after the hatchery operator has departed).

Fish usually recover from transport stress but for this to happen as quickly as possible, they should be left alone, apart from the odd check-up, in top quality water without disturbance or strong light. Make sure the pH and the water temperatures of the transport water are close to those of the water in the quarantine facility and that there's heaps of aeration.

Darker than usual colouration

In finfish, this is usually a sign of stress. It can be caused by a number of things, including being knocked on the head with a net. These fish can usually be seen swimming slowly around the top of the tank. If you want to play doctors you can put them aside in a 'hospital' aquarium but don't waste a lot of time or sympathy on them: it's part of the grander scheme of things.

Milky colour of flesh or eyes

If the fish are infested with some of the smaller external parasites, their mucus covering may thicken up and take on a milky appearance.

Inspect a scraping from the mucus under the microscope and try to identify the problem. If you can't find any sign of parasites seek a second opinion from a neighbouring fish farmer or the local Extension Officer.

Dip to remove parasites and bath to prevent infection of the damaged site.

Fine white spots

The disease *white spot* takes after its name and shows as small white blemishes all over the fish. The spots are caused by a protozoan and can overwhelm the fish by sheer weight of numbers (as can any of the external parasites). White spot can also open the way for secondary infection but is a fatal condition in its own right. It is treated by dipping but can be difficult to cure.

The lowering of temperature will also prevent the activity of some pathogens. For instance, white spot will be pretty much inactive at temperatures under 15°C. This doesn't mean dead, just inactive. This allows the fish farmer a softer target to treat and allows, presuming the temperature is within the fish's activity range, a better chance to 'throw off' the disease.

Red patches on skin

These can be skin abrasions or lesions. Sometimes red patches appear on the skin of finfish. Rough handling can cause abrasions where the blood comes up near the surface of the skin, but if the blood spots appear to be ulcers or lesions notify your fish vet immediately for positive diagnosis, and let the hatchery operator know all about it.

Damaged fins

Damaged fins are a sign of rough handling and offer an inviting site for infection. They will appear ragged around the edges and inflamed along the spines. Sometimes black mould or white fungus can be seen on fins and this is generally an indication that the finfish have been kept in water of less than adequate quality. Salt dip and bath the fish, then hold them for observation until any inflammation has gone down. If there are no signs of improvement, or a worsening of the condition, inform the hatchery operator of the problem. If the hatchery operator can't suggest anything, seek professional advice.

Morts

This means fish dead on the bottom of the tank. Watch for this by slipping an aquarium net along the tank floor to see what's happening down there. It is natural to have a few deaths from time to time, but if death rates increase suddenly, there could be a problem on hand.

Fish that have died from being deprived of oxygen or from carbon dioxide poisoning usually have their gills flared and their mouths agape.

Crayfish are an entirely different kettle of fish (to coin a phrase). They aren't nearly as prone to disease as their scaled compatriots, but they do have their problems. Bacterial infection is the main one; followed by external parasites; and the bane of all crayfish growers, *Thelohania*.

Hatchlings

When your hatchlings arrive, they should be healthy looking and active. If they are very young, they'll be balled-up together. Gently separate them and watch their movements. They should be robust even though they don't flick all over the place like a box of silver perch.

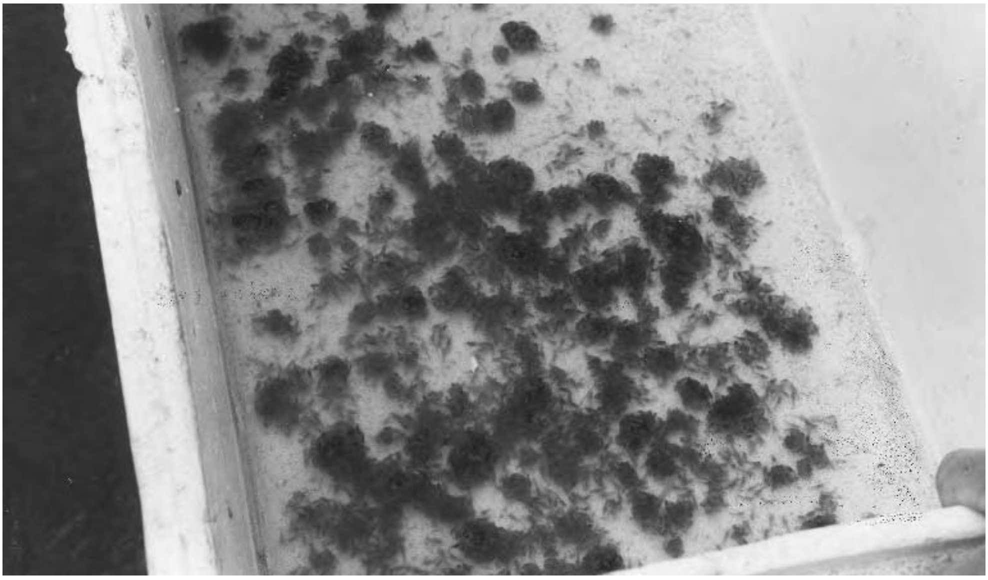


Figure 13.1. Yabby hatchlings clustering together in the transport box prior to liberation in the pond.

Crayfish

Look at the claws when they arrive. If they've been stressed they generally grab hold of the thing nearest them and hang on for dear life. In this case it will have been the claw or leg of their neighbouring sibling. Widespread damage of this nature is an indication of rough handling.

It is harder to notice erratic behaviour in crayfish. It has been noticed from observation that if they stand high up on their legs, with their tails straight out behind them, and rock to and fro, there is a good chance they are not feeling too good. While this is easy to notice in glass aquaria, when looking down on them when being transported 'dry', such as in a prawn tray or polystyrene box, a sure sign that they aren't feeling too good is when they have their claws fully extended in front of them.

Bacterial infection is arguably the most common cause of losses in crayfish handled for aquaculture. Freshwater crayfish ponds by nature tend to be rich in nutrients and organic matter; a perfect environment for bacteria. Bacteria move in and infect gills damaged by parasites, particularly by *Temnocephalids*, and the stress of handling adds to the problem.

The art of yabby farming is to maintain a rich natural food source, while at the same time ensuring a healthy environment. At some stage the conditions conducive to natural food production will be in conflict with conditions conducive to animal health. It is at this stage that you will have to flush out the pond and either start another detrital food web or start feeding a supplementary ration.

By holding the crayfish for a week or two in your holding room, that you should know from experience with your own crayfish is efficient, you will be able to gauge the mortality of the incoming crayfish. There may be an initial rush of deaths due to the trauma of external harvest and transport damage but it shouldn't be more than 1% from a commercial as well as a clinical point of view. The mortality will most likely occur over the first two to three days. Deaths over the next two weeks shouldn't be more than 1%, or 2% at the most. Compare the mortality rate with that experienced when you bring your own stock in from the ponds.

If you do have stressed crayfish you'll know all about it. Check your prawn trays daily and remove the dead and moribund crayfish. Tired little crayfish don't bounce back the way tired little teddy bears do. Losses of 30% can be expected, with ruinous total mortality not unknown. If the crayfish were liberated at the time of delivery these losses would have occurred underwater with the evidence most likely scavenged by the survivors leaving the farmers wondering what they'd done wrong.

One grower told us that he had a rule when he was packing for export: if the yabby didn't bring its elbows back hard against his fingers when he picked it up, it wasn't good enough to last the distance.

If you start having mass mortalities at this stage there's no practical solution to the problem. It has been imported onto your farm. Contact your supplier and ask him or her to come and take them away. More importantly: make sure you have this understanding before you commence your commercial relationship.

In a clinical sense, a formalin dip may destroy the bacteria and a pristine environment will stall the spread of the infection, but by the time you get the crayfish most of the damage has been done; and once you return them to a detritus-rich production environment there will always be the risk of a renewed outbreak. It would be impractical to treat all but valuable broodstock.

From a commercial point of view, especially in the scale of the short production cycle of crayfish, the lost production mucking around bringing the crayfish back to health, the catch-up time in the pond recovering lost condition and the disruption to the marketing schedule is just not worth it. They are stock you bought in good faith and if they don't measure up then it's your prerogative to return the sub-standard stock.

If you do decide to treat crayfish thus infected, there may some doubt as to the weakened crayfish's ability to withstand the treatment, especially if they have damaged gills, so test a few in the treatment solution before committing the lot.

The authors have noticed that crayfish raised in purpose-built aquaculture systems under sound aquaculture management practices seem to be less prone to health problems than wild caught crayfish.

External parasites of crayfish are usually one of two kinds: *Epistylis* and the so called lice (*Temnocephala*). The *Epistylis* is the slimy-brown hair-like covering found on some crayfish; and the lice are slug-like objects that can be seen on the shell. Neither is particularly life threatening except in extreme cases where they damage the gills of the animal.

Both can be removed from the stock by a salt dip. However, their presence is an indication that the crayfish have come from a particularly downgraded environment, usually one over-rich in organic matter. It is also an indication that the seller of the crayfish has poor knowledge of the job. You may need to ask yourself whether you want to put the results of their poor practices into your ponds.

Sometimes you will find a green slime on the crayfish. This is generally a type of algae caused by sunlight entering a clear water pond which is very high in nutrient. If the crayfish have this slime, it's an indication that they have been sitting around long enough to collect this coating – sort of like falling asleep on the beach and getting severely sunburnt – and it is reason to reject the animal.

Thelohania

This is the yabby farmer's worst nightmare. *Thelohania* is a microsporidian protozoan, which will enter the host body and multiply internally. Its presence is indicated by a white appearance to the tail of the infected animal. The mortality rate is not known but the yabby thus infected is un-saleable and the loss of production and the infection factor are frightening to contemplate. One method of infection is thought to be by a healthy animal scavenging an infected one. More on this little beauty later.

Thelohania is extremely hard to get rid of, but fortunately it appears to be isolated in particular regions. One such area is the Victoria–South Australian border known as the Mosquito Creek Drainage Basin and you should be cautious when buying yabbies from there.

This disease is associated with (as is the case with nearly all crayfish problems) high water temperatures and low oxygen levels, either independently or in combination. One could be excused for rushing to the conclusion that stress is the trigger of disease outbreaks in freshwater crayfish farming.

Little is known about the life cycle of the *Thelohania* and the only way suggested so far to get rid of it is to leave the offending pond exposed to the summer sun to well and truly dry out and to dose the bed with slaked or quick lime.

Quality of juvenile prawns

The quality of juvenile prawns relates to hatchery success still being an art rather than an established science. Generally, broodstock come from the wild and the quality of eggs is dependent on factors entirely outside of the control of the hatchery operator. If the young don't get a good start in life (good yolk sac etc.), they don't kick on too well. In many cases disease is really a symptom of poor nutrition of the mother prawn.

Post-larvae (PL) prawns are bigger, and more can be determined by a visual examination. Vitality is a hard thing to describe in written words, and experience will help. Vital PL prawns are healthy PL prawns. Dead PL prawns over the bottom of the container are a danger sign. Take a photo and it may assist with any discussions between you and the hatchery operator. Take a sample and send it to the fish vet for examination.

Quality of molluscs

Molluscs have hard shells on the outside, but the internal working parts can be damaged just like other kinds of stock. Gills are just as susceptible to damage, and the consequences are just as serious. Unlike finfish that can swim to an area with more oxygen (the surface) and gasp, molluscs generally do not have that option and do not demonstrate the same obvious behaviour.

Most molluscs keep their working parts out of sight, so it is difficult to evaluate if they are feeling out of sorts, but there are some tests.

Bivalves (mussels and oysters), when happy, will have their shells slightly apart and be sucking in and squirting out water. If there is a threat, they will slam their shells shut. A light tap will simulate a threat. If they don't respond, they are not at their best (or might even be dead). Scallops can swim off, looking remarkably like a pair of flying false teeth. If they don't start clapping their shells together in response to a threat, it would indicate less than perfect health.

Gastropods (abalone, trochus and similar beasts) really only have their foot showing. If an abalone is feeling a bit seedy, they tend not to hold on so tight, and their shell sags away from whatever is they are holding onto. Their skin becomes a little whitish and pasty. Another check for vitality is light. Most gastropods, particularly abalone, prefer to avoid bright light. If they are living in a dark place (as when they are hiding under a rock or piece of PVC) and it suddenly becomes light, most abalone will high-tail it away to somewhere more secure. If species that normally respond in this way decide they can't be bothered, warning bells should ring.

Likely problems

A few deaths are to be expected. In nature, most aquaculture species have a very high death rate during the early parts of their life. So how do you know you have a problem?

There are some rules of thumb:

- a mortality rate less than 1% losses would be very good and if you match this goal, both you and the breeder can take a bow;
- if the mortality rate is higher, you should keep a close watch on the stock, writing down and dating any observations;
- if mortality is higher than 3%, there is reason for concern.

While it is true that stock in the very early stages of life are more vulnerable than more mature stock, the hatchery operator, as part of his or her product's presentation, should absorb the loss of the more fragile juveniles before offering them for sale.

What do you do?

If you have a problem, what do you do? The very first thing is to isolate the problem stock. It may be that the problem is batch-specific or hatchery-specific and it may be infectious. If the stock are isolated, the problem won't get transferred to other stock or production systems.

If problems are encountered with the stock, they shouldn't be liberated into the production system until they are in a healthy condition and feeding on their intended ration.

Once the stock are isolated, contact the supplier. This is done as a commercial precaution and as a courtesy to a fellow fish farmer. A responsible supplier will be only too willing to help you solve the problem and should join this process willingly. They're bound to have had more experience than you so their advice should be invaluable, and cheap. They may know what the problem is, and how to address it.

If you believe the problem is their fault, make a request for compensation and an invitation to inspect the stock.

The next step is to define the exact problem and find its cause. Be scientific about this. Treating for the wrong pathogen may not only be ineffectual, it may cause extra problems. Keep a cool head (but don't dilly-dally).

The observations mentioned above should provide a few clues as to where to start looking.

The first thing to check is water quality. Take the readings, write them down, date them and sign them. Record them even if the water is perfect.

Take some samples of the diseased fish. Chapter 15 on fish health deals with preserving samples of fish for forensic inspection.

You hope you haven't got a serious infectious disease or outbreak of parasites, but hoping won't make it better. Be prepared to carry out post-mortems on any stock that die for no apparent reason. This will mean having microscopes and slides as well as having undertaken training in their use and maintenance. A 20/40 power microscope should be enough but you can get interchangeable lenses. If you need to go beyond 100 power I'd suggest you should be taking your problem to a vet. Take a look at some random samples of slime scrapings under the microscope. Look at the gills of some of the fish. You don't have to kill a fish to get slime, but sampling gills is a pretty traumatic experience for a fish. It is a cheap exercise if you're dealing with 1 g fry but it can become more costly if you've got a tank full of 300 g Murray cod you're planning to grow out to 2 kg. Nevertheless, if you don't know the cause of a problem, you are courting disaster if the stock (and/or the disease vectors) get into your production system, so the value of a few fish is nothing compared to the alternative.

If you have found a problem: don't panic, especially if you're dealing in large numbers of stock. Take considered action to address the problem.

If water quality is off, correct it, and see if this makes a difference. Even if poor water quality was not the source of the problem, good quality water will assist sick fish to recuperate. Raising the salinity of the holding water for freshwater fish to 3 ppt to 6 ppt (3 g to 6 g of salt per litre) is helpful. This has the effect of reducing the stress on the fish's osmoregulation of its body salts during times when they were likely to be under a bit of a strain. It should go without saying: raise DO levels to saturation point, or as near as practicable.

If you don't know what to do, get advice. The first person to call if the fish look at all out of sorts in quarantine is the hatchery operator. First, as a courtesy; second as a commercial precaution; and third for advice as to what the problem could be. This will be the first test of your strategic alliance. Some states provide their licence holders with an Extension Service. These Extension Officers are well versed in fish problems and should be able to set you on the right path. They also have a scientific network to call on should the problem be beyond them. If between the three of you, you still can't solve the problem and reverse the downward spiral of the fish in the quarantine system you should call in a fish vet. Fish vets are thin on the ground but some states have them on the payroll. If your Fisheries Department doesn't provide that service you will have to find a fish vet in private practice. They're there to help and they love their work. You'll find them friendly, obliging and knowledgeable.

The first thing they are likely to ask about is a history of the water quality, so it helps to have taken the readings before you contact the vet. Follow the vet's advice.

If treatment can be applied, do it. But if possible treatments are unlikely to make a difference, consider damage control. In south-east Asia, there is a disease of prawns called yellow head. In an area where yellow head is present, an infected pond will show a few dead prawns one day, a few more the next, and have a total wipe out on the third day. Infected prawns are not dangerous to humans. Farmers, as soon as they see a few dead prawns, immediately harvest their ponds. They may not get a good price for their small stock, but it is better than nothing at all if all the stock have died.

Weaning

Quarantine also offers the time and place to wean finfish onto an artificial diet. They can be brought onto the dry ration that they are going to be fed after they go out into the ponds.

Weaning is a term generally only applied to finfish, although there are some exceptions. Abalone start off life eating slime, then move onto more substantial tucker. The process of transition is also termed 'weaning'. In the case of purchase of abalone, they would be most likely weaned by the time they are purchased.

The key word is 'weaned'. Fish in quarantine don't have to be fed to commercial levels, only introduced to the new ration they'll be expected to take in the pond after liberation. If too much food is put into the tanks it will overload the filtering system, so introduce it slowly; and make sure the fish are eating all the food. Once fish have learned to take formulated food, keep up a maintenance ration, being ever mindful of the impact that extra loading might have on the filtration system.

Some species of fish, like silver perch, take to a supplementary ration readily. Others are much slower. Some, notably Murray cod, may have to be weaned onto artificial food by first weaning them onto a dead natural food, such as frozen brine shrimp or frozen blood worms, then moved onto a formulated ration. It can take a bit of patience, but once they get the idea it doesn't take long.

Among any particular species, some individuals may always be reticent to take an artificial ration. They are termed 'shy feeders' and identifying them in the short time they are in the quarantine/weaning tanks is not practical. You'll be able to identify them easily enough once they get out into the grow-out system as they won't grow as fast as the others. There's nothing to gain by carrying these fish and they should be discarded from a commercial system. They will probably do well in a farm dam somewhere and they make wonderful pets, but they will be uneconomical in your production system.

Shy feeder syndrome can be addressed: sometimes successfully, sometimes not. The usual procedure is to give the fish a couple of days to settle down and then start feeding at very low rates. If they don't come at the new feed first off, hold back for a day and try again.

As well as shy feeders, there are some fish that might be termed 'recalcitrant feeders'. Golden perch are by nature very much a predator, and even when weaned prior to liberation, if they go into a pond with natural food in it, they will revert to hunting again and ignore the pelleted diets.

Stocking

There is no perfect time to undertake stocking but most operators prefer doing it after the heat has gone out of the sun or first thing in the morning after the phytoplankton has started to raise the dissolved oxygen levels.

It's important to minimise the shock of the change of environments from the quarantine water to the production water. Make sure the two waters are as close in pH and temperature as possible. Condition the fish by gradually adjusting the quarantine water prior to stocking.

Younger fish are more sensitive than larger fish. There are some rules of thumb that can be applied here. Healthy stock can generally withstand a 1°C of temperature variation for every 25 mm of fish length.

If the temperature difference is greater than that allowed for by the rule of thumb, the process needs to be gradual. Introduce the fish to the new water gently by mixing the pond water with the carrying water. The mixing should be slow. If the carrying water and the pond water are as close as 2°C you should be able to start and finish the mixing procedure within about 10 minutes. If there is a temperature variation greater than 3°C, a more gradual process is needed and the process could take 20 minutes to half an hour. One of the authors recollects watching one person undertaking the mixing process. A plastic rubbish bin was filled with pond water and an aquarium airline hose was used to siphon this water into the transport water. Aquarium airline hose does not have a wide bore and it takes a while for the process to be complete.

While the water is being mixed, aerate the transport water to maintain maximum DO levels to reduce stress on the fish. Continue with the aeration right up until the fish are released in the system.

Liberation

When it comes time to liberate the fish, do it gently. Don't stand up and chuck a bucket-load in from a distance. Place the container in the pond and let pond water swirl in. Remove the bucket gently, leaving stock behind. Liberate around the pond to minimise crowding.

Crayfish that have been out of water for a while may have had the water fall out of their gill cavities. If this is the case, and they are dropped straight into the water, they may float for a while, becoming very attractive to any birds in the proximity. It's best to liberate them right beside the water where they can walk in, holding onto the bottom and void their gills of air.

After liberating stock, hang around until you can see that they are oriented and have moved away from becoming prize targets for birds.

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14

Breeding

In this chapter we'll look at the things the farmer should consider when breeding seedstock for the market or for their own system. Topics covered include:

- Selecting broodstock
- Conditioning broodstock
- Spawning
- Incubation of eggs
- Rearing larvae.

Selecting broodstock

As seedstock production has been described as the foundation upon which aquaculture is built, it is vital to the industry. The best offspring come from the best parents, so selecting the right broodstock is a key ingredient for successful breeding.

Ensure the brood fish are in the best of health. The standard of eggs, and the food reserves they contain, is strongly dependent on the health of the female. When the larvae hatch, they will have a greater chance of survival if they are well endowed with nutrient reserves, or as is sometimes said, 'come with a full suitcase'. The quality of sperm might not depend so much on the health of the donor male, but if the male parent is not in good condition, he might not supply the quantity needed, or even feel like performing at all.

Stock may appear unhealthy because they carry infectious disease. Infectious disease may have serious consequences if it can be transmitted to the young. Not only may it induce mortality or slow growth, but if the word gets around that a producer is selling infected stock, the price that can be obtained for the stock will fall – if the stock can be sold at all. There is even the possibility that government agencies regulating the aquaculture industry may step in and quarantine the producer, leading to financial disaster. Avoid sickly looking broodstock.

Some diseases can be transmitted from parent to offspring. An example is nodavirus in barramundi. An infection rarely shows in adult stock, but the larvae can die from it. It is sometimes possible to test for the presence of the pathogen in potential broodstock and discard infected animals. The larvae can then be accredited as specific pathogen free (SPF) and command a premium in the marketplace. In some states, notably those outside the barramundi's natural range, purchasing stock from an SPF certified hatchery is a mandatory part of the policy for that species.

Healthy finfish

You can tell healthy finfish by an appropriate level of fat reserves, good clear eyes, no excess slime on the body, no ulcers on the side. For more details see chapter 15.

Healthy crayfish and molluscs

It can be more difficult to gauge the health of crustaceans and molluscs. One method is to determine how fat they are in the shell. A healthy animal has plenty of flesh to fill their shells, and an experienced operator can pick up individuals and tell by the heft whether or not the shell is full. This is a skill that requires a bit of experience but can soon be picked up. In species like prawns a good colour is an indication of health. Look for a clearly defined normal pattern with colours bright and clear. Listless individuals should be avoided.

Selection of sexually mature adults

Broodstock need to be sexually mature. The ability to distinguish mature individuals involves doing your homework on that particular species. Size is often used as an indication, but even in closely related species, the size of first maturity may be dramatically different. For example, blacklip abalone usually first mature at a shell size somewhere between 60 and 80 mm, but related species (eg *Haliotis coccoradiata*) will mature when they are smaller than a 20 cent piece.

The size of the individual brood animal may be of importance. It is common belief that the bigger a brood female, the better. The reasoning goes that bigger brood females carry more eggs, so that inducing spawning is likely to result in a larger number of offspring, thereby reducing the unit effort required of the farmer for each offspring. This view may sometimes only be partly correct. Younger animals are quite often more fertile, and produce higher quality eggs, with a resultant reduction in mortality of the offspring.

Selective breeding

From time to time the authors hear discussion on improved genetic lines for aquaculture. In the well-established non-aquaculture farming sectors, selective breeding has produced far-reaching developments in farm stock, with very significant increases in efficiency of production. Overseas work with salmonids would suggest that gains from genetically selecting aquaculture species for their farming attributes will offer major benefits to fish and crayfish farmers. Research in Queensland has shown that some strains of redclaw are much more suited to farming than others. In the USA and Europe, there have been some particularly fast-growing strains of salmonids developed.

However, the concept of acquiring a better-performing variety is something that should be tempered with common sense. The authors remember how certain entrepreneurs have made extravagant claims for lines of stock only available from them. Time has shown that many of the claimed benefits were illusory. One of the authors has worked in several states at various times. He noted that in each place the locals have species that they suggest is the best in the world for some particular reason. Usually the reasons put forward are logical and well argued, and seem to make sense. However, after you have heard the same claims made for a variety of species, all well argued, scepticism sets in.

Some people believe they can obtain better genetic lines by importing them from somewhere else. There is an old saying that 'An expert is someone from out of town', and the further from out of town, the more expert they become. The same psychology seems to apply to farm stock: if it comes from far away, it acquires a glamour that makes it somehow far more desirable. In fact, the opposite is more likely to be true as local variants are already pre-adapted to local conditions and farming methods.

Claims made for high-performance aquaculture stock should be carefully assessed before you part with your hard-earned cash. In fact they should be backed by scientific evidence. Check with other farmers, then do a cost–benefit analysis before expending time and effort seeking the magical better line of broodstock.

There is another consideration, since most aquaculture species are naturally occurring indigenous species, should farmed fish escape, they have the potential to breed with their wild cousins. Conservationists are concerned that traits that might be bred into farm stock, might not produce the fittest wild stock, and generally weaken the race. While this refutes Darwin's theory of survival of the fittest, it has become part of the translocation policy of some states. In some cases rules have been instituted requiring strict isolation provisions for given cultivars, and complying with these rules can increase farming costs significantly.

Breeding performance

Some broodstock are good performers and others aren't. For no obvious reason some have different likes and dislikes. When it comes to breeding, some take to mating and breeding readily, and some are duds. Sometimes success just takes practice and all the duds need is a little time to adapt. Murray cod take some time to settle down in their brood ponds. However, with some individuals they just don't perform. These stock should be abandoned.

Broodstock that have been induced to breed with hormones should be changed regularly as they suffer from burnout under these circumstances. Certainly fish that have been induced five times deserve to be put out to pasture.

Sexing broodstock

Assuming that the broodstock are healthy, mature and of appropriate genetic lines, the next step is to distinguish males from females.

Indicators of sex of farm stock are often species-specific. It is essential to do your homework to be able to successfully sex them. It is beyond the capacity of this book to provide details on all possible species, but a few examples will provide general principles. Once you have the principles, you can search out the information you might need for the species of your choice.

Many species of finfish are easy to sex, but some may be hard. Ripe male finfish will sometimes dribble sperm if lifted out of water and held. Light pressure around the vent will stimulate ripe males to release milt. Females develop a swollen belly when they are full of eggs. Colour and fin shape can be a guide. In the case of some species of aquarium fish, the males are more ornate with longer fins that extend out and have pointed ends.

Size is sometimes important. For example, barramundi first mature as males, so that a fish smaller than about 1 m in length is almost certain to be a male. But they change as they grow and if a barramundi is over 1 m, then it is very likely to be a female.

Crayfish expel eggs and sperm through pores (termed 'gonopores') at the base of their legs. Identification is assisted by the fact that the pores are on different legs in females and males. In the case of the male they are at the base of the rear legs, and in the female, on the second pair from the front. In some instances there are secondary identifying features: in redclaw crayfish, the red on the claw is more prominent in males.

Marine lobsters have more or less the same arrangement with pores on their legs and can be sexed in the same manner.

Prawns have separate sexes that stay distinct through life. Mature female prawns have an external receptacle for sperm packets called a 'thelycum', which is situated between the fourth and fifth pairs of legs. In some species it is closed by a couple of flaps, but more commonly it is a series of open, plate-like structures. The males have an appendage called the 'petasma' which is used to transfer sperm packets to the female. It resembles a penis and is formed from the front pair of swimmerets (pleopods) under the abdomen.

Molluscs such as abalone develop their eggs and sperm in gonads located just under the soft skin visible between the foot and the shell. In the males, the gonad containing sperm is tan, but in the females, the eggs are green. (The distinction can be obscured in inactive females, where the green colour can fade to brown.) In species of abalone that have little pigment in the skin (as with greenlip abalone for example), the colour of the reproductive organs is easily seen through the skin and it is relatively easy to determine the sex. In species with more pigment (like blacklip) it is more difficult, but facility comes with practice.

The sex of bivalves, such as scallops and mussels, can be difficult to determine by external examination, and opening the shells to view the internal organs is likely to cause damage. However, the inability to guess sex in bivalves is generally not a problem as they spawn en masse, so that large numbers are likely to involve a good mix of sexes and sexing of individuals is not required.

Under some circumstances, it may not be necessary to actually determine the gender of the individuals involved. The individuals are able to undertake this task themselves. If you put five or ten individuals in a container, chances are that you will get a mix of sexes. Natural pairing will take place. In the case of freshwater angel fish for example, two of them will pair up, and go off to dig a nest by themselves which they will aggressively defend, often confining the other fish to a corner of the aquarium.

Conditioning the breeders

Broodstock have to be ready to breed. All the technology in the world cannot make a female fish breed if there are no developed eggs in her belly. Trying to induce spawning in an unready individual may damage its health. The process of bringing stock to readiness is generally termed 'conditioning'. Various techniques are used to ensure stock are in breeding condition at the time required by the hatchery operator.

There are many reasons why stock are not ready to breed.

- *Age influences stock's propensity to condition*. There is no point trying to condition an animal that has yet to attain sexual maturity. Unfortunately wild stock rarely carry a notice of their age, and it usually has to be inferred by size. This requires an understanding of the species. If information cannot be collected from other sources, one method is to sacrifice a few individuals, and dissect them to determine if they have developed sex organs.
- *Old age may have an impact too*. Very old individuals rarely make good broodstock. Age in fish is accompanied by growth. Large individuals will be old fish.
- *Stress can delay conditioning* and external events may distract stock from breeding. Distractions/stressors can take the form of people or shadows moving past the holding area, or loud noises. One of the authors remembers that when he used to work in an aquarium shop, it was uncommon for fish to breed in the display tanks. However, the shop used to close for a few days over Christmas, and when the staff returned, large numbers of fishes would have taken advantage of the quiet to spawn. The principle applies to larger species: curtains surround barramundi broodstock tanks, with 'No Visitor' signs prominently placed.
- Of course the best, or worst, *stressor is poor water quality*, followed closely by overcrowding. When human couples fail to conceive, one of the first treatments suggested is for them to take a holiday. If they move to a stress-free situation, nature may well take its course. To condition aquaculture broodstock, provide, what is to them, the equivalent of a comfortable stress-free holiday.
- *A variety of good foods is a key element* in conditioning stock. Fish diets are improving all the time, and most formulated food contains all the nutrients the stock might need, but a little extra variety never hurt anybody. Aquarium fish breeders in particular make a habit of varying the diet of their broodstock as much as possible, and including as much live food as possible.

  Having emphasised the importance of variety in food, it is worth noting that some experienced breeders contend that, as a species becomes adapted to living in captivity, it becomes easier and easier to bring them to condition, and they don't seem to need to have the variety required by their wild cousins.

  There can be too much of a good thing. One of the authors worked in a barramundi hatchery where the prime brood females stopped producing. One of the females was sacrificed for a post mortem examination and was found to be very fat and oily. The vet suggested this was what was preventing egg production. These fish had been fed on a diet of anchovies, which were very oily and it seemed likely that this diet was too rich for the barramundi. The diet was changed, with mullet being substituted. The brood fish grew meaner and leaner, and performance improved.
- *Adequate exercise is generally considered to be important* for health, yet brood fish are often confined in small tanks where they can hardly turn around. Large holding tanks can be expensive, but if broodstock are not performing it is worth investigating if they will benefit from more room.

Breeding triggers

Each species will have its breeding trigger. Temperature and/or day length is the most common trigger for the commercial species. Murray–Darling perch species breed at water temperatures above 23°C; the intensity of the breeding appears to be dependent on the extent of the flood of the particular season. Murray cod breed when water temperatures are above 20°C. The season or the weather can have an impact. In many cases, species time their breeding to bring young into the world when there is the most food and cover, thereby giving them the best chance of surviving. In southern climates, this time is usually spring. In the tropics things are not necessarily so locked-in, but species like barramundi generally cease to be interested in breeding in the dry season, when the productive coastal wetlands have dried out and are no longer available to the young. Some species are more opportunistic. Many of the Murray–Darling fish breed following a flood, when the flood plains are inundated and there will be plenty of food for the larvae.

Goldfish farmers will tell you that their stock only come to the best breeding condition following a cool winter, when the brood fish are ready for spring.

When the causal factors are understood, it may be possible to control when a species will come to condition. In the NT, some barramundi broodstock are kept in cool conditions over the wet season, and then warmed at the start of the dry, simulating a climate six months out of phase. These fish become ready to breed over the dry season, when their wild cousins are not active.

In cases where species breed only once a year, such as Murray–Darling perch and cod, and Northern Hemisphere salmonids, growers have to stagger the production of that seedstock to ensure markets are serviced on a 12-month basis. This means holding stock back to satisfy the year-round market demand for a standardised product. As fish grow faster when they are young, valuable production efficiencies are lost through this practice. Hatchery operators can, by manipulating exposure to light and water temperatures, control the breeding cycle of some species to ensure out of season seedstock production.

Signs when fish have come to breeding condition

Breeders who have an understanding of the biology of their stock know when their stock are ready.

Finfish

Some species of finfish show very clear signs: their colour and pattern becomes brighter and the fish can display behavioural traits. An experienced eye can pick the signs straight away. When male finfish are running with milt (that is, white liquid is expressed when they are lifted from the water), they are generally ready. Signs of breeding condition in female finfish may be a little more obscure – it could be a belly full of eggs, slightly swollen and an extruded and inflamed vent. A practised operator familiar with a fish can pick maternal swelling. This is not a perfect guide as a good meal can result in swelling, as can digestive disorders.

More technical approaches involve direct inspection of eggs to see if they are ready for fertilisation. The first step is to obtain the eggs. In most commercial finfish hatcheries, female fish are 'cannulated'. This involves inserting a plastic tube (often aquarium-size air hose) up the anus/genital opening of the brood fish. Slight suction is applied to the other end of the tube (usually from the mouth of the hatchery operator) and some eggs are sucked out. The eggs are then examined under a microscope. This process requires a light hand, as it can be very stressful, and it is common practice for the fish to be sedated. The technique is best learned directly from an experienced operator.

The maturity of finfish eggs can be determined by examination. Generally a microscope is used to examine the internal components of the egg. Mature eggs contain clearly separated oil droplets (that are not extremely dispersed) around the nucleus. A practiced operator may not need a microscope and can often judge the stage of readiness of the eggs by eye.

Crayfish

With species like crayfish, there are few external signs of conditioning and you just have to rely on experience to get it right. Crayfish breeders usually have a high degree of success.

Prawns

The species of prawn most commonly farmed in Australia, the black tiger prawn, is not very amenable to domestication. For this species, the industry still relies on catching females from the wild that have come to sexual maturity before harvest. Many of the brood females caught are not only in condition, but have also engaged in sexual congress with males, and carry, in sacks, raw sperm ready for fertilisation. Since the harvesting relies on commercial techniques designed to trawl prawns for food, the stock receive rough treatment, and the capture process damages many. All are stressed to some degree.

Prawns holding eggs can be readily distinguished from those without. Prawn flesh is more or less translucent, and the eggs inside a female prawn can be seen through the body wall. Larger prawns tend to be less translucent, but it is still possible to see the eggs if a light (for example a torch) is held behind the flesh and the prawn viewed from the other side.

Research is being undertaken to further develop the technology to condition black tiger prawns in captivity and this may be an area where advances occur in the coming years.

Species of prawns other than black tigers may not be so difficult. Banana prawns readily condition in captivity, and closing the life cycle is not an onerous task.

Molluscs

In some gastropod molluscs, for example abalone, a swollen egg sack can be detected by eye. Individuals ready to breed have full reproductive organs. If you are familiar with how those organs normally look, it is not too difficult to identify when the organ is swollen, usually showing strong colour from the eggs or sperm. A more technical approach can be adopted by directly inspecting eggs and milt, either by sacrificing an individual, or by careful extraction through the body wall. Mature eggs are clearly separated and are not mushy or broken down.

Bringing stock to condition may incur costs and take up time. Some aquaculturists attempt to avoid these costs by taking 'short cuts' which may, or may not, actually result in savings. The authors have seen potential abalone farmers propose to harvest conditioned stock from the wild, planning to induce breeding shortly thereafter. The process of harvest then translocation to hatchery can be extremely stressful. The stock might be induced to breed; but then again they might not. Stock respond better if they are kept in good health and in a stress-free environment for an appropriate period of time. Not only is there greater success in achieving and maintaining breeding condition, but the stock become more predictable in their response to husbandry, with the most likely result being a reduction in overall costs.

Spawning

Spawning is the shedding of sperm or eggs for the purpose of fertilisation.
If fish farmers fully understand what makes their stock spawn, they can control when and where spawning takes place. Having this control is often essential, as many of the arrangements needed for the care of newly conceived individuals are best set in train before conception, so they are in place when the resultant young require them.

There is usually some event, a 'trigger', that spurs a well-conditioned animal into the breeding act. For some species, the only trigger needed is the presence of a well-conditioned member of the opposite sex, but other species/individuals sometimes need a particular stimulus. The actual stimulus can vary from species to species. (There is a general rule though; the more complete the conditioning of the parent stock, the lesser the stimulus required.)

Figure 14.1. A Murray cod breeding box on display during a warm water aquaculture workshop.

Triggers to spawning

- The least intrusive stimulus the farmer can use is a water change. The water change is often accompanied by a mild temperature change too and this may have an additional triggering effect. If the breeding behaviour of the species of your choice is not established, and conditioned stock appear a little reluctant to perform, a water change is probably the first thing to try. This stimulus will often work with a very diverse range of species from finfish through to gastropod molluscs such as trochus and abalone.
  In the case of stock small enough to be kept in an aquarium, or similar size container, undertaking a water change is not too difficult. However, if you are trying to induce spawning in a one-hectare pond, it may well involve a little more trouble.
- Passing a temperature threshold might provide the necessary trigger. When breeding fish in an open pond, for example with Murray perch, spawning often occurs when the water temperature reaches the mid-20s (°C). With goldfish in outdoor ponds, the threshold temperature is lower, in the high teens. In these outdoor circumstances, it is splitting hairs to ask whether or not the temperature induces conditioning and readiness, or whether it actually induces the spawning. What is important to know, is what the threshold is, and when the pond water is likely to pass it. Once that happens, your task will be to collect the eggs.
- Some reluctant finfish require a dose of hormone to make them perform in captivity. In days gone by, a hormone extract was taken from the pituitary gland of carp and injected into the brood females. The extract provided a mixture of hormones that had a multiplicity of effects. Amongst these effects, appropriately conditioned females would expel eggs, and males (being males) took advantage of the circumstances to fertilise them. Another very rough method involved injecting a large dose of hormone into a sacrificial fish, and feeding that to the broodstock. These were very inexact approaches.
  In more recent years, purer forms of hormones are being injected into brood fish in carefully metered doses. The hormones are usually the same as those used for human fertility treatments. The hormones are only available on prescription from vets. Injecting fish with hormone is a process that is best learned from an experienced operator.
  Hormone dosages vary from species to species, and dosage information is generally obtainable for most species of finfish. It is worth noting that some dosage rates are a little flexible, and it seems that for a given species of fish, cooler climes require greater dosages.
- Sometimes, brute force is required, Some fish, like salmon and trout, have the eggs and milt forcibly stripped from conditioned adults, basically by squeezing a conditioned individual. The eggs and milt are then physically mixed in a bowl to achieve fertilisation.
- Salmonid eggs, if subjected to a sudden change in temperature just after fertilisation, will become triploid. The hereditary material, DNA, is not changed, but some of it is doubled up. Triploid fish do not mature sexually. They become

something akin to a neutered tomcat. Since they don't waste energy on sex, they grow fast and become fat, and in some species, grow to a larger size. In some farming sectors this can have a favourable influence on profitability.

- With crayfish, the season may control when the species is ready to breed. This is clearly true of marron. Yabbies appear to be a little more flexible, and redclaw, in tropical environments, seem not to be too influenced by season at all. (However, they do exhibit some seasonal sensitivity when kept at the cooler limits of their natural range.) In the past, it was commonly held that day length had an impact on yabbies' propensity to breed, and breeding facilities were provided with artificial light to increase day length. Contemporary thinking is to downgrade the importance of day length, and to suggest that the key determinant is temperature.
- It is not commercial practice to give any chemical stimulus to induce hatchery crayfish to breed.
- Prawns differ in their pattern of breeding. When males and female prawns copulate, fertilisation does not necessarily occur at that time. The male gives the female his sperm in sealed packets. She retains them, still sealed, for later use. If the mother prawn is subject to stress she may not use the sperm, saving her energies for more immediate survival. It has been found that the hormonal balance of a gravid female prawn can be altered by amputation of an eyestalk. This process is termed 'eye stalk ablation'. The result is fertilised eggs.
- Molluscs that are fixed to the seabed, such as oysters and mussels, are at a definite disadvantage when it comes to sexual congress. They can't move. So they utilise spawning methods that work without actual conjugation. They rely on the fact that there ought to be other individuals, of the opposite sex, not too far away, and if they release gametes into the water column, they will find an opposite number, with a fertilised egg resulting. It's not only fixed species that do this. Abalone are able to move, but still shed eggs and sperm for external fertilisation.

  To prevent wastage, shedding of gametes needs to be coordinated, and this may rely on an environmental trigger. For example, an increase in water temperature provides the appropriate stimulus for many species of molluscs. The presence of other spawning products (eggs, sperm and associated compounds) in the water may act as a stimulus for many species. Abalone and some other molluscs also respond to certain chemicals in the water, for example, hydrogen peroxide. If water is exposed to concentrated ultraviolet light, chemicals are produced that also provide a spawning stimulus. These stimuli have been utilised to induce spawning-conditioned broodstock on farm. The ultraviolet light method is convenient, allowing the farmer to: set a timer switch on the light, go home and get a good night's sleep, and to have a good chance of finding fertilised eggs on return to work in the morning.

  When fertilisation occurs externally, and spawning can be controlled, this opens another option for the farmer. It becomes relatively easy to mix eggs and sperm of different, but related species (for example, greenlip and blacklip abalone) to produce a hybrid. Fertilisation success rates are usually lower than for the same species, but some hybrids have commercial advantages. Most hybrids are sterile, don't waste growth energy on making eggs and sperm, and may therefore grow faster with less food. The hybrids may appear attractive in certain market sectors, increasing the price that can be obtained for them.

Taking care of eggs

A successful spawning produces a fertilised egg. If they aren't cared for in an appropriate way, they may well be lost to the farmer. When fertilisation occurs in open ponds, it is sometimes desirable to harvest fertilised eggs and put them in conditions where they can be given special attention.

Murray cod can be left alone to condition and spawn in an outside pond. It is in the nature of these fish to find a protected place to lay their eggs, and this is often inside a hollow log. The adhesive eggs are attached to the inside wall of the log by the female, and the male passes over, spreading milt to effect fertilisation. Farmers have utilised this natural inclination by making fake hollow logs, which are essentially a metal frame in the shape of a tube, that are wrapped in shade cloth. At the right time of year, the farmers check the inside of the egg tube on a regular basis, usually by an operator duck-diving and running a hand over the inside. When eggs are felt, the tube is retrieved from the pond, the shade cloth unwrapped, and the parts with eggs adhering to them are cut into convenient-sized strips, which can be given special care.

Goldfish will spawn adhesive eggs over vegetation in shallow water. On farm, vegetation is replaced with artificial 'spawning mops' that are later removed and taken to a nursery pond.

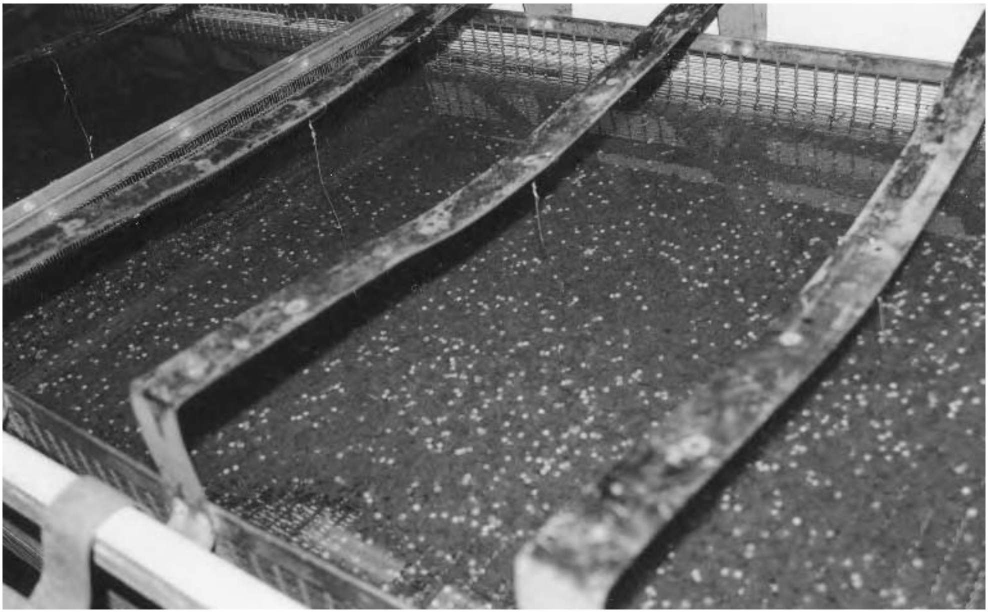


Figure 14.2. Murray cod eggs on trays during incubation. Notice the dead eggs, prospective sites for fungal infection, showing up as white specks amongst the healthy eggs.

Figure 14.3. A simple but effective way of inspecting egg condition at the breeding tanks. A magnifying glass is a handy tool around a fish farm.

Barramundi may be induced to spawn in large holding tanks. Their eggs are not adhesive and become distributed through the water in the tanks. Collecting these eggs by hand can be difficult so a trap has been devised. The trap is a floating basket, usually made out of very fine mesh and often supported by a PVC tube collar. Water is moved into the basket by an airlift tube, which has its intake outside of the basket. This trap is left running in the tank, when the barramundi are hormonally induced, and after some hours will collect most of the fertilised eggs.

A mother *crayfish* will carry eggs, and newly hatched young, under her tail. A female in that condition can be moved to wherever the farmer wants, taking the eggs/babies with her. If the female is placed in a mesh cage, the young, when ready, can fall through the mesh, stocking a pond without having any adults liberated in there as well.

Some *bivalves*, for example *mussels and edible oysters*, naturally reproduce in the wild, and the resulting larvae settle onto suitable substrata shortly thereafter. Farmers catch the newly settled larvae by placing suitable substrata where young are likely to settle. Mussel farmers use ropes hung from buoys and long lines, and in the NSW oyster farming industry it has been a longstanding practice to place sticks in the water to collect oyster spat.

Once eggs have been collected, they can be cared for. Eggs are generally well supplied with nutrients to provide the new individual the best chance to grow and develop. Other organisms, such as predators, or decomposers like fungi and bacteria may attempt to exploit that nutrient for themselves. The technologies of aquaculture protect the egg and dramatically increase the number of individuals that survive to grow.

Finfish eggs are prone to attack by fungus and to a lesser extent by bacteria. Some species, for example, cichlids, a group of aquarium fish, are very attentive parents and tend their eggs, removing any that might have died and contain fungus that might infect other eggs. Perhaps the most extreme care is given by mouth-brooders: fish that keep the eggs and young safe in their mouths. Not all finfish are such good parents and sometimes the farmer has to assist with the incubation. Eggs are generally kept in the best quality water with a gentle current or aeration. It is common practice to treat them with a mild fungicide, such as a methylene blue solution or diluted formalin, and to renew this treatment if needed.

Adhesive eggs, with the right technology, can be easy to handle. As described above, *Murray cod eggs* can be on strips of shade cloth, and *goldfish eggs* on spawning mops. Other species of fish, such as some aquarium species, can be induced to lay eggs on a tile or a sheet of glass, and this also can facilitate handling.

Some finfish eggs are not sticky. Examples would be the *eggs of golden perch and silver perch*. These eggs can require a little more care. They can be placed in a smooth-bottomed container, and a gentle current of water passed over them, just fast enough to gently turn over the eggs, but not so fast as to wash them away. There are proprietary containers available for this, but the authors remember a time when plastic Coke bottles had rounded bottoms and made very useful egg incubators.

Crayfish eggs can be removed from the mother and incubated separately, but there is no real advantage in doing this. It is not common practice.

Many of the invertebrates and marine species, such as *abalone*, produce a large number of very small eggs, but these often hatch into larvae in a very short time, so the incubation phase is not an overwhelming part of the breeding process for these animals.

Figure 14.4. Hatchery reared yabbies are bred in flow-though breeding boxes. It is a labour intensive procedure but rewarding in the long run.

Rearing larvae

When eggs hatch, or develop to a stage where movement is possible, the resulting juveniles are termed larvae. The process of rearing these larvae is, in most aquaculture sectors, referred to as the nursery stage.

Some species have very small larvae that take a long time to mature, and this can add significantly to costs. Rock lobsters provide an example. Many marine species of finfish also have small larvae that are difficult to rear.

Various technologies are used for the nursery stage, determined very much by the natural biology of the species being grown. When there are alternative technologies available, the most appropriate one depends on a trade-off between the cost to build and establish the hatchery, the costs of production and the reliability of the process.

Nursery facilities can be intensive, using specialist equipment, power and plumbing under a roof. Under these circumstances the environment of the larvae can be closely monitored, hopefully being maintained at the optimum. Predators are denied access.

The infrastructure of these nurseries is usually similar to that used in intensive growing of larger fish, but with appropriate adjustments made for the size of the stock. Larvae are considerably smaller than adult stock and this is reflected in the size of the facility needed.

A key ingredient of success is providing food that the stock find attractive. The kind of food may also be changed as the larvae develop.

Some larvae, especially those that are quite small, are adapted to eating floating algae. In intensive nurseries, algae are provided by the nursery manager, usually in the form of cultures of one species of alga. *Tetraselmis* and *Isochrysis* are examples of such algae.

As very small larvae grow to a larger size, or for species that hatch out at a larger size, the preferred food changes to zooplankton (small animals that swim through the water

Figure 14.5. A typical algae room.

column). Quite a few stock species are stimulated to feed by the presence of live moving prey. In many nurseries, small animals like rotifers and copepods are cultured as food items. As larvae get larger still, they can be fed on larger food such as brine shrimp larvae.

It is not uncommon for intensive nurseries to run three farming processes at once: they grow the larvae, grow the fodder animal used to feed the larvae and also the algae that are used to feed the fodder animal. This can be complex and costly. The authors have noticed a trend toward packaged nursery feeds (algae and microgranules) over recent years. These packaged foods are costly, but do add to convenience, and their quality and availability have been steadily improving. Unfortunately not all species can be induced to take non-moving food.

Other stock species are adapted to grazing off a surface, rather than plucking food out of mid-water. The larvae of these species graze on bio-films (sometimes less charitably referred to as slime).

Natural bio-films consist of a variety of life-forms. They can include bacteria, and single-celled algae, predominantly diatoms. In some cases they also include the smaller multi-celled algae too. As larvae grow, they may move from eating the smaller individuals of slime life to larger ones.

The technology for producing bio-films can vary from simple to quite sophisticated (see chapter 8). The species of algae may be selected for nutritional value, and also for a size most easily handled by the dental equipment of the farm species, which will change as the animal grows.

Managing an algal lawn grown on a plate can require close attention. Fortunately there are tools that enable the farmer to match the pace of growth of both crop and larvae. Algae are plants, and their growth is limited by the availability of plant nutrients and light. The amount of light is the easiest to control, and many algal plates are shaded for the first parts of the nursery growing process. Some aquarium fish require algal lawns. Other species such as catfish and loaches live off the bio-films on the plates.

The food does not necessarily have to be algae or bacteria. Fish food can be crumbled and mixed in with a jelly. When jellies are warmed, they become liquid, and plates can be dipped in the liquid to produce a jelly/food layer.

Nurseries can use more extensive technologies outdoors in specially constructed ponds that can be produce an environment suited for the survival and good growth of larvae.

Many of the stock species grown in outdoor nursery ponds feed on planktonic algae and zooplankton. The pioneers of this approach noted that when an empty pond is first filled, a succession of creatures appear. The first thing to appear is planktonic algae. The algae provide a food source for the smallest of the grazing animals (zooplankton), which then start to increase in number. Once there is a steady population of small zooplankton, this provides a food source for larger zooplankton that may eat them … and so it goes. The idea is to stock the larvae into the pond when it contains algae or zooplankton of the right size to be eaten, but not so large to be predators that attack the larvae. Depending on the size of the larvae, and the local climate, these ponds are filled about a week before the larvae are stocked into them. As the days pass, the larvae should grow to stay ahead of the rest of the life in the pond.

Judicious fertilisation of these 'plankton ponds' can boost productivity and growth of larvae. Per unit fish, plankton ponds tend to be cheap, but until the pond is drained to harvest the grown larvae, it can be hard to predict the survival percentage, making forward planning more difficult.

Species like golden perch and silver perch, which are grown in the cooler parts of the continent, are often reared using a plankton pond nursery stage.

Barramundi are reared using a wide range of technologies. In Queensland plankton ponds are commonly used. Some precautions may be needed for this species. Very small barramundi, in nature, take up life on the coastal mudflats and perhaps in mangrove communities. Water here is very salty, and there are few naturally occurring predators, so at this age the barramundi do not have many natural escape responses. Despite their natural propensity to seek out a saltwater habitat in the wild, young barramundi have the physiological capacity to live in freshwater. Farmers take advantage of this and stock juvenile barramundi into freshwater ponds. However, these ponds often contain insect and fish predators to which the young barramundi are easy prey. Some farmers find it useful to keep barramundi larvae in shade cloth net cages for the first couple of weeks. Barramundi are also grown in intensive nurseries under roof cover.

Grazing species are grown outdoors as well as under cover. Some farm species feed on detritus found on pond beds (see chapter 8). Crayfish are such a species. Farmers flood a grassed pond, allowing the submerged grass to rot, then stock it with small crayfish. The decaying grass should provide them with food for the first few weeks of their lives. However, as they grow, crayfish will eat the first lot of detritus. Some farmers have ponds that they fill progressively, increasing the area under water and thereby increasing the amount of detrital food. This works well enough, but rarely is there enough area to continue to do this for the whole of the growing cycle.

With prawns it is common practice to rear larvae in an intensive nursery under roof. They are fed first with algae, then moved onto live food or formulated food. Not only are larvae kept in a nursery, but it is common practice to keep them for an extra fortnight after they pass out of the larval stage, so that the resulting stock are termed post-larvae or PL for short.

With molluscs such as mussels, oysters and abalone, it is the natural biology of the larvae to go through a short floating stage that finishes when they settle onto the seabed and become 'spat'. Spat are more or less miniature versions of adults.

Oyster spat can be caught from the wild, but the industry is increasingly moving to hatchery and nursery technology, spawning the stock in intensive management, and settling the spat onto small pieces of sand or shell. The spat can then be easily transported and handled.

In the mussel farming industry, spat are caught from the wild, avoiding the need for a nursery stage.

Once stock have moved through the breeding and larval rearing stage, they become juveniles, fry, spat, and from a functional point of view become seedstock. They are ready to move into the next stage, which is termed 'grow-out' (or in the case of oysters 'fattening').

15

Fish health

This chapter gives an idea of how to approach fish health management and some basic procedures for the fish farmer. Topics include:

- components of infectious disease
- external and internal diseases
- treating disease
- anaesthesia
- some of the more common diseases.

Keeping fish healthy is essential. As fish farming systems are dynamic and volatile the penalty for not being vigilant is a lot of backbreaking digging to bury the crop.

Managing fish health can be a complicated matter. Even though system managers are not expected to have more than a basic knowledge of fish diseases and how to treat them, they should have a thorough understanding of how diseases work.

Two things to bear in mind:

- you're more likely to have disease in the hothouse environment of an aquaculture production system than you are in a low density pristine river system or an open ocean; and
- you must think health rather than disease.

Components of infectious disease

As with human health management, it is easier and more cost effective to prevent disease than to treat it. First, we'll be looking at what allows a pathogen to become a threat to our stock.

For a disease to take hold, three elements need to coexist in the system:

- an environment conducive to disease (conditions that help the pathogen or suppress the immune system of the host, such as stress);
- a susceptible host; and
- the pathogen or parasite.

Figure 15.1 shows that where these three elements overlap, disease occurs. Remove any of the elements and the disease can't exist.

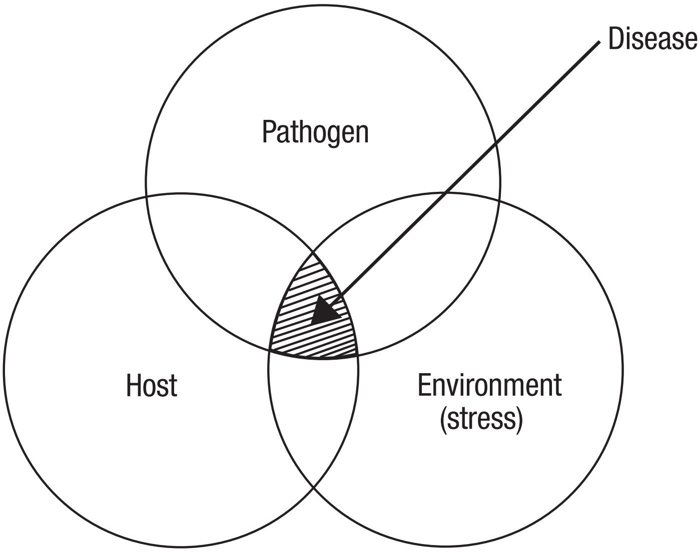


Figure 15.1. The three elements required for disease to flourish.

The environment

The environment is often the easiest of the three components of disease to tackle. If we keep our fish production systems as close as we can to conditions found in a pristine river system or an open ocean, the less likely we are to have disease. A challenge? Yes, but it is achievable. If you can get the environment to a stress-free level, it will be more productive.

The opposite of a diseased condition is a healthy condition. To maintain a fish farm in good health is the production manager's job. The two key impacts on fish health are water quality and nutrition.

Water quality

Water quality parameters outside the fishes' comfort zone will create stress. Stress will suppress the fishes' immune system, and if their ability to cope with disease is reduced this will allow the pathogen a toe-hold.

Critical pond conditions to monitor in this regard are:

- dissolved oxygen
- ammonia
- temperature
- pH.

Stability

Stability is another environmental factor that will help calm fish, presuming of course that the system is stable within the preferred parameters of the stock.

Hostile environmental conditions can attack the defensive mechanisms of the stock. As an example, healthy finfish are covered in a layer of mucus, or slime. This layer provides a protective skin between it and what's outside. Adverse conditions can overtax a fish's ability to manufacture mucus thus compromising the fish's own external disease barrier.

Overstocking

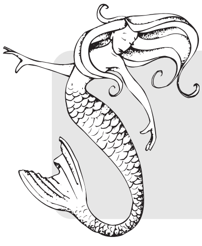
Overstocking is a common cause of stress. It is rarely intentional, so it may not be noticed immediately. Overstocking can cause two impacts. The first impact comes when densities are above the fish's social limit. Hierarchical behaviour will develop as the fishes' survival mechanism kicks in. The fish may appear to feed as vigorously as usual to the casual observer but there will be some fish hanging back from the feeding frenzy and falling behind in growth rates. This is reflected where growers say that once they graded the fish, separating the larger from the smaller, the so-called 'slow growers' caught up, to a degree.

A stressful environment is not only putting your charges at risk of disease but also costing you growth. Not being on top of when to grade stock is poor management. The argument, that there's no point in grading the fish until there's a significant size differential upon which to base a grading, doesn't hold water. For 'size differential' read 'slow growth'.

The second impact of overstocking is degradation of the biochemistry of the system, specifically a drop in water quality, under commercial feeding rates.

Overstocking becomes more of a problem as the fish grow to larger sizes. At this time there is the temptation to carry them through that last little growth stage to avoid one final grading, and the temptation can overrule sound management practice.

Avoiding the poor environment caused by both the first and the second impacts is simple: grade the fish, and sort into manageable densities before you lose control and the environment becomes excessively stressful for your stock. Once growth rates have been established, develop a routine for stock movement so none of the above overstocking scenarios arise.



GWQEHN says:
To know where your fish are going to be in 12 months time is to know what your bank balance will be at the same time.

Undernourishment

Undernourishment will cause stress. Undernourishment should not be confused with under-feeding (see chapter 9). A dietary deficiency will leave the fish malnourished, affecting the physiological capability of the animal to resist the incursion of disease.

Fish have a great capacity to conserve energy, but they still need nourishment. This is particularly significant in systems where the stock may not have access to natural food from which they can draw supplementary nourishment. Food should be carefully managed – if it has been stored for a long period, it can deteriorate. Vitamins are the first to break down, and their absence can in turn affect the fishes' immune system. When fats oxidise, they go rancid. Poorly stored food can become damp and colonised by fungus. Funguses produce aflatoxins that are poisonous.

Food that has gone off should be discarded. Don't even feed it to the dog. It should be buried in a place where its fertilising properties will most benefit.

Of course, if you've stored food correctly, and if you feel that the food has gone off prematurely, you may have a case against the manufacturer.

Water temperature

Water temperatures outside the species' natural range can cause stress. Stress is most often found at the higher temperature tolerance limit during summer or the tropical wet season, but prolonged exposure at the lower critical temperature limit can also place undue stress on stock.

If the farm site has been well chosen these periods should only be occasional and of short duration. Inducing the stock to take some nourishment during times of stress can be difficult, but it's worth trying. There are several techniques that might be used. Aeration and/or a flush of fresh water will often get stock stirred up. Some growers turn on the aerators in the late afternoon to mix the surface water with the water below the thermocline. The aeration and water movement will also have a positive influence on the pond. If the problem has arisen from low temperatures, look to feeding in the late afternoon when the sun has warmed up the surface water a few degrees. During a sunny period in the cooler time of the year, pond temperatures have been lifted by up to 3°C during a particularly long sunny period.

Even when not outside the fishes' preferred range, high water temperatures can also favour certain diseases without actually being overtly stressful to the fish. However, high temperature susceptibility is more likely to be found in cold water species such as salmonids than native species.

Minor infections

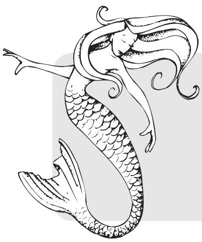
Minor infections can also cause stress. The presence of an otherwise minor disease reduces the fishes' ability to ward off the other pathogens. The result might be multiple infections and sometimes mortality. For example, wounds made by skin flukes can become a site for fungal or bacterial infection, the combination of both primary and secondary diseases can prove fatal.

The fish room

In most cases the fish room will be the same room in which the fish are purged and quarantined. If they are being brought in to treat a disease, it's essential to make sure there's no cross-contamination of fish already in the room and that no viable pathogens remain in the system after the diseased fish have been removed.

The ideal system would be one that uses flow-through bore water that is used to grow a terrestrial crop. This would deal with any water-borne pathogens and remove the need to operate a costly re-circulation system.

Remember, young fish are more susceptible to poor water quality and stress than older fish.



GWQEHN says:
The only short cut in aquaculture is the one straight out the back door.

A susceptible host

Having a susceptible host is unavoidable. After all, growing the host is what the whole exercise is about.

It is gross stupidity to choose to farm a species that will become susceptible under the farm's conditions. For example, goldfish soon become prone to skin diseases if kept in tropical temperatures.

In some cases, only a certain age group of stock will be prone to a particular disease. For instance, the nodavirus that attacks barramundi is expressed during the hatchery process and rarely worries the fish once they get passed the fry stage. To make it more insidious, to date it has only been recorded in hatcheries in Australia. It should also be pointed out that the disease is managed by hatcheries reducing stress by reducing stock loads.

The pathogen or parasite

Aquaculture 'invents' disease. Bacteria are present in an aquaculture pond at levels not usually encountered in the natural environment. Where bacteria might be present at several hundred per millilitre in a river system they can be at densities of 1 000 000 per millilitre in a normal aquaculture system. This doesn't mean they are going to overcome the fish, but the fish will need to be fit and healthy, and they can only do that with your help.

Pathogens sometimes come in from outside the farm. However, many of the common or garden diseases we'll be looking at here are ubiquitous. They aren't always at dangerous levels, but like fleas on a dog, they can wreak havoc if allowed to get out of control.

Quarantine

Quarantine can prevent the arrival of many pathogens – if they don't get into the system, they can't attack the stock.

Quarantine has been mentioned in other parts of this book but it deserves a mention again now that you have an understanding of disease and what it can cost you.

The money spent on good farm layout and pond design should also make more sense now. Don't skimp on the fish room either.

In normal farming arrangements, parasites and pathogens can be introduced in several ways:

- with incoming water;
- on organisms that arrive in your ponds with the incoming water;
- attached to birds and other predators attracted to your ponds;
- in bird and other predators' faeces;
- airborne;
- on in-coming farm stock; or
- on stock translocated from other systems, such as a nursery within the farm.

In some cases the susceptible host shares its living area with non-cultured species that find their way into the ponds with the incoming water. This can become a particular problem if the unwanted fish re-infest with every addition of water to the ponds. The authors know of one pond-based farm that incorporated the incoming irrigation water with an integrated agri-aquaculture program. On closing down, the manager cited, among other reasons, the inability to control parasites that came in with the water pumped through the ponds. Obviously the best form of defence is to strain the water as it comes into the ponds to draft off the unwanted carriers.

Some diseases pass through several cycles and utilise more than one host. The fish only serve as an intermediate host and the removal of the intermediary host will break the cycle. In the case of Trematodes, molluscs release the final larval stage of the pathogen, which must be ingested by water rats before they can mature as adult flukes.

Goldfish have a disease called goldfish ulcer disease (GUD) which also affects perch. This is a notifiable disease. Fortunately, the incidence of goldfish bringing GUD onto a property is uncommon, but the example demonstrates how effective predator exclusion control may also benefit from quarantine.

In cases where the farm is based on culturing, or introducing, fodder species to feed the species grown for sale, a judgement will have to be made as to the risk–benefit factors.

You can take precautions that enhance quarantine. Floating cages can be de-fouled from time to time to remove algal build-up. The de-fouling will help break the life cycle of pathogens that have settled on the netting of the cages. The usual procedure is to dip or soak the netting in a solution that will kill the algae. Then the nets are dried before the dead and dry algae are brushed or shaken off.

Pump-ashore land-based systems will have to have their pumping lines reamed from time to time as fouling builds up on the inside of the line. This will help remove the habitat of any organisms detrimental to the system. Another method of control is to have two pipelines. One is left static and sealed off while the other is in use. Water quality in the static pipe declines to the extent it becomes toxic to everything but bacteria, killing off unwanted fouling.

In re-circulation systems, tanks and piping may have to be sterilised between crops to prevent a pathogen becoming established, but most water can be sterilised during the operation of the system. Sound quarantine will reduce the need for this to a minimum.

Drying out the ponds between production cycles and maintaining adequate predator control will be major tools in the fight against disease: predator control becomes your quarantine control.

The vigilance against pathogens has to be never ending. They all have their preferred seasons and you will find you've just got over one wave of pathogens just as another is about to enter its peak.

A lot of government regulation is aimed at maintaining quarantine. Permit requirements to stock certain areas and limitations on moving stock from place to place or from state to state are based on the need to protect those areas from contamination. 'The National Strategic Plan for Aquatic Animal Health' is outlined in *Aquaplan*.

Having just sung the praises of quarantine, its time to bring in the 'but'. Exposure to sub-lethal doses of pathogens may help the fish develop a competent immune system, so don't go overboard trying to run a system totally free of all pathogens and parasites (not that you could achieve this anyway).

Correct diagnosis

A correct diagnosis has to be made before you even think about any kind of treatment for a disease. If you're not exactly sure what the disease is, don't try to guess it. Get a second opinion; either a more experienced fish farmer or a vet. Don't be afraid to ask. There are no dumb questions in aquaculture, just dumb answers.

Once you are sure of the cause, either having obtained a diagnosis or made one yourself, you can then remove it from the system.

If you can't identify the cause, then any treatment may be useless, or even worse, may be downright damaging. For example, dips that work well for external parasites will be useless to address internal parasites, but may stress stock. Antibiotics that work well on bacteria may be useless for a disease caused by a virus.

You don't have to become a fully-fledged vet – you only have to be able to identify common problems so they can be treated effectively. This should not be too difficult as most of the diseases you'll encounter will be of the common or garden variety, and these are well documented and illustrated in any textbooks on the subject. Sometimes, however, a disease may be unusual and there may be a bit of detective work required before a positive identification can be made.

There are many well-illustrated books available to draw on when confronted with some weird creature moving in the skin scraping under the microscope or a festering lesion the size of a golf ball. One the authors often reach for is *Australian Aquatic Animal Disease: Identification Field Guide* by Drs Alistair Herfort and Grant Rawlin. Published by Agriculture Fisheries and Forestry – Australia (AFFA). It is a comprehensive field guide that outlines the physical condition of the fish, their behaviour and the ecology of the disease in question. This is in addition to the cause of the condition, the species likely to be affected, where the disease occurs and whether or not it is present in Australia.

Another handy field guide the authors have referred to is *Fish Health for Fish Farmers* by Tina Thorne. Published by Fisheries Western Australia, this handy and inexpensive publication is well illustrated and informative. It can be obtained from the Department or any information service supplying aquaculture textbooks.

Should you add the above guides to your collection of reference books, don't be daunted by the horrific photographs. They are clinical shots chosen for their graphic depiction of the disease in question.

Diseases fall into categories

The diseases you're likely to come across fall into several categories. Generally speaking, these categories influence the ways the problems might be addressed, but it's unwise to take a gung-ho, treat-all approach to disease control.

The habitat in which a disease occurs in can be used as a category. For the purposes of this book diseases can be categorised into those that are found in marine or freshwater conditions.

The group of organisms causing the disease can be used to categorise it. Examples are:

- viruses
- bacteria
- protozoans
- funguses
- trematodes
- nematodes.

The location of the disease on the stock can be used to categorise the disease. Diseases can be divided into external diseases and internal diseases. Most external diseases respond readily to treatment, as the pathogen is easy to reach and treat. External prob-

Figure 15.2. Be prepared to sacrifice a few fish to see how they're travelling. Some growers, particularly those concerned about fatty liver, carry out regular inspections.

lems are commonly the result of attack by protozoan parasites, bacteria or fungus, the latter two often triggered by the trauma caused by parasitic infestations. Internal diseases are those that occur in the flesh and internal organs of the fish. They are more difficult to treat and, in some cases, not worth the effort; or are incurable. Fortunately, most of your problems are not internal disease.

Diseases of freshwater finfish

External diseases

The most common health problem you will find in a fish pond are caused by external parasites (ectoparasites). The parasites are rarely fatal in themselves but, in large numbers, will stress the fish to the point where the stock's health will suffer. Outbreaks often occur when the fish are already stressed by pond conditions approaching, or beyond, the upper or lower critical limits.

The sooner the presence of disease can be established, the easier it is to treat. The best management strategy to ensure your fish keep healthy is for you to physically check the stock on a regular basis, at least weekly, to see if there are any signs of disease.

Signs to look for are:

- dead fish floating on the surface, in numbers more than just the occasional fish, are cause for an immediate and thorough examination; and
- changes in behavioural patterns are an indication that something has changed in the biology of the system. It may just be the onset of advancing seasonal conditions but it could also be the fish telling you that something's not quite right with them.

When examining individual fish, look for:

- changes in skin colour and slime coating (suggesting the presence of ectoparasites such as *Trichodina* spp.) These are sometimes noticeable when the eyes turn milky in colour;
- growths, abrasions and/or fungal infections;
- bright red or brown colour of gills (damage to gills suggests the presence of ectoparasites such as *Oodinium* spp. in freshwater species and *Amyloodinium* in marine species);
- furry white or brown growth on the fins (suggesting ciliate diseases such as *Epistylis* or a outbreak of fungus such as *Saprolegnia*);
- damage to fins (suggesting the fish are under stress and behaving badly, or it could indicate the onset of fin rot);
- rapid gill movement and/or gulping for air at the surface (suggesting that respiration is being limited. This could be due to low dissolved oxygen levels but it could also indicate the gills have a bacterial infection and are compromising respiration);
- 'flashing' of the fish, either by scraping themselves along the bottom or flinging themselves into the air to crash down on the water's surface (indicating they are trying to remove irritants, such as ectoparasites); and/or

- lethargy, loss of appetite and erratic behaviour (all signs of stress caused by external parasites).

The most common pathogens and parasites:

- Anchor worm: *Lernaea* sp.
- Gill flukes and skin flukes
- Protozoan parasites: *Costia*; *Trichodina*; *Chilodonella*; white spot
- *Epistylis*
- Fungus
- Bacteria: columnaris disease, ulcerative diseases such as goldfish ulcers (which also has an internal phase), motile *Aeromonas* disease, and so on.

This list is not comprehensive, but gives you an idea.

Internal diseases

Internal diseases are caused by the pathogens that lodge themselves in the flesh and organs of the fish. They are harder to remove and may require stronger treatments, such as antibiotics, to kill off the pathogen or parasite.

The signs of internal diseases can often be picked up through observation of the behaviour and appearance of the fish.

Signs to look for are:

- a general deterioration in health;
- lesions or blood spots at the base of the fins;
- pop-eyes, or bloodshot eyes;
- dropsy (the medical term is 'ascites'. The fish have swollen abdomens and, if they have scales, they feel like a pinecone due to the internal pressure pushing up the scales);
- erratic and/or lethargic behaviour; and/or
- colour change, either a darkening or a fading of colouration of apparently healthy fish.

The external signs may not become visible until the disease has reached an advanced stage, so observation of external signs might best be complemented by an internal examination. Of course you have to be prepared to sacrifice an individual, but it is for the good of the crop.

You should undertake regular weekly inspections which should include looking at the fishes' internal workings under the microscope. It may take time but you'll become more proficient every time you do it. More importantly, it will save you time in the long run. If you don't do the checks, you might find it also takes time to harvest a pond of fish that have gone belly up, dig a hole and bury them. Then there's also the time spent in remorse lamenting the lost stock and calculating what the stock had already cost you. Then there's the time spent phoning clients to explain why there'll be a gap of several weeks in your delivery schedule… Suddenly an hour or so a week checking stock doesn't seem such a waste of time at all.

Examining a fish

To make an examination, a fish has to be cut open. You cut along the base of the belly from the anus to the gills and then along a semicircular line from the gills, up towards the lateral line and back down to the anus. The flap can then be removed exposing the organs.

To be able to pick an abnormality, you first need to familiarise yourself with what the working parts of a healthy fish look like, then you can identify what is different.

Things to look for are:

- livers with lumps, uneven, pale or overly reddish colouration, suggesting something is wrong. The liver should be an even dark brown colour and smooth in texture;
- kidneys varying from the healthy smooth dark red appearance;
- worms showing up in the gastric organs (they generally can be easily spotted);
- excessive fluid in the abdominal cavity; and
- swim-bladders swollen beyond normal size, suggesting infection.

Types of pathogens that will attack your stock internally are:

- worms
- bacteria
- viruses. Viruses really are the perfect parasite. They live within the host's cells and use them for their own objectives often damaging the host in the process. Many do not survive well outside the host or in the environment so a live or fresh carrier is usually needed to introduce the problem. A virus may also be latent in a population, only causing problems when the conditions are ripe for an outbreak.

Diseases of crayfish

The various freshwater crayfish species share a similar habit niche and biology. It's not surprising that most of their health problems are also similar.

External diseases

These can be split into two categories:

- cosmetic and harmless; and
- unsightly and potentially dangerous.

Cosmetic damage

The signs of cosmetic damage, are by their very nature, seen on the outside of the shell. When crayfish are eaten they are generally served whole, and any blemish to the shell detracts from the market value of the product. As far as disease is concerned, cosmetic damage includes stains and any damage to the shell not caused during harvest: such as missing appendages.

Staining of the shell can be caused by excessive iron and/or magnesium in the water, or from high organic loadings. Crayfish shed their shells to grow and every time they do they look as though their shell has just come back from the dry cleaners. Shell staining is an indication of slow growth and a solution is to get them moulting more regularly.

Bubbles in the shell are indication of the crustacean's immune system isolating an earlier bacterial infection. Again, wait for a new shell.

Blisters can be found on the tail. Nobody is quite sure what causes these but most likely abrasion from the substratum opens the way for bacterial infection that the crustacean's immune system isolates by surrounding it with a blister.

External parasites and ectocommensals

Strictly speaking, most of the organisms found on the external parts of crayfish are ectocommensals. They live on the crayfish but they feed on the algae and what collects on the shell of the crayfish and comes in from the habitat in which the crayfish live: mainly the detrital food web. They use the crayfish as a conveyance.

In most cases ectocommensals only detract from the appearance of the crayfish and can be easily removed at harvest time in a salt dip. However, under appropriate conditions their numbers can increase dramatically. The conditions we are creating for the crayfishes' natural food source is also creating conditions ideal for the proliferation of those that live on the crayfish. Some of the ectocommensals lay their eggs in the crayfish's gill cavity as well as on the shell. Heavy infestations can reduce oxygen uptake, cause loss of production and, in a severe outbreaks, mortality.

Ectocommensal eggs found on a crayfish's shell are not easily removed – in fact it's not possible to remove them without destroying the animal. The only way to improve the market value of that particular crayfish is to put it back in the pond and wait until it has undergone another moult.

Ciliates

The protozoan ciliates, of which *Epistylis* is probably the most common, appear as a brown fur or slime over the crayfish. Their level of infestation can range from hardly noticeable to an unsightly blanket. They are prevalent and associated with the decaying organic matter on which freshwater crayfish love to browse.

Ciliates can multiply rapidly when conditions are favourable for them; especially from midsummer onwards as pond temperatures reach their maximum and organic loadings are at their peak. If the infestation becomes worrisome, there are several things you can do:

- increase the rate of water exchange;
- stop chucking bales of hay into the ponds. Increased aeration will increase microbial activity on the remaining organic matter and hasten its degradation;
- change the diet from natural food to a supplementary ration.

These measures will enable you to control the input to the pond and manage the stability and balance of the water quality and organic load.

Epistylis are not dangerous to the crayfish in small numbers, but they are a colonising animal and can devastate a crop by enveloping their hosts, including the gills, should conditions favour their proliferation.

Salt dipping at harvest time will kill *Epistylis* but the remains may initially stick fast to the shell of the crayfish. This dead residue usually rubs off as the crayfish rub against each other during the purging process in prawn trays.

Epistylis are active in organic-rich ponds. Reducing reliance on natural food towards the end of the growing season, as the pond biomass builds up, is the wisest management tool.

Algae

Algae can grow on the shells of crustaceans in clear nutrient-rich ponds where the light is able to penetrate. The same algae that forms the carpet of nutrients in an algal lawn can settle on crayfish if they are not growing and exchanging their shells.

Algae is unsightly and will, like the ciliates, reduce the crustacean's tendency to moult, thus reducing production. In extreme cases it will not so much cause mortalities as be a consequence of too much light penetrating to the pond bottom and stressing the crustaceans. Avoiding algae may well be one of the reasons wild crustaceans seem to do better in turbid water, or only move at night.

Maintaining a plankton bloom in the mid-water will reduce sunlight penetration and minimise the growth of the algae on the pond bed and on the cray.

Temnocephalids

These are organisms that appear on the shells of crayfish and are given the generic term 'lice' by farmers. They are not biologically related to the lice found on cattle and sheep (they are in fact a flatworm) but they have a similar nuisance value. Their real name is *Temnocephala*, or 'temnos' for short. They are small (1 mm to 12 mm) ectocommensals, pale white in colour and caterpillar-like in movement. They feed on small pond invertebrates and use their host as a means of getting around, although they can be free swimming if they choose.

Temnos present two main problems to farmers: one potentially fatal, and one cosmetic. In large numbers they can 'choke' the crayfish by inhabiting its gill cavity. While this is not automatically fatal it will inhibit oxygen uptake, which will reduce the growth rate of the animal. The gills can be mechanically damaged, which compounds the problem. Further to that, the temnos can lay their eggs in the gill cavity and even on the gill filaments. At this point their activities can prove fatal to the stressed crays.

The cosmetic damage arises when they lay their eggs on the tail-plate of crayfish, reducing the market value of the animal. Because the eggs are not dislodged during cooking this further reduces the commercial value. The crayfish discards the old egg-spoilt shell when it moults so this is not a major problem in well-managed ponds in which the crayfish are growing fast.

Salt dipping as described for *Epistylis* is effective on temnos but not the eggs. To further complicate matters, eggs are also laid in the ponds substrata making their eradication a long and tedious battle once the pond has been colonised.

Salt dipping before purging crustaceans from organic-rich ponds, and especially when introducing adult and even juvenile stock of dubious origins, would help reduce the chance of clean ponds becoming infested with *Temnocephala*.

If you already have 'temnos' in the ponds you can control their numbers by managing the amount of organic build-up. Unfortunately, as is the case with *Epistylis*, the conditions conducive to crayfish production tend to be the same as those favouring ectocommensals.

Aquatic insects

Corixids, or water boatmen, as they are more commonly known, swim right-side up. They feed on detritus and being able to leave the water and fly, can quickly colonise a crayfish pond. It's not bad enough that they help themselves to the detrital food web you are developing for the crayfish, but to add insult to injury they will lay their eggs on the carapace of the crayfish, generally the belly-plate. This obscures the translucent tail meat and downgrades the market value.

Coroxid eggs are adhesive and can't be removed without further reducing the market value of the animal.

Coroxids are air-breathing insects and come to the surface to breathe. They can be removed by spraying the surface of the pond with a mixture of diesel and motor oil (8 parts diesel to one part oil is a mix used by the authors). Because of the effort required, the mess around the edge of the pond, and the fact that the pond quickly becomes re-colonised, growers generally rarely use this approach.

Fast-growing crayfish moult constantly and the unsightly eggs are discarded with the old shell.

Notonectids, or back swimmers, are common inhabitants of aquaculture ponds. Like the water boatman they are airborne and can colonise a pond in a matter of days. They are carnivorous and feed on zooplankton, small invertebrates, tadpoles and fish larvae and fry. They are more of a nuisance in fish fry-rearing ponds than crayfish ponds, but they do eat the plankton being established to feed the crayfish.

Daphnia have been observed to grow larger head shields and tail spines as a deterrent to predation in the presence of some species. Being air-breathing they can be controlled in the same way water boatmen are controlled, but most growers feel they aren't a problem worthy of the effort.

Internal infections

Internal infections can strike crayfish, and as with finfish, they can be difficult to address.

Bacterial infection

Bacteria are everywhere in an aquaculture system and crayfish ponds operating on a detrital food web carry high organic loads; a perfect place for bacteria to breed up. Bacteria should not cause a problem in a well-managed production pond but they have been identified as a major cause of mortality under poor pond conditions or by transport trauma in the US crawfish industry. Stress will weaken the natural capacity of the immune system leaving the crayfish vulnerable to bacterial infection. If the poor conditions continue, the resulting bacterial proliferation may well prove disastrous for the farmer.

Maintaining near-saturation levels of dissolved oxygen is the easiest way to keep the crayfish in good spirits in the ponds. Salt dipping flushes the gill cavity and carapace after harvesting (see chapter 13).

It has been suggested that bacterial septicaemia causes many more unidentified mortalities in crayfish than the industry realises. Losses can be large amongst badly stressed crayfish, especially those from the wild and farm dam harvest where losses of over 50% in purging systems, are not uncommon. This is a major problem for an industry that sells most of its product live and exports them around the world. Bacteria isolated in crayfish with bacterial septicaemia include *Vibrio cholerae* and *Pseudomonas* spp.

Avoiding problems with bacteria is simple: lift farm management practices. Improve your pond management techniques and treat the crayfish with the respect they deserve when you're purging and transporting them. Work on maintaining a healthy pond environment, especially with regard to monitoring DO, especially in ponds carrying high detritus loads.

Internal parasites

Internal parasites also afflict crayfish. Some parasites will lodge themselves in the flesh of the animal and dislodging them ranges from difficult to impossible.

Microsporidians

These are a protozoan which can attack crayfish, forming cyst-like structures in the muscle of crayfish. The white blemishes caused in the tail meat make the crays unsuitable for marketing. The microsporidian *Thelohania* is particularly infamous and in the advanced stages is fatal. *Thelohania* is not believed to be harmful to humans but the meat of infected crayfish is inedible.

The way in which *Thelohania* passes from one crayfish to the other is not fully understood, but a primary route of infection is by an uninfected crayfish scavenging an infected carcass. There is no doubt the crayfish is a primary host, but there could be other vectors. Fish-eating birds have been cited as possibly having a role in moving infection around: a factor that adds to the value of the system's predator control regimen.

Regular flushing and fallowing is extremely helpful in keeping ponds clean and free of pathogenic build-up. Once a crayfish has contracted a *Thelohania* infection, there is no known cure. However, infected individuals are generally associated with the wild harvest, particularly in regions where crayfish are stressed, such as during drought conditions. It isn't a common disease in well-managed ponds and the authors know of no outbreaks in commercial operations.

If *Thelohania* does become established, remove all the stock, dry out the pond and lime it as detailed later in this chapter.

Diseases of prawns

In many ways, prawns run parallel to crayfish. There are many physical similarities between the two groups of animals, because, while they live in water of differing salinities, both fit a similar niche and feed on detritus.

Their differences generally come from the fact that prawns live in water with higher salinities. These salinities prevent the growth of larger green plants and fewer varieties of fungus can survive these conditions than freshwater, decreasing the impact of this group on prawn health.

Like crayfish, the key thing with prawns is the available surface area on the bottom of the pond. Prawns can swim and they do move through the water column, but they focus mainly on the bottom. Prawns do better on clean beds. Feeding and the ongoing biological activities of prawns results in silt and sludge forming on the pond beds, and where this builds up, prawns do not grow as well. Pond areas with sludge become lost to production. Clever use of water movement (brought on by paddlewheels and other aerators) will scour much of the pond bed, increasing the useful area of the pond. It has also been suggested that appropriate use of pro-biotic bacteria may remove build-up of silt and sludge.

External diseases

External diseases afflict prawns as they do crayfish. Prawns can acquire fellow travellers and shell damage that reduce the value of the crop. Like crayfish, these can be prevented (or minimised at least) by close attention to environmental conditions in the ponds. Many prawn ponds are managed to have a continual bloom of planktonic algae. This denies light and plant nutrient to algal species that would otherwise grow on pond beds, or more importantly on the shells of the prawns. Like crayfish, the way to address a problem that leads to less than completely attractive shells is to allow the animals to moult. Moulting can sometimes be induced by a water change in a pond.

Internal diseases

Internal diseases are an issue with prawns. Where prawns seem to differ from crayfish is in the area of susceptibility to virus infections.

Yellow head and white spot and other viral diseases have, in Asia in particular, been disastrous to prawn farming. In many cases they have destroyed economic viability. (Please note that white spot of prawns is different from white spot of finfish.)

Fortunately these diseases have yet to appear in Australia. It may be that the pathogen has not made it here. In which case, national quarantine with strict import controls on live and uncooked produce should be continued. It is also possible that the virus is present here but has not been discovered, as the conditions needed for it to flourish – vast prawn farms located close together – do not exist here. The way to prevent this is to ensure that not too many prawn farms are situated in close proximity and to ensure that sound quarantine is undertaken on individual farms. Naturally, management of the stock's environment, that is, good water quality management and husbandry practices, are essential weapons in the fight against outbreaks of exotic diseases.

Quarantine may not be as simple as it first appears. Other crustaceans, such as crabs, also carry white spot. Crabs can walk overland, so a dry area between ponds presents no quarantine barrier, unless we are talking a kilometre or so.

Gill associated virus (GAV)

This is a local disease. Australia may not have really nasty exotic diseases, but it does have its own suite of viral diseases of prawns. Several have been clearly identified but, so

GWQEHN says:
The most common disease found on fish farms is BMV – Bad Management Virus.

far, none of these appears to have the disastrous impact of the diseases overseas. GAV can have an economic impact, however. Virus diseases cannot be treated by pharmaceuticals, and the only recourse farmers have is to address the environment, that is, reduce stress on the stock.

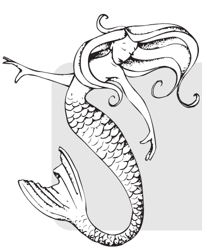
Treating disease

You can use chemicals of one kind or another, applied in various ways, to attack pathogens and parasites in fish.

The fundamentals need to be in place first

Before getting into the details of attacking pathogens and parasites: remember the three factors needed for disease to occur? No amount of clinical treatment will remove disease from your production system if the fundamentals of managing the stock's environment are not in balance. If you don't have effective control over the stability and balance of your production system you won't be able to manage the health of your fish. If you don't understand what is going on in the pond, you won't be able to understand what is happening to the fish.

The first thing to do when you discover that you have a fish health problem is establish that the system is operating at maximum oxygen levels and, if it isn't, take steps to make sure it is. Check all the other water quality parameters, particularly pH, ammonia, nitrite and nitrate levels, to ensure they're operating within acceptable limits. If they aren't, make adjustments to the management of your system to ensure they are.



GWQEHN says:
One of the most efficient and cost-effective pharmaceuticals you can have on a fish farm is oxygen.

The pond manager should review the stocking rates. As fish grow they make up more of the biomass and the underlying problem could well be overstocking. Equally, the water quality management procedures may be inadequate for the BOD of the larger body of fish.

Also recalculate the feeding rates in case overfeeding is part of the problem. It is important that all management inputs are re-assessed and adjusted, if necessary, before you take the next step.

If the problem is in the environment, the fish will have to be removed as soon as possible and the conditions will have to be corrected before the fish can be returned.

Use the right treatment

Most treatments are stressful to your stock (they work because they are even more stressful to the pathogen or parasite). Before treating, ensure you have determined the cause of the problem, and that the treatment is the right one to address it. Don't hesitate to call in veterinary advice the moment you feel out of your depth.

Considered forethought is important. Some chemicals might work well with one variety of stock, but be disastrous to others. For example, copper-based materials are highly toxic to invertebrates, but not to finfish, and can be used successfully to rid finfish of invertebrate parasites. However, crayfish are invertebrates, and much more susceptible to copper toxicity, so a lot more care is needed if you want to use copper to treat a parasite on them.

Some substances used to treat stock, such as antibiotics, may be very powerful, but their use may have a variety of ongoing effects. The law says these materials may only be used under the supervision of a vet. Follow the law.

Treating external diseases

It is generally easier to treat external diseases than internal, as a treatment chemical can be added to the water in which the stock are held and there is no requirement to find a way to introduce it inside the body of individuals.

The farmer has most control when stock are removed from the pond and treated in the fish handling facilities: the fish room.

The intensity and duration of the treatment can vary. Stock can be 'hot' dipped or given a short- or long-term bath. Water temperatures of all treatments should be as close as possible to the ambient water temperature on the farm.

The hot dip

This is generally between 30 seconds to 20 minutes in duration and, as the name implies, can be injurious to the fish at that high intensity but it will belt the Hell out of the pathogen. Watch the stock, if they show signs of stress, remove them from the dip or dilute it. Always use plenty of aeration under these circumstances.

The bath

The bath is generally between 20–30 minutes long and is a more dilute mixture of the same formula, which is not so threatening to the fish but equally gentle on the pathogens, hence the need for longer exposure. Don't forget the aeration: you're still dealing with sick animals under stressed conditions.

The permanent or prolonged bath

As the name suggests, the permanent or prolonged bath lasts the duration of the treatment, which may be several days or several weeks. This can be carried out either in the fish room or outside in the pond. The same chemical mixture is used but in an even more diluted form than in the 30-minute bath. It is not usual to use the prolonged bath method in the fish room due to the tank space it ties up, but if you are dealing with valuable broodstock you may wish to keep them under observation to ensure complete recovery before returning them to their pond.

It is sound practice to hold back a few fish from the quicker turnover treatments for observation. This can be done in either a holding tank in the fish room or a floating cage in the pond.

A variety of chemicals can be used for dipping or bathing stock. Over the years, several favourites have evolved. Details will be given shortly but first a word on safety.

Safety

Should you be in any doubt as to what chemicals can be used on fish destined for human consumption you should check with the Agricultural Pesticides And Veterinary Medicines Authority (APVMA). Their website is www.apvma.gov.au. Go to their homepage and click on 'Search for a Product' in the top left-hand corner. There's a 'Help' section for first-time users on the 'Search for a Product' page.

The website is very easy to use. You can trace a medication by pest, host or active constituent. Let's say you've got white spot on your fish. On the 'Search for a Product' page type in 'white spot' where it says 'pest' and click 'Search'. There might be nearly 20 medications. If you want to find out more about the product, click the unique product number to the left of the product name and it will take you to the 'Product information' page. On this page there are tabs that will take you through the constituents, the states in which it is registered, the size of the pack and it will even display the label on the packet once you've read and accepted the disclaimer notice. How easy was that?

You can do the same thing for say formalin in 'Active 1', or by typing in fish where it says 'Host'. By typing in a % sign before and/or after the keyword you can widen your search capacity.

Many of the chemicals referred to are restricted. The APVMA will issue a range of special use permits. Quoting from the APVMA web page on the subject, these permits will allow:

> *'a person or an organization to use agvet products in situations that would, if it were not for the issue of the permit, be an offence either against certain provisions of the federal legislation (Agvet Code) or of appropriate State control of use legislation. Permits can only be issued, in response to an application.'*

The previous comments notwithstanding, several chemicals have been commonly used in aquaculture, and we give some background information on them and possible dose rates.

Salt

Salt is one of the cheapest, most widely used and convenient 'pharmaceuticals' you will use in the fish room. It is employed extensively to remove parasites from freshwater fish. Many external diseases can be treated successfully with salt as most of the protozoan parasites of freshwater fish have a low tolerance to it and will be destroyed by salt baths.

The following are industry standard concentrations and durations for freshwater fish

- **Dip:** 2–3 kilograms per 100 litres, for five to 10 minutes or until fish show signs of stress (equivalent of 30 parts per thousand (ppt). Sea water is 35–37 ppt)
- **Bath:** 1–1.5 kilograms per 100 litres for 20–30 minutes (10–15 ppt)
- **Permanent bath:** 500 grams per 100 litres (5 ppt).

Some pathogens and parasites, as well as fungal and bacterial infestation, don't respond to this treatment and more stringent methods, such as formalin and malachite, have to be employed.

Freshwater

Freshwater can be used in a similar manner to treat external pathogens, parasites and ectocommensals on marine species. It works best with species that have a wide salinity tolerance (barramundi) as a more stringent regime can be applied than can be with less tolerant marine species such as coral reef finfish. Stock should be removed from freshwater as soon as they show signs of discomfort.

Formalin

Dips or baths containing formalin are particularly effective for most ectoparasites. It is perhaps not quite so effective on fungus – see the section on malachite green for treating them.

The suggested treatment regime is:

- **Bath:** 17–25 millilitres per 100 litres for 30–60 minutes.

N.B. These doses rates are for formalin, not formaldehyde. Formaldehyde Solution BP is widely available and is loosely referred to as 'Formalin'. Check with your supplier. If they're unsure, seek more informed advice.

In organic-rich pond water it may be better to use the higher dose rate to compensate for organic contamination.

WARNING: Formalin has a deoxygenating affect. Use with heaps of oxygen; trial a few fish first until you're comfortable with the procedure. Some growers lower the water level so they can quickly add fresh water should they run into any problems.

Textbooks warn that any white deposit of paraformaldehyde should be filtered out of formalin and disposed of since it is extremely toxic to fish. The authors have never noticed it forming so don't be disappointed if you can't find any.

WARNING: Avoid contact with skin and inhalation of formaldehyde and formalin.

Malachite green

Malachite green is effective for treating funguses and complements the use of formalin for treating ectoparasites. The two are sometimes used together.

Industry standard concentrations and durations are:

- **Dip:** 100–200 milligrams per 100 litres for 30–60 minutes. Use the stronger dose rate for large fish in hard water only
- **Bath:** 20–30 milligrams per 100 litres for 2–6 hours.

Malachite green is used to prevent the onset of fungal infection and to treat it once it has taken hold. It comes as either a stock solution or in powder form. The dose rates are given as dry weight of powder per litres of water.

If you're getting malachite in powder form make sure it is zinc free; and that it is an oxalate salt (MG-oxalate). The pre-mixed solution will have the dilution rate on the container. If you are using large amounts it is far cheaper to buy the powder and make up your own stock solution.

It is easy to mix and use your own stock solution. Let's take an example to see how it works. A stock solution of say 50 grams in 1 litre of water would be made up and kept in a cool dark place. Malachite breaks down readily in sunlight so use a dark bottle with a well-sealed top. Mix it well and shake thoroughly before use. If you are having trouble keeping the malachite crystals in solution make a more diluted mixture and adjust your dosing calculations accordingly.

Always add water to crystal. If you add crystal to water it tends to float. Add the water slowly at first to saturate the crystals. Warm water will advance the process.

Example: let's presume you wish to bathe some fish in a 4000 litre tank. The dose rate is 25 mg/100L, which is 0.025 g/100 L. This means we will want to get 1 g of malachite green crystals into the 4000 L of water. Now the stock solution consists of 50 g/L so 20 ml of stock solution represents 1 g of malachite crystals. To mix the bath just add 20 ml of stock solution to the 4000 L of tank water to give the required dose rate of 25 mg/100 L.

WARNING: Some American work suggests that there is a possible carcinogenic risk associated with malachite green but this has been disputed by recent reviews of the evidence. Wear a mask when mixing the stock solution and gloves when using it.

WARNING: Malachite green is not allowed to be used on fish that are intended for human consumption. If in doubt, seek veterinary advice on treatment procedures.

Malachite Green/Formalin

Also known as Leteux-Meyer solution, this mixture can be used where treatment calls for a dual approach to a particular problem. There are variations of the basic combination of this blend but the ones presented here are fairly standard mixes.

Mix 5 mg of malachite green with 1.35 L of formalin for use in *flow-through situations* such as raceways and floating cages.

For *static pond situations* a milder stock solution of 5 mg of malachite green to 1.5 L of formalin should be mixed. Any formula containing formalin will present an oxygen depletion issue and DO levels should be monitored constantly and maintained at >5 mg/L.

Standard dose rate for Leteux-Meyer solution are:

- **Bath:** 2.5 mg/100 L for 60 minutes
- **Prolonged bath:** 1.5 ml/100 L as three treatments at intervals of 3 to 4 days when appropriate.

Trichlorphon

Trichlorphon is an organophosphate insecticide used to treat such parasites as external crustaceans, copepods and helminth. Manufacturers' preparations vary in strength so the composition of the particular chemical will have to be established.

The standard dose rate for Trichlorphon is:

- **Bath:** at 0.25 ppt to 0.4 ppm of active ingredient. It will be inactive after 24 hours and can be repeated in 20 days to 25 days.

The dosages and treatments are shown in Table 15.1.

Table 15.1. Dose rates

Material	Mode	Concentration	Duration
Salt (for freshwater species)	Hot dip	2–3 kg/100 L (20–30 ppt salinity)	5–10 minutes or until fish show signs of stress
	Bath	1–1.5 kg/100 L (10–15 ppt salinity)	20–30 minutes
	Permanent bath	500 g/100 L (5 ppt)	ongoing
Freshwater (for marine species)	Hot dip	Freshwater	Until fish show signs of stress
Formalin	Bath	17–25 ml/100 L	30–60 minutes
Malachite green	Hot dip	100–200 mg/100 L	30–60 minutes
	Prolonged bath	20–30 mg/100 L	2–6 hours
Leuteux-Meyer solution	Bath	2.5 mg/100 L	60 minutes
	Prolonged bath	1.5 ml/100 L	3 treatments at intervals of 3–4 days when appropriate
Trichlorphon	Bath	25–40 mg/100 L	Less than a day, with possible repeat 20 to 25 days

The intensity and duration of treatment chosen is purely a management decision.

A few handy hints when treating stock

- If possible, check the condition of the stock's gills before undertaking treatment. If the stock are suffering from an infection where gills are badly damaged it may be wiser to use the prolonged bath method of controlling the disease; and use plenty of oxygen.
- Some pathogens are persistent or have a life cycle that requires more than one treatment to eradicate them totally. By prepared to repeat treatments at regular intervals, or as required, to completely halt the progress of an outbreak.
- Test a few fish in the treatment solution before committing the whole batch, especially when incorporating a new procedure. If they show discomfort (or even death) review your proposed treatment procedure.
- Only partly fill a pond or container when undertaking treatment. If the dose proves to be too astringent, the solution can be quickly diluted by topping up the water level.
- In open pond systems, treat during the least stressful part of the day, usually early morning when DO levels are set to climb to their maximum during the day.
- Treatments may have impact on whether or not your stock are for human consumption. Be aware of the withholding period and the final destination of the treated water. This also applies to the fish and crayfish; and you'll have to check with the State Fish Veterinarian as to the withholding period for commercial stock destined for human consumption.
- Record everything you do in the pond and the fish room books.
- Use chemicals sparingly. There's nothing to be gained by throwing chemicals at your stock on the off chance that they might need a dose of something. Diagnose the problem properly and plan a course of action.

- If a vet has prescribed a particular treatment with an antibiotic, continue the treatment until it has been used up, regardless of the condition of the stock. Anything less will promote the evolution of strains of bacteria that will become immune to the antibiotic.
- Aeration should be thorough but gentle, not turbulent as would be the case with an aerojet. Remember you are dealing with stressed fish and they need calmness as much as they need medication and oxygen. If your aeration system is turbulent in nature, arrange it so the effect of the turbulence on the fish is minimised; or use a gentle system such as a diffuser or water lifter.

GWQEHN says:
The two most commonly used, cheap, convenient and effective treatments you'll use on a fish farm are salt and oxygen.

As mentioned above, a prolonged bath can be undertaken outside in a pond. If you have a large number of fish, and the condition is manageable in the pond, you could opt for the prolonged bath outside. If the fish are weak there could be the added risk of mortality during handling, and this factor might make you disinclined to bring them inside.

Then again you may be of the mind that it would be better to get the stock treated and then put them back into a clean environment where they will gain health, condition and productivity rapidly. This is not an option if the pathogen cannot be treated in the ponds, or the cause of the disease is in the pond itself.

Treating pathogens in the pond

First, a few specific factors need to be taken into account.

Before you start, check the stock's environment. No amount of clinical treatment will remove disease from your production system if the fundamentals are not in balance. If you don't have effective control over the stability and balance of your production system you won't be able to manage the health of your fish. If you don't understand what is going on in the pond, you won't be able to understand what is happening to the fish. Adding chemicals to a pond containing poor quality water is only going to increase the level of stress on your stock, and stress is one of the key components of disease.

In outdoor ponds, the least stressful part of the day is usually early in the morning once the photosynthesis has commenced boosting levels of dissolved oxygen. Have spare aeration on stand-by in case it is needed.

If practical, partly drain the pond. You may need more aeration to compensate for the increased stocking density. By lowering the water and reducing the volume you also reduce the amount of chemical needed. The other factor is that if the concentration turns out to be too stringent, additional water can be quickly added to dilute it.

This will only be practical in a pond built with the functional features discussed in chapter 11.

Some problems can be treated in the ponds by herding all the fish into a corner, surrounding them with a tarpaulin and dosing the holding water. A floating cage can also be partitioned by a tarpaulin to seal off the water and treated the same way. In other cases the whole pond can be dosed. Thorough oxygenation will ease the stress on the fish during this procedure.

Be aware that treating a pond may have negative consequences for the pond. Some of the chemicals, such as formalin and methylene blue, could have a detrimental effect on plankton production and the pond's bio-filtration system.

Take a few animals out of the pond and keep them in an observation tank, so that you can compare their response, and get some idea of the effectiveness of the treatment.

It's not good enough to treat and assume 'she'll be apples'. And this applies equally to treating fish in the ponds as it does to treating them in a fish room. Bathing stock is only of value under certain restricted circumstances. There is no value in treating stock and then placing them back in infested water where they will quickly become re-infected or stressed by conditions and fall sick again. Check the water quality after treatment. Always keep the particular pond under close observation after treatment or returning fish treated in the fish room and pay close attention to the unaffected ponds for a similar outbreak.

You may opt to return treated fish to a different pond, one that has been thoroughly dried, in order to give the fish a fresh start in a fresh pond. This further removes the fish from the possibility of re-infection.

If the fish in the fish room observation tank recover and the fish in the pond become re-infected, it is most likely that the problem is still in the pond, or in your farming practices. The fish will have to be placed in a clean environment and the offending pond treated chemically or by baking it in the sun.

It's when you're dealing with an outbreak of disease that really demonstrates the benefits of good farm layout and design. Most fish diseases are easily treated once the disease has been positively identified and you've got the fish in a position where they can be treated. Where fish have to be treated in the ponds or removed for treatment, the work put into designing and building the systems for ease of operation in mind is rewarded. The same need for good design applies to the fish room. When you have sick fish the stock are stressed enough without adding further stress by having an inefficient handling system.

Disposing of treatment water

Careful thought should go into deciding where to dispose of water that has held sick fish or in which treatment was undertaken. The first thing to consider is quarantine. If your problem was caused by an infectious pathogen, you need to be absolutely sure you won't be exporting the problem when you dispose of the contaminated water. Only dispose of water if you can ensure that any pathogen or parasite it might contain is:

- harmless to the environment;

- already exists in the environment; or
- has been killed off or removed from the dumped water.

Treating the water with high concentrations of toxic chemicals can kill pathogens and parasites in waste water, but this chemical must be one that will break down and become less toxic before it reaches the environment. Chlorine and ozone are powerful sterilising agents and both can be removed from the water by vigorous aeration. If water is first filtered to remove any particles, it can also be sterilised by being irradiated by ultraviolet light. Boiling is also an effective way of sterilising water, but it's a lot easier to add chlorine to a large volume than it is to boil it.

Contaminated water can also be dumped on an irrigation pasture or wood lot without treatment, but only as long as there's no chance that the water-borne pathogen can survive and find its way back into the water system. Don't even think about it if the dump-site is near a stream or other waterway.

Treating internal diseases

The problem with internal diseases is that they are internal, and any chemical treatment has to be administered so that it will get inside the host.

In aquaculture, the most common internal treatments are those that attack bacteria – antibiotics. Antibiotics are administered either by putting them in the water or in food. Antibiotics can be used, depending on:

- being able to identify the bacteria; and
- there being an antibiotic available with which to treat that particular bacteria.

Antibiotics cannot be legally used or obtained unless you have a prescription from a vet.

Medication can be included in the diet to treat most diseases but it can be expensive, therefore it is essential that the pathogen has been correctly diagnosed so that it can be specifically targeted. There is no place for individualism at this point. Veterinarian advice and supervision of the course of the disease and the treatment will be well rewarded in the long run.

Treatments have been developed to immunise fish (this is particularly true in the salmon industry). These treatments are given at an early age, and the fish's immunity system is given an appropriate boost, improving its ability to resist a given pathogen. There are few immunisations around for native species, and getting pre-immunised stock is almost impossible. Luckily farmed native species seem to have few disease problems. However, research in this field would benefit the local industry in the future.

While some internal diseases can be easily treated, most growers feel more comfortable seeking professional advice.

Drying out the pond

In some cases the pathogen or parasite can complete its life cycle outside the host. You can treat the host (your stock) until the cows come home, but as soon as it goes back into the system, they become re-infested.

Figure 15.2. The advantages of having a well-designed and built pond are apparent on many scores, especially to break pathogen cycles. The results of not having bottom draining can be seen in this pond on an early yabby farm, built in the days when the industry emulated conditions found in productive farm dams.

Sometimes it is an environmental problem, and rectifying the environment will remedy the problem. An example of this would be the build-up of organic matter that is causing an outbreak of *Epistylis*. In this case the cause will have to be removed. Often relief can be achieved by exchanging the nutrient-loaded water.

In other cases, it may be necessary to attack the pathogen/parasite directly. The first and most obvious way to do this is to remove all the water. Lack of water is often fatal to pathogens and parasites. An overload of organic matter can be either removed or tillered to allow oxidation of the material.

Some pathogens and parasites have a stage that can survive in the mud in the pond bed enabling them to re-appear once the pond is filled again.

Should a persistent unwanted organism establish itself in the ponds it will be necessary to treat the pond mud and possibly fallow the pond for a season. The usual treatment is to dose the pond with hydrated lime (calcium hydroxide, also known as 'slaked lime' or 'builder's lime') or quicklime (calcium hydroxide, also known as 'unslaked lime' or 'burnt lime'). Once you have harvested the crop, drain the pond and treat the damp substrate with one to two tonnes of hydrated or quicklime per hectare.

Lime in concentration is very toxic, but it quickly reacts with chemicals in the soil to become neutralised. In fact, if the soil on the pond's bed has become sour, liming will improve it.

This treatment will usually clean the pond. Some growers may even choose to leave the pond fallow for the summer or a dry season to thoroughly break the cycle. If the ponds are to be brought back into production immediately, they can be filled and re-stocked within two to three weeks once the power of the lime has diminished. Once filled, check the pH of the water to ensure it is suitable.

Certain pest species can establish themselves in ponds and these can be particularly difficult to deal with as they have resistant stage: usually an egg or a cyst. These species are adapted to living in waters that periodically dry out. Where the problem is the cysts (eggs) of unwanted invertebrates such as fairy shrimps or back swimmers, the pond bottom can be dried out, and then re-flooded to a shallow depth. The eggs will hatch, presuming the temperature is warm enough, and the larvae can be literally flushed down the drain before they can initiate their breeding cycle.

When do you holler for the vet?

If, after drawing on your total resources and experience on fish diseases, you come across a health problem that you are unsure about we suggest that it is time to call in a qualified fish vet. Each state has a veterinary officer to help the farmer and there are others in private practice specialising in these matters.

If there are dead or ailing stock in a pond and the farmer is unable to provide a reason for it, he or she should preserve the specimen as best they can and get it to the local fish health adviser. Moribund specimens are better than dead ones, as the vet can get a first-hand look at the behaviour of the animal and the clinical symptoms before the system closes down.

If you are only able to provide dead animals as an example of the disease, pack them in ice and send them off by express courier, or take them in yourself. Don't freeze them as this will break down cell walls and remove histopathology and bacteriology as a tool of diagnosis.

Anaesthesia

You may wish to sedate the fish or put them to sleep. This may not necessarily be as a reaction to disease. However, it fits here as well as any other part of the book.

Anaesthesia can be put to several uses:

- making stock compliant during a physical inspection;
- settling stock to facilitate injecting them with an antibiotic or an ovulation-inducing hormone;
- calming stock during transport over long distances. (If you are doing the deliveries yourself, trials should be carried out to establish safe dose rates before committing large consignments. The stress involved in transportation often makes fish more susceptible than during a test when a sample package may be left in a quiet corner); and
- calming stock during harvesting.

Anaesthesia is usually induced in the fish room but it can also be used to quieten excited and large broodstock prior to capture in the ponds and during transportation to the hatchery.

It is also used to sedate fish after harvesting, especially those that are destined for the live fish trade. These fish may have to be purged before being transported to market. Minimising damage during the process, that could take several days until the animal meets its final destiny, is part of the fish farmer's job.

Several kinds of anaesthetics have been used in aquaculture. Old favourites are quinaldine or MS222. Since the time when these two were the stalwarts, a variety of other veterinary anaesthetics have also been used to a greater or lesser degree of success. Clove oil is popular because of its low cost. However, at time of writing, clove oil is not registered for use on fish that are to be used for human consumption.

Registration of chemicals for use in farming has become a big issue and growers will be well advised to keep up with what is legal and what is not. Using an unregistered chemical leaves the individual grower exposed to litigation, and the industry as a whole vulnerable to accusations of irresponsible behaviour.

Anaesthetics can be used to induce varying levels of torpor through to unconsciousness and the dose rates used to achieve a particular result appear on the label. However, different species react in different ways in different circumstances and water conditions.

In all cases when using a pharmaceutical of indeterminate strength you should proceed with caution by trialling small lots of fish before progressing to large batches. At one time, one of the authors spent some time anaesthetising finfish in order to take photos. He found a noticeable difference in susceptibility between species, with, perhaps, the most marked being between finfish species that had scales and those that had naked skins. To start the process off, he would provide the minimum dose recommended on the bottle (if all else fails, follow the instructions!) then slowly increase the amount till the fish became torpid. The problem he encountered was that if a fish was slow in responding, he tended to lose patience and add increasingly large amounts. Nothing would happen, then all of a sudden the fish would be overdosed. The lesson is, take it easy when increasing doses of anaesthetic and give the fish time to respond before increasing the concentration.

An important note

It is not possible to cover the entire topic of fish health and the art of keeping fish alive in a book of this broad nature. Fish health underpins husbandry in the same way water quality underpins aquaculture. State aquaculture agencies generally have an extension service that runs workshops on fish health and every effort should be made to make the most of such opportunities. Growers' associations often have field days and workshops covering fish health issues. These too should become an integral date on the fish farmer's almanac.

GWQEHN says:
Keeping fish alive is the first step in aquaculture. You can't get them to grow if you can't keep them alive.

Finfish – some common diseases

Fin rot

Fin rot is a particularly common infection that attacks the gills, fins and skin of freshwater fish. Caused primarily by *Flexibacter columnaris* it can be caused by any bacteria or fungi that finds a toe-hold on these areas. Omnipresent in the water, these bacteria become a problem when water temperatures rise and the fish become stressed.

Low DO levels, high TAN levels, parasite infection and temperature fluctuations are all contributing factors, either individually or in combination, to an outbreak of fin rot.

Look for a whitish-grey to creamy coloured rim of mucus forming at the tips of the fins or as a saddle between the dorsal and tail fins. This disease is fatal if left untreated.

Fish newly delivered from the hatchery are particularly vulnerable as excessive handling will leave many of the fry scratched from harvesting and grading activities, and the conditions in which they are held is a trigger for stress and an incubator for bacteria. Examine them under a microscope for any tell-tale signs.

Malachite green, formalin and salt are methods of treating the disease externally. Antibiotics are available that can be administered as a coating on the feed. Naturally, review all possible sources of stress, including stocking densities. Infected fish should be quarantined and treated separately. A product used in the aquarium industry to control fin rot is Fungonex, manufactured and distributed by Aquasonic of Wauchope, NSW. Oxytetracyline introduced to the holding system at 250 mg per 10 litres of water is also effective against fin rot.

The disease is easily treated and the success rate is high. Many of those fish you see in a tank wagging their tails like fury and being left behind by their compatriots are survivors of a fin rot outbreak.

White spot

White spot is caused by the ciliate protozoan *Ichthyophthirius multifilis* and has proven itself to one of the more insidious diseases found around a fish farm.

The causes, like those of fin rot, are stress related. Check all the usual suspects.

The disease appears as a white spot, hence the name, covering the skin of the fish. Under the microscope the 0.5 mm to 1 mm sized cells will reveal a distinctive horseshoe-shaped nucleus. Symptoms include flashing, darker colouration as they become stressed, lethargy, and the fish appear to have breathing problems. The disease, if left unchecked, will prove fatal.

The pathogen burrows into the flesh of the fish but jettisons its cysts to the system floor where they incubate. Treatment will not only have to destroy the adults present on the fish but also catch the re-infestation from the newly hatched animals. To achieve this, treatment will have to be continuous until it catches the newly hatched ciliates. Incubation is advanced at higher temperatures so the warmer the water the shorter the treatment period will have to be. For instance:

At 3°C white spot cysts will take 90 days to incubate
At 7°C white spot cysts will take 20 to 35 days to incubate
At 13°C to 15°C white spot cysts will take 12 days to incubate
At 18°C to 20°C white spot cysts will take 7 days to incubate
At 23°C to 24°C white spot cysts will take 3 to 6 days to incubate
There is no development at temperatures below 3°C or above 30°C
White spot can't proliferate at water temperatures below 3°C or above 30°C

White spot can be treated with a malachite/formalin or straight malachite. Ichonex, as used by the aquarium industry, is equally effective.

Marine white spot

Cryptocaryon irritans is the marine version of white spot although these diseases aren't related other than in appearance and treatment. The aquarium industry also uses the proprietary lines Oodonex or Vertonex.

Chilodonella

Chilodonella is a cold-water protozoan parasite found on the skin and gills of fish. It is seasonal in warm-water species but cold-water species present a much wider opportunity for infection.

The symptoms are similar to white spot as the infected animal flashes on the bottom or sides of the system in attempts to dislodge the irritants. The slime layer will often turn a bluish-white. Lethargy and rapid breathing are all symptoms of a *Chilodonella* infestation.

The parasite is small, 50 µm to 70 µm long and 20 µm to 40 µm wide, heart-shaped and has hairlike cilia on its underside.

The outbreak can be treated with Leteux-Meyer, a malachite solution or a salt bath. Fungonex is a proprietary line used in the ornamental fish industry to control the disease.

Trichodina

Trichodina are ubiquitous and relatively harmless. However, they can cause major problems in aquaculture systems should their numbers get out of control. This is most likely to occur during the spring warm-up and during the ensuing summer months.
The symptoms are similar to *Chilodonella*, as is the treatment.

They range in size from 40 µm to 100 µm and are easily identified by their layers of hair-like cilia protruding from a distinctive round body.

Costia or *Ichthyobodo*

Costia is a flagellated protozoan. It is rare in the tropics but is present in most freshwater environments. It thrives during the cooler times of year.

The symptoms and treatment are similar to *Chilodonella* and *Trichodina*.

They are extremely small and will require a microscope of over 400 power to positively identify them. They give themselves away by moving with a jerky spiral motion on a wet slide. As the treatment and symptoms are the same as for the two other commonly encountered protozoan parasites, this is not as much of a problem as it may seem at first. Treating for one will remove the other even if the diagnosis is slightly off the mark.

Oodinium

Also known as 'velvet disease', oodinium is a difficult disease to treat and care should be taken to keep this protozoan out of your production system. Different species will attack different parts of the fish so you may find an outbreak on the gills or on the skin, or both.

The symptoms can range from a dusty gold appearance to a glossy white hue in the fishes' mucus. The fish will be listless, cramp their fins and scrape the side and bottom of the system.

Measuring 30 μm to 150 μm, you will have to look at a skin scraping or a gill biopsy to find the cause of the fishes' poor health.

It is a difficult disease to treat as the parasite is resistant to the standard treatment for protozoan parasites. Copper, although it reacts badly with most fish species, can be used under certain circumstances. The procedure is explained in more detail in chapter 18 but simply put, copper can be used in conjunction with a known carbonate hardness level. The solution generally recommended is 0.2 mg/L of copper sulphate. Naturally, before you treat the whole batch of infected fish, trial the treatment on a small number to make sure you've got everything under control.

Ichonex is used in the aquarium industry to treat the same disease and some ornamental keepers have used salt baths to effect.

Amyloodinium

There is also a saltwater version of velvet disease called 'coral fish disease'. The symptoms and the appearance are the same but the generally recommended dose rate is 0.5 mg/L of copper sulphate.

The aquarium trade uses Oodenex to treat marine velvet or coral fish disease.

Gill and skin flukes

Common and persistent, these helminth parasites can become a major problem on freshwater and marine fish farms. The two species most often encountered on freshwater farms are *Lepidotrema bidyana* (gill flukes) and *Gyrodactylus* (skin flukes). Their method of locomotion is to haul themselves around fins, skin and gills with the aid of caudal hooks. These hooks broach the fishes' natural defence against fungal and bacterial infection and once the secondary disease sets in the immune system finds it very difficult to cope with the load.

Symptoms are the standard for a fish in poor health from heavy parasite infestation: flashing, lethargy, heightened respiratory activity, clamped fins, lacklustre appearance.

The flukes range in size from <1 mm to 30 mm and can sometimes be picked up with the naked eye but microscopic examination is the only sure way to identify an outbreak.

Treatment is by formalin bath or with the insecticide Trichlorphon. A proprietary treatment used in the aquarium trade is Para-gone.

Copepods

'Fish lice' is the common name used to describe a group of parasites that includes *Argulus* and *Caligus*. The are a pest in both marine and freshwater systems. Like the flukes, they weaken the fishes' immune system. They are blood suckers so apart from the persistent drain on fishes' blood supply their activities create open wounds vulnerable to bacterial, viral and fungal infection.

The creatures are round to oval in shape. Grey to green in colour, they can range from 5 mm to 10 mm. High temperatures, crowding and low energy sites or static ponds are conditions favoured by these parasitic copepods.

Treatment is the same as for flukes. The aquarium industry uses Para-gone.

Anchor worm

Its scientific name is *Lernaea*, it is a large relatively harmless parasite active in waters over 17°C. Common in the wild, the highly visible female of the species buries itself into the body of the fish to deposit its eggs. In cold weather these eggs can lie dormant for months. The parasite is not dangerous in itself but the ugly red welts the breeding activity leaves reduces the market value of the fish considerably.

The parasite is 5 mm to 10 mm long, white to grey in colour and can be seen protruding from the red pimple-like sore it has made in the fish's flesh. Under aquaculture conditions the enflamed site issues an invitation to bacterial, fungal and viral infection.

Unfortunately they are difficult to treat as they are free swimming and the eggs are safely encased in your stock. *Lernaea* can be killed with Para-gone or Trichlorphon used as a repeated dose.

Fungus

Fungus, or *Saprolegnia*, is more active in the colder part of the year. Like most of the common problems in fish production systems, it is ubiquitous and sits waiting for an opportunity to propagate. It has been associated with massive winter kills in NSW silver perch ponds over recent years.

An outbreak of fungus on the fish is a sign of stressed conditions such as poor water quality, high parasite loads, body trauma caused by predation or intra-species attrition. Remember, poor nutrition can cause stress as well and is usually associated with poor water quality.

Commonly a secondary infection after protozoan parasites have weakened the animal's natural immune system and created a trauma site, it appears as a grubby white 'cotton wool' on the fins and body of the fish. It can be treated with malachite and can prove persistent once it has established a toe-hold, but healthy fish are not cross-contaminated.

The aquarium trade uses the proprietary fungicide Fungonex.

Chemical use – what's legal?

Should you be in any doubt as to what chemicals can be used on fish destined for human consumption, you should check with the APVMA. Their website is www.apvma.gov.au.

The APVMA will issue a range of special use permits (see under the earlier section 'Safety'). Permits can only be issued, in response to an application for:

- a minor use;
- an emergency use;
- research purposes.

To cover these situations, the APVMA has established the following permit types:

- Off-Label Permit (OLP);
- Emergency Permit (EP);
- Supply/Use Permit (SUP);
- Export Permit (XP); and
- Research Permit (RP).

Minor use

The Agricultural and Veterinary Code Regulations 1995 state that a minor use:

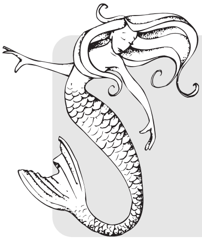
> *'in relation to a chemical product or an active constituent, means a use of the product or constituent that would not produce sufficient economic return to an applicant for registration of the product to meet cost of registration of the product, or the cost of registration of the product for that use, as the case requires (including, in particular, the cost of providing the data required for that purpose).'*

Notifiable diseases

Some diseases are what are known as 'notifiable diseases'. That means should you discover you have a suspected outbreak of one of them you are compelled by law to notify your state's Chief Veterinary Office. The list of notifiable diseases varies from state to state so you will have to find out what they are. The Aquaculture Extension Officer in your region should be able to provide the list.

IMPORTANT – READ THIS!

It cannot be stressed too often – fish for human consumption can only be treated with registered drugs or chemicals. The only exceptions are those items that are prescribed by a veterinarian or under a current Minor Use Permit (MUP). There are no exceptions and there are no excuses. The circumstances will change as additions are made to the registration list and some drugs or chemicals are removed. Seek professional advice from your local fish vet or Extension Officer if you are at all uncertain as to the status of a particular drug or chemical.



GWQEHN says:
Litigation is costly, both to defend and to lose. But it's more than the individual who suffers. The whole industry gets a bad name and consumers lose confidence in the products we produce. Don't even think about bending the rules.

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16

Predators and pests

This chapter deals with one of the most overlooked factors affecting aquacultural production. It covers the different kinds of predators and the ways you can control them:

- fish and cold-blooded water predators
- water rats, seals and sea lions
- sharks and crocodiles
- birds
- netting control, materials and costs.

The importance of predator control

It isn't just the weight of fish or crustaceans that is eaten that is the problem; it's the number of tails consumed, and the potential growth forgone that really hurts the bottom line. A 1 kg cormorant may consume 200 g of yabbies a day, but you have to ask, 'Is it taking four 50 g yabbies or is it taking twenty 10 g yabbies with a potential to become a kilo of 50 g yabbies?

Another aspect of predation is the stress predators place on the whole crop. The predators may only remove a few slow-moving victims but they will leave the remainder of the crop badly shaken and very likely off their tucker. Salmon farmers can tell when seals have been around the cages because the fish don't feed well.

A little arithmetic will tell you how this relates to dollars. In a pond you might have 10 tonnes of fish. The fish are to be sold at the farm gate for $5 per kilogram. If the fish are growing at 1% of their body weight a day, that's an increase of 100 kg per day, with an increase in value of $500. If a predator is hanging around, and stressing-out the stock so that they drop to half their normal growth rate, that's a drop of $250 per day in value forgone. If they're selling at $10/kg then that's $500 a day going down the gurgler in lost growth. Of course, if the stock are growing faster you're losing even more. Not addressing a predator problem is 'Penny wise and pound foolish' as GWQEHN would say.

The list of predators given is extensive but there is a chance that you'll come across one not envisaged so don't let down your guard at any time. Constant patrolling of the predator defences to check for breaches is part of that vigilance. Predators are wary when people are working around the ponds, and sleep during the heat of the day. Visit the ponds at all sorts of odd hours of the day or night to try to catch them out.

Figure 16.1. Every two of these gastroliths represents a crayfish. This is the residue from just one cormorant 'squirt'. When crayfish are in moult they are totally vulnerable to predation and the birds seek them vigorously. Judging by the size of the gastrolith, one of the victims was quite large.

GWQEHN says:
There is no point doing anything towards raising fish or crustaceans unless you have adequate predator control. End of story.

Fish

Predatory fish can enter ponds by swimming down the water supply channel. Fry, larvae and eggs can all pass through a pump, and grow into larger more formidable individuals. It is amazing what comes through the pump or irrigation channel as the ponds are being filled.

It doesn't end there, however. They can also swim up an unguarded water outlet pipe.

Again, it's not the weight of product they eat so much as the number. Small fish will grow in the ponds undetected. They'll always be eating fish smaller than themselves and can take a cruel toll of juvenile fish or crustaceans. You want your crop to be at the top of the food chain, not part of it.

In the Murray–Darling Basin and the south-eastern corner of Australia, species such as redfin, carp, Murray cod, perch and catfish have all been found living the life of Riley in aquaculture ponds. These fish will prey on your stock and eat your fish food. Should you not drain your ponds as a part of the management program, they may even breed in them. The impact this would have on the ponds would be catastrophic should the juveniles survive predation from the stock in the pond.

Live bearers (including guppies, mollies and so on) are native to North, Central and South America. The brightly coloured species are popular with aquarium enthusiasts and a few feral populations have been established in the northern half of the continent from liberations of unwanted pets. In the wild in Australia, the most common species found is *Gambusia affinis*, the mosquito fish. A native of North America, this species was introduced to control mosquito larvae, hence the name. Anyone who has sat out on a balmy summer's night will verify that the exercise was as successful as the introduction of the cane toad. *A Guide to the Freshwater Fish of Victoria*, by Cadwallader and Backhouse, describe it as a:

'small, olive coloured fish with dorsally-flattened head; tiny, protrusible, upturned mouth; single, short based, soft-rayed, dorsal fin; large scales; no lateral line. Anal fin of males elongated, pointed; that of females rounded.'

For those who still aren't sure what it looks like, refer to the illustration below. The females grow larger than the males, in fact nearly twice as large: 60 mm compared to 35 mm.

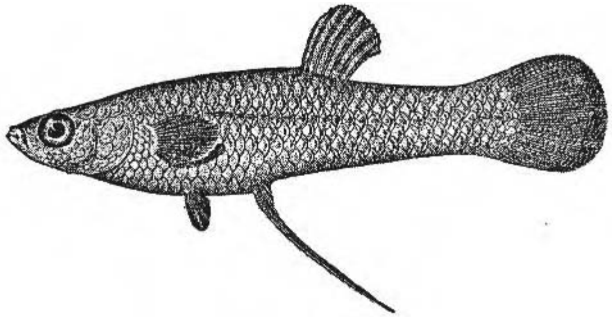


Figure 16.2. ***Gambusia affinis*** **or mosquito fish can build up to plague proportions in your pond, damaging stock with their annoying habit of fin nipping as well as competing for food, either natural or supplementary.**

Mosquito fish are live bearers and serial breeders. They breed from spring through to autumn and gestation is between 21 and 28 days. Broods are usually in excess of 300 and these will be sexually mature in 6 weeks. They can tolerate a wide temperature range – 6°C to 37°C – and can tolerate some salinity. The good news is that they don't live beyond the summer in which they become sexually mature.

This species not only takes up valuable bio-space in your ponds but they also eat your fish food. Then there's the nasty habit of nipping the fins of larger fish thus causing a site for infection. They are particularly savage on fry or fingerlings. Unfortunately they aren't readily taken by our native species and their introduction is to be avoided at all costs.

Australians have been prolific in the pest species they have liberated. Whilst the north has not been entirely free of this, perhaps the worst impact is in the south. In the tropics it is possible to get an influx of exotic tilapia, but it is more likely for unwanted fish predators to be species like barramundi or one of the various grunter species. Having these species in your ponds is great if you want to grow barramundi or grunters, but disastrous if you want to grow crayfish or prawns.

Some marine fish are good at cracking open molluscs. One of the authors has found abalone shells in the gut of trumpeters and the other has found freshwater mussel shells in the gut of Murray cod. Bream and pink snapper can crack soft shells. Leatherjackets have been accused of scoffing mussels. Fortunately, these predators generally confine their feeding activities to juvenile specimens and can't get through the thicker shells of larger molluscs.

Control

The key to controlling finfish predators and pests is to stop them getting into growing areas in the first place.

Some growing areas are contained, for example, prawn ponds and freshwater ponds. The ultimate level of containment is in re-circulating systems. Since the area is enclosed, it is possible, providing sound quarantine practices are employed, to prevent the unwanted species from ever getting in.

If the intake water cannot be guaranteed to be free of fish life, all is not lost. Ponds can be screened to prevent the entry of unwanted fish. You may choose to install a series of screens of diminishing size but if you're trying to keep out fish eggs and larvae you will need to make the final barrier at least 500 μm. But be prepared to thoroughly investigate the local conditions over a whole season to see what's about. In extreme cases it has been found necessary to install final stage filtering nets down to 70 micron because the presence of small eggs and larvae of unwanted species in the incoming water has been thought to be a risk factor.

A filter as fine as 70 μm presents a lot of resistance to water flow. To get around the resistance, a large area of filter material is needed. Generally this is achieved by having your filtering cloth in the shape of a sock. You will have to clean out the sock regularly to ensure that it doesn't become clogged. The longer the sock, the greater the interval between cleanings. Two or three metres wouldn't be too long.

Intake water is not the only way fish can access a pond. Care should also be taken to prevent fish swimming up into the pond against the outgoing water and fish are just as capable of swimming into your ponds through the drainage outlet. In fact, many fish are attracted to fresh water movement and will follow it up to see if there's anything in it for them. If they find your ponds they'll think they hit the jackpot. Be aware of intrusion through the back door.

If you wish to remove fish from a water body, there are approaches that can be taken. The idea is to make the water as toxic as possible, till the unwanted fish die, then to return it to a benign state suited to fish farming.

Theoretically there are a variety of ways to do this:

- *One way is to make the water very alkaline by adding Limil, quicklime* or something of this nature. Make sure the material is well mixed in the water. The rule of thumb is to take the pH above 11. A day or so after treatment, the earthen bottom of the pond will bind up the excessive alkalinity and the water will return to a more fish-friendly state.

- *Another treatment sometimes used is to add swimming pool chlorine.* After some days the chlorine will dissipate into the atmosphere and the pond water will be suitable for fish again. The rule of thumb for this treatment is to purchase an indicator test kit for chlorine from a swimming pool supplier, then add enough chlorine to take the indicator up to the limit and then add the same amount of chlorine again. In other words, double the dose.

The downside to this is that you will have to deal with a body of water full of dead fish. Some will float to the surface but not all of them. If this procedure has to be undertaken, bear this in mind.

These treatments are not always effective. Sometimes the materials are not mixed through the water well enough. Use the normal approaches to mix the water, for example, aeration, paddlewheels or the old nose-the-duck-punt-into-the-bank-and-run-the-outboard approach.

The water body will settle back to a normal background level within three weeks.

It can also be expensive as a surprisingly large amount of Limil and/or chlorine may be needed for anything but the smaller water bodies.

Both of these treatments are for freshwater. The authors are not aware of a similar approach for seawater.

The best and most complete way of removing fish is to drain the pond and leave it to dry. Fish don't live well in air. Screen new water when it comes in.

Eels

It may be possible to argue that eels are, strictly, finfish, but their habits, and the nature of the problem they pose is sufficiently different to warrant a section of their own.

Eels are more prevalent along the coastal watersheds of the east and sides of Austalia than people realise. They are not found across the top of the country, as the currents required by their life cycle are not present. They don't naturally occur inland and should not be a problem in places such the catchment of the Murray–Darling Basin.

In the appropriate areas, eels can quietly slip into your ponds one wet night, settle in and start helping themselves. Like normal finfish, eels enter ponds with the incoming or outgoing water. However, they are also capable of sliding over wet ground and can climb walls. During rain, when most fish farmers are sitting inside, run-off turns normally dry paddocks into a shallow lake, a few millimetres deep, and at these times, eels can find access to the most unexpected places.

The impact of eels can be significant. There was the tale of the chap who harvested his silver perch ponds after three years and only found 500 kg of fish, where he thought there was going to be 5 tonnes. He also found a 63 kg longfin eel. He reckoned that explained the absence of cormorants around the ponds and what happened to his silky terrier the year before.

Figure 16.3. Eels can quietly slip into your ponds and unobtrusively help themselves.

Control
Once eels have found their way into a pond, there is very little that can be done to get them out. They are hardy and can survive conditions that will kill your stock. They bury in the mud so drag netting doesn't work, and even draining is only partly successful.

If you are in eel country, a barrier should be built around the ponds to keep them out. Something about 30 cm high leaning slightly away from the ponds should suffice. Water outlets should have some kind of a waterfall where the water doesn't touch anything. An example would be a pipe, the open end of which sticks out 30 cm or so above the collecting channel.

Crustaceans

Just about every aquatic animal likes a feed of crustacean. It's amazing how they survive in the wild. As a consequence there are few crustaceans that are pests or predators, but there are some.

Pests don't have to actually eat your crop to be a problem. In the north, it is not uncommon for prawn ponds to be filled with water containing indigenous prawn larvae. These are not the target species, but use the same space and consume more or less the same food as the species grown.

Control
Unwanted prawns are denied entry by screening the inlets or, in rare cases, by using groundwater.

Crabs can attack small oysters and other molluscs kept in the open ocean. In this case, the solution is to keep the stock in mesh containers made of the general gutter-guard type of material, the size of the mesh being large enough to allow free water exchange, but small enough to keep out the larger crabs.

Some bivalves, for example mussels, have fellow-travellers: pea crabs, living inside their shells. The pea crabs don't do any damage, but they can be off-putting to somebody eating the bivalves, and thereby lower market prices. Pea crabs find their way into bivalves by walking over the seabed. If the crop is grown hanging from long-lines, the pea crabs never seem to make their way into the shells.

Another problem with crabs is that they can be carriers of some of the very nasty prawn diseases, like white spot or yellow head, which, thankfully, have not made it to Australia at the time this book was written. Crabs can walk over land and have the potential to carry infection into ponds. Should the unwanted diseases come to Australia (perish the thought!) it may become necessary to situate prawn ponds with wide expanses of dry land between them, or to build some kind of crab-proof fence.

Tortoises and terrapins

These unobtrusive amphibians are common pond dwellers and capable predators. You mightn't even be aware of their presence until you drain the pond or catch one in a crayfish trap. They need to breathe from time to time, but will hide underwater when somebody comes along. If you sit quietly by a pond for a while, noses will start to come up. Occasionally you will see one.

Control

A bit of careful chasing with a net will remove tortoises, but it is time consuming and less than efficient as you will be chasing the stock all over the shop as well. Prevention is the best cure and tortoises can be kept at bay by the same defensive barricade used against eels.

Water rats

Water rats migrate over long distances by following watercourses until they find a good spot to settle down and raise a family. The overflow from your fish ponds would rate as a watercourse to a water rat. The scent of fish in the water would attract these rodents from long distances.

They betray their presence by leaving their dinner scraps lying around in neat little piles. They select the biggest crayfish in the ponds and just eat the backs out of them, seeking the rich digestive juices in the 'mustard'. This is not only infuriating, it's costly; the crayfish they take are the ones that attract a premium on the market, and to see a dozen or so just tossed in a heap can really get your blood boiling. It is almost as though you can hear the little blighters sniggering in the background.

Control

Water rats are cunning, intelligent and determined. Electrically charged chicken wire has been found to be the most effective defence against them. Poles should be tinned to prevent them being used by the rats as an entry point. They will dig under a shallow barricade so any barricade must be buried at least 30 cm. They live and hide under heavy cover, so anything that would provide a harbour for rats should be kept away from the ponds and vigilance kept against any breaks in the defences.

Seals and sea lions

Seals and sea lions are the number one predator of cage-farmed fish in cool temperate to cold water fish farms. Seal numbers around salmon cages have increased dramatically around the world over the last few years. It's hard to say if it's a collective consciousness that the living is easier around fish farms but the reality is that the protective netting surrounding the farms has had to be made stronger. With the current wildlife laws seals have also become less fearful and bolder, and divers have found themselves confronted by the odd old bull that doesn't want to take a backward step. One of the authors has been in this situation and vividly recollects the overwhelming diameter of the seal, and the fact that its teeth were each larger than his little finger.

As with all predation, it's not the weight of fish they eat, it's the number they destroy. One Tasmanian salmon farm manager has said:

> *'They get in between the cage net and the predator net and catch the fish through the mesh. They don't actually eat the fish. They suck the liver out and go back and get another one. For every one they get hold of there's probably three or four they kill just trying to catch them. Then there's the stress and loss of production from the attack.'*

Control

Total exclusion is the first line of defence. Predator nets are strung around fish cages. A steel mesh fence running from the surface to the seabed is installed around the perimeter of the sea cages to keep the seals out of the area.

Seals are much loved in the public mind, and politicians follow the views of the voting public. If there is a confrontation between seals and aquaculture, and the confrontation results in damage to the seals, aquaculture will be the factor that is removed, not the seals. Do not hurt seals, even if they have wreaked havoc. Call in wildlife officers to relocate any rogue elements that develop a love of aquaculture.

Some rogue bulls, however, have outstayed their welcome by attacking members of the workforce and permission has been granted by the wildlife authorities to undertake a long-term relocation procedure before a member of the public receives an injury.

Sharks and crocodiles

In tropical regions crocodiles replace seals as the amphibian predator, while sharks are a threat wherever fish are grown. Seals may be smart, but sharks grow to a large size and develop tremendous power. Crocodiles are the same. Crocs in particular are attracted to fish farms. Dead fish really attract them.

Control

Both these potential man-eaters are protected and as with seals, total exclusion is the first line of defence. When barramundi cage farming started, the farmers tried the same sort of predator nets that been used successfully against seals. They weren't up to the power of the tropical predators. Thicker steel nets (like chain mesh) were employed and seem to solve the problem.

Dead fish should be quickly removed from the farm (which is good practice anyway). They should be disposed of in a place far enough from the shore to prevent crocs smelling them out. One of the authors recollects visiting the area where mortalities from one farm were buried. Before he got there, he could tell by the tracks of crocodiles coming up the beach where the burial pit was located.

Crocs have the ability to jump quite high out of the water, but experience has shown that while they will attack people in canoes, they don't attack people in boats (well not normally, there was one example of a croc that made a habit of eating outboard motors). For operators' safety, sea cages should have fences around the walkways which should be located as far above the water as possible.

If a crocodile is a persistent offender, relocation is an option, but this would have to be done in conjunction with the wildlife authority.

Poachers

Poachers are two-legged predators and they have the potential to do a lot of financial harm to a fish farm. Watch for tell-tale tyre tracks and net drag marks around the ponds. Hopefully it won't be a problem but be aware of it.

There is a school of thought that the word 'poacher' has a romantic ring to it, which unnecessarily glamorises a criminal activity. Followers of another school of thought prefer to use the term 'fish thieves'.

Another aspect of seafood theft is the food safety issue. Thieves won't be as meticulous about food safety as industry participants with their life savings tied up in their businesses and there's the chance that someone will get a bellyache from a crook oyster. It may expose the end of the trail but by then it's too late: the damage has been done. Once it hits the press, seafood sales plummet and all that hard marketing effort goes down the drain as the industry moves into damage control.

There's even a chance that the person receiving the stolen goods will try to protect his illegal supplier by using his false paper trail to pin the blame on his legitimate supplier.

Control

Poachers fall into two categories: those who do it for fun and those who do it for profit.

Use any security measure you feel would be necessary. It isn't an easy task to harvest a pond (as you'll find out), however, petty pilfering can add up to some serious dollars over a period of time. Make it even harder for the thieves: put snags in the ponds; have a mean dog on patrol; take irregular walks around the ponds at night and use other ruses that should soon keep the local lads on their toes.

Professional thieves are more determined but they still have to make it pay. Making it so difficult that it ceases to be cost-effective should demolish their bottom line. It's a nuisance but it's a sign of the times unfortunately.

Another way of tackling seafood theft is to attack the money end of the trail. Thieves need a market outlet, and with seafood trails being required by food safety laws

GWQEHN says:
If you don't have adequate predator control you're not really serious about aquaculture.

the fences taking the stolen seafood are open to audit of their inventory. We're all aware that paper can be provided that will smudge an audit trail but a vigilant enforcement officer, provided with good information, should be able to uncover the trail.

Birds

Birds are the most common cause of losses from predation around inland and coastal pond systems. Birds' mobility and social organisation gives then access to a widespread territory. The authors have seen them decimate crops when they've moved onto the ponds in numbers.

As well as eating stock, birds can also transfer disease from one water system to another, in which case your predator control becomes part of your quarantine system.

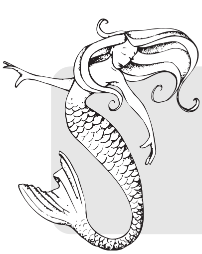
Birds come in a variety of shapes and sizes. Different species may have different attributes and need to be addressed in different ways.

Cormorants

The lone cormorant seen poking around your ponds might be roosting in a 500-bird rookery 30 km away at the nearest reservoir or wildlife refuge. That lone bird is doing a bit of intelligence work for his numerous mates. Once the stock is of a size that suits the cormorants they will come in their droves. They will round up the fish and only leave when the ponds are all but cleaned out. Crustaceans are particularly vulnerable to cormorant predation. The cormorants will wait until the freshwater crayfish or prawns have got a bit of size on them (about 15 g to 30 g) before they move in. They seem to prefer to hit the ponds when the crustaceans are in moult and more vulnerable than usual.

In the southern reaches of the continent there are four species of cormorant that you're likely to come across: the giant black, the small black, the large pied and the small pied. The small pied is generally a lone worker but the small black is a team player and a flock of them can really do some damage when they work your ponds over. The large pied is more a coastal bird but the large black has an inland network and covers vast distances, usually in small flocks, in search of a meal. Further north, cormorants are more or less replaced by darters, egrets and herons.

Stories of cormorants eating several times their own weight a day probably emanate from fishermen watching cormorants catch fish while they can't even encourage a nibble. Chris Barlow in *Silver Perch Culture* estimates they consume 20% of their body weight a day (p. 91). The size of the fish or crayfish they can consume is also surprising. He goes on to say that a large black cormorant could eat a 500 g silver perch, which is not far off market size. Little pied and little black cormorants have been found with trout in their stomachs as long as 23 cm. This too is not far off market size.



GWQEHN says:
If you haven't got any birds hanging around your farm it's usually because there's nothing left for them to eat.

One grower in the irrigation region of Victoria's lower Goulburn Valley could tell when the rice growers in southern NSW stopped irrigating. The cormorants would turn up on his ponds the next day.

Other aerial predators

This list includes herons, kingfishers, egrets, snake birds, spoonbills and some wild ducks. Hardhead (sometimes called a widgeon in NSW) are fish eaters. Any sediment-straining duck (blue-winged shoveler, pink-eared duck) or weed-eating duck (black duck, grey and chestnut teal) will take juvenile yabbies while they're foraging. Crows will pull yabbies out by the antennae from the edge of the ponds and any bird seen hanging around the pond's edge is after one thing: your stock.

Herons have been chased off fish they'd hauled out onto the bank that have been big enough for a person to take home for a meal.

Pelicans are a most graceful bird and are a delight to watch flying and landing. They work together in the most calculated way: lining up and corralling a section of water before systematically working it over. This wonder of Nature's loses some of its appeal when they are working over your ponds and eating your stock.

Nankeen night herons are particularly good fish and crustacean harvesters. As their name implies they roost during the day and work unnoticed at night. They can gang up on a pond or string of ponds and quietly clean them out over a number of nights. At one fish hatchery in Victoria's lower north-east, of the authors' acquaintance, the night herons would turn up each summer and make themselves comfortable in the glades of bamboo that were around the place. They were welcomed as part of the seasonal cycle, until it was discovered the hatchery's fry ponds were part of that seasonal cycle.

Control

There is only one effective method of control: total exclusion. By covering the ponds with bird netting the birds will be kept apart from the stock. Netting options are discussed in the next section.

With apologies to the people who market them, *scare guns, sonic devices, scarecrows* all have periodic moments of popularity but in the long-term have all been proven to be total useless in protecting commercial fish and crustacean ponds from aerial predators.

Scare wire is another financially attractive option that has been found wanting on commercial fish and crustacean farms. Not unlike fishing line in appearance, the wire is supposed to shimmer in the sun as the wind moves it about. One grower who tried it was told gaps of 60 cm between lines would do the trick. He found himself narrowing the gaps until he had a mesh of lines across the pond that prevented the birds from getting through it. Then the lines began to break and when one loose end caught him around the neck as he rode past on his farm bike the whole rig came down and was replaced with netting.

Keeping *steep batters on the pond walls* will reduce wader activity, but doesn't have any impact on the diving or swimming birds. However, the steep batter will only last as long as it takes the water to erode it to a natural 3:1 batter.

Constant human surveillance is effective but it means patrolling the ponds around the clock because one of the most unobtrusive and efficient invaders is the nankeen

Figure 16.4. The scariest thing about scare wire as a predator control is that it is inefficient. It didn't scare this lot of birds one bit.

Figure 16.5. In some state jurisdictions tyres can't be buried and while they can be left under water, will cost over a dollar to dispose of under EPA regulations. These shown here would cost a pretty penny to dispose of.

night heron. Visiting a farm in the central west of NSW one author was told the crew were down the back doing a cormorant run. Four cups of tea and a tray of scones later the crew returned. It turned out that three men spent two hours patrolling the ponds each morning and another two hours in the evening. That's a full week's wages it was costing the owner without keeping the cormorants on the move over the weekend. It would have been cheaper to spend the money on effective predator control.

Dogs have been used with mixed results. It all looks spectacular at first but the dog's only doing it for fun, or out of sheer bloody-mindedness. The birds are doing it for a living. The dog eventually tires and the birds get their feed.

At this point the matter of putting *tyres in crayfish ponds as hides* should be examined. The authors have always felt that tyres are inefficient when it comes to predator control. If you look closely at a cormorant you'll notice it has a long beak with a hook on it attached to a long neck attached to a stomach. Ideal for hooking crayfish out of car tyres for delivery to the stomach you would have thought. A veritable self-serve cormorant supermarket. The other thing about tyres is that they block the flow of water around the ponds and create dead pockets, which just isn't good aquaculture practice.

Bird netting

In places where there is a big problem, total exclusion of birds is the only way to go. That means surrounding the ponds with nets and building suitable structures to support the nets.

The life of the actual netting will vary with the grade and manufacturers make claims of two to five years. Ensure that the netting is UV treated, that the erection is solid and the netting is securely fastened.

There are several suppliers ready to sell you bird netting but not all of it is strong enough for the job. See what's advertised in trade magazines and ask them for references. Ask other growers how long their netting has lasted and where they got it.

Netting can usually be custom-made to fit a particular job but don't be drawn into making the spans too wide thinking it's going to make the erection easier and/or cheaper.

Beware of under-strength material. If you can tear the netting easily yourself, it won't last long in a strong wind.

The most commonly used netting is polypropylene twisted cord. There is also a netting material made of extruded plastic available that has been used successfully.

Types of bird netting control

As we've already dealt with el cheapo options, followers of GWQEHN will only be considering total exclusion netting. Netting can be either slung over wires stretched along the length of the ponds at water level or it can be attached to wires erected above the ponds to make an aviary with the birds kept on the outside.

Water level cover

Some growers prefer the low netting because it is easier to erect, and having less material in it, is cheaper. The disadvantages are that the netting has to be folded back for

Figure 16.6. Low level netting is easier to erect and can be pulled back for harvesting and pond maintenance.

harvesting and the low structure can interfere with pond maintenance when equipment has to be worked in the pond to clean out sludge or apply lime and fertilisers.

Aviary type cover

The high 'bird-cage' structure is more costly to erect and utilises more netting but once in place the farmer doesn't have to touch it again except for normal maintenance and replacement.

Mesh size

Don't use any mesh with a hole size over 100 mm x 100 mm, as the birds will land on a post and dive through the netting. They walk out at ground level when they've had a feed. You may wish to go smaller but there's no need to go below 80 mm. Most of the netting used in the industry is 100 mm x 100 mm.

Erecting netting

The weakest link of bird netting is the erection. Ensure that the structure is solid and well supported. Don't skimp on this. Use a contractor if you're not a good builder. There may be someone in the district that has experience in erecting bird netting. There's been more than one fish farmer who finds their netting dumped in the next paddock after a decent blow. Be guided by those who have been there before.

Netting also rips if it gets a decent flap up. Have the mesh as taut as possible to prevent birds getting caught in the slack mesh and the netting flaying around in the

Figure 16.7. The penalty for not having the netting spread evenly along the wires is the impossible job of getting the threaded wires to meet at the cable.

wind. Some growers strain some wires over the top of the mesh once it's erected to batten down any flapping. Others say it's not necessary, so it will have to be a management choice.

Talk to growers who have had bird netting up for some time. Seek their views on the matter. They may even be prepared to spend a day with you to help you get started. Joining an industry association is a good way to meet other growers and extend your aquaculture network.

Don't skimp on material. Use cables to strain the outside posts. Use cable as the main support for the netting panels. Double-strain corner posts. Strain key internal posts, or all of them, if you feel it will make the structure more secure. Use sound timber for posts. It has been known for 100 mm treated pine to snap like a carrot under violent winds. And let's face it, it's the once-in-a-decade blow that always seems to arrive just as you get your netting up.

Ask the supplier if they have an erection manual that goes with the netting.

From experience, erecting netting can be very frustrating. The standard error is to not feed the netting onto the wire evenly. This gets the netting out of square and when you get to the end, the 100 m x 10 m bolt of netting seems to have shrunk to 80 m x 10 m. If this situation arises you will need to go back and make sure the mesh is evenly fed along the support wires.

When contemplating the design of a predator control system to suit your operation, first consider what you're trying to achieve. For instance if your operation is not in eel country there will be no need to build in any protection against their intrusion.

Figure 16.8. Well-erected netting will last for years and, if you have any sort of a crop to protect, will usually pay for itself in the first year. Note the steel posts and solid structure of this frame, a real engineer's job.

First start with the erection of the poles. The lines of poles will form panels of a predetermined size. The panels will match the size of the netting. Make sure the poles are straight, in line and well strained. Include turnbuckles in the strays so the structure can be tightened as the whole thing stretches.

Next, the cables are connected to the poles. They will run around the perimeter and along each line of poles. This will give the poles added support as well as providing the cables onto which the panels of netting will be hung.

Erect a rabbit-proof fence around the outside of the poles. This will prevent stock from getting caught in the netting and prevent any animals from chewing at it.

A solid barricade of some sort is then dug in around the base to keep out eels and tortoises. If water rats aren't a problem, plastic or polypropylene sheeting could do the job. Thirty centimetres should be high enough. It will also prevent crayfish from migrating off the farm, although it won't stop them moving from pond to pond.

If water rats are a problem then the sheeting will need to be more substantial, probably tin sheeting or corrugated iron. You may not need electric wiring to keep out water rats, but if they prove a problem it is a ploy you may consider

The netting panels are made up on the ground. Fencing wire is run out on the ground below where it is to be lifted up to the cables to be clipped on. The netting is fed onto the wire and worked along until it is all threaded. Work thoroughly at this to ensure that the netting is going on squarely. This is the key to it all. If you get that netting unevenly spread it won't match the panel space you allowed and you'll have to go back and square it all up. This is the frustration in erecting bird netting. It's not hard to do but it does take some concentration.

Once the panels have been made they are lifted up to the cable and clipped onto the cable with wire clips.

Hanging the side curtains between the cable and the top of the rabbit-proof fence is straightforward.

The weakest link in your defence is the gateway you use yourself to bring in food, fertiliser, limestone and earth-moving gear for pond maintenance as well as take out the finished product. If there's a weak link, water rats will find it.

Quantifying the cost of predator netting

Everyone can tell you how much it costs to erect bird netting, but very few can tell you what it costs NOT to erect bird netting. Referring to *Silver Perch Culture* (Rowland and Bryant, p. 95) we find the following table.

Table 16.1. Yearly loss of income per hectare of ponds resulting from various levels of bird predation, given combinations of projected yields of 5 and 10 tonne/ha and market prices of $5/kg and $10/kg.

Projected yield			Lost income ($) at predation levels of			
Yield (tonnes/ha)	Price ($/kg)	Income ($)	2%	5%	10%	25%
5	5	25 000	500	1250	2500	6500
5	10	50 000	1000	2500	5000	12 500
10	5	50 000	1000	2500	5000	12 500
10	10	100 000	2000	5000	10 000	25 000

A ballpark figure for the cost of getting a contractor to erect an aviary-type, total exclusion predator control could run to $10 000/ha. That sounds like a lot but let's look at what would happen if the predator control wasn't in place. We'll use freshwater crayfish as an example as they are the species most vulnerable to predation.

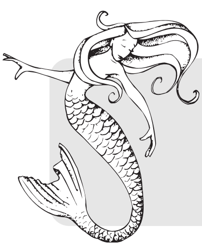
Redclaw farmers in the tropics say an annual harvest of 4 t/ha can be achieved in well-managed and designed ponds. Growers in regions conducive to yabby farming claim 2t/ha as a fair estimate from ponds in which everything goes favourably.

On the other hand, from talking with yabby farmers, it would appear that 500 kg/ha would be a healthy crop from a non-protected area, 1000 kg/ha tops. That leaves a discrepancy in the yabby harvest of 1500 kg from one set of ponds or 1000 kg from the very best-case scenario. At a farm gate price of $10/kg that's $10 000 to $15 000 a year the grower is feeding predators. Yields are likely to improve as growing methods and diets become more efficient, but predators will still only leave the 500 kg/ha in the pond as not being worth the effort of chasing. The losses would be magnified. A potential 3 t/ha yabby crop reduced to 500 kg would be costing the grower another $10 000/ha more each year.

It could all be avoided by building the ponds with adequate predator control for an outlay of $10 000/ha at the most. Giving the bird netting a life of only five years that's $50 000 to $75 000 that has been sacrificed for want of spending $10 000 to erect it. Most farmers will be saying they could do it for half that price, and they'd be right most times.

The sums for redclaw are even more frightening on two scores. First, they tend to attract a better farm gate price on average than yabbies. Second, as they farm just about all the year round in the tropics they will recover more from the ponds, but the losses will be greater because the potential crop would be greater. If the recovery from non-protected ponds is 1 t/ha to 2 t/ha over the year, then the loss ranges from 2 t/ha to 3 t/ha. If we stick to $10/kg at the farm gate as the market value, that's $20 000 to $30 000 per hectare per year.

One of the cruellest aspects of all this is that the grower never finds out if the improvements he or she has been incorporating in their husbandry, the new line of super yabbies they've been meticulously breeding over the last couple of years or the new dietary regime they've designed, is really effective. The farmer may have been farming really well and heading in the right direction at a rate of knots but doesn't know it because the extra crop is flying out of the ponds with the birds or being eaten up by a load of young carp that came in with the water. I wonder how many fish farmers have given the job away in frustration without realising how close they came to cracking the jackpot?



GWQEHN says:
It's not what you do right in aquaculture; it's what you do wrong.

17

Harvesting

Harvesting is what you've been working towards. In this chapter we will cover:

- harvesting methods for fish
- harvesting methods for crayfish
- general hints for successful harvesting.

Most of the hard work has been done: the fish have been nurtured through the numerous traumas they face in your production system and are ready to pay their way. All you have to do now is get them out of the water and prepare them for sale. Because of the well-designed and planned layout of your ponds and handling facilities this shouldn't be a drama.

Like everything else involved with aquaculture, plan what steps you're going to take in advance and go over them a few times until you are certain what you are going to do and why. In other words write yourself a manual: a pro forma manual. Be prepared to streamline it as you get the feel of the operation and your layout.

There are several options open to the fish and crayfish farmer and they serve different purposes. For instance you might use a drag net to take a quick sample of a crayfish pond but you wouldn't subject the whole crop to such violent harvesting methods if you were taking them out for sale.

The three factors influencing the decision of harvesting methods are that it be:

- gentle on the stock;
- easy for the operator to manage; and
- efficient in terms of time and pond clearance.

Harvesting methods for fish

The seine or drag net

This will work well if the net gives good pond coverage; if it doesn't, the fish will swim around and/or under the net. Net shape is important. It should be deep enough to allow the lead line to sit on the bottom, the cork line to float and the net to billow under the water pressure and weight of fish as you drag it through the pond. It should be weighted enough to keep it on the bottom under the same pressure.

The net should be of made of soft, knotless netting so as not to damage the fish. This can be expensive but don't be tempted to use a cheaper material if it is going to cut into the fish or snag their noses and gill plates.

The net has two size measurements: the outer dimensions and the mesh size. The size, and weight, of the net should be in keeping with the physical capability of the crew and equipment to handle it in both its wet and dry condition. Oversizing is a common fault: think this one through carefully.

The mesh size is also important. A fine mesh is harder to haul through the water and tends to hold more pond debris and small pond life, thus unnecessarily increasing the load on the net and the grading at the end of the haul.

Also consider the size and species of fish being harvested. For instance: silver perch have small pointy heads that easily get through the mesh right up to their gills. Then there's the size of the fish you're harvesting. The mesh size need only be small enough to contain the average size of the fish in the pond or tank.

The shape can be anything you like and the shape of the pond will have a bearing on the dimensions of the net; but most fish farmers prefer a purse or pocket (the seine) in the net to hold the fish as the haul progresses.

Have the net made on the square, not on the diamond. Netting is made so that it is set on the diamond pattern when hanging from the selvage. When under load this pattern tends to draw together forming a solid front that will scoop up mud and debris from the bottom of the pond, thus increasing the drag on the net. If the net is made so that the mesh is square to the lead line this will allow the mesh to remain open under load and reduce this drag.

The drag net, unless it is extremely efficient, won't clean the pond out totally and you will have to drain the pond to be able to declare it 100% devoid of fish, but with practice you'll get near enough to a total harvest. The drag net will enable you to take a partial harvest without having to drain the pond. Of course, the lowering of the pond's water level will reduce the amount of water between the fish and make them easier to round up.

In summary, it could be said that seine netting in ponds is efficient but hard on the operator and, under inappropriate conditions, can be stressful on the fish.

Figure 17.1. Make no mistake, netting is backbreaking work.

Harvesting from tanks in re-circulation systems is straightforward and most comments in this section refer to pond harvesting.

The drain harvest

By far the most efficient method is the drain harvest – it's easy on the fish and operators and gives a total harvest in a very short period of time.

The pond is drained down to a sump from where the fish are collected and taken to purging tanks. An outside sump is far more efficient and is the preferred option.

The outside sump is situated outside the pond so that the outgoing water runs into a mesh cage, which in turn sits in a box. The box holds the fish in water but as the box overflows the fish remain trapped in the mesh cage. The cage can be lifted onto the pond bank and inserted into another waterfilled box on the back of a vehicle or trailer.

If the fish are not being purged or sold live they can be put straight into an ice slurry at this point.

Fish pumps

Fish pumps are expensive to buy but easy to operate. However, there is some concern about the damage they can do to fish that are going to be on-handled as live product and adequate research in this area should be undertaken before purchase. They operate by drawing the fish out of the pond with the water and separating them. You'd need to have sufficient volumes to justify their purchase.

The fish can be crowded by netting them into a section of the pond or by lowering the water. The fish pump picks the fish and water from the concentration of fish and lifts them out of the pond. A grader can be situated at the outlet to further reduce labour input.

Figure 17.2. A fish pump set up to harvest silver perch. The fish are crowded at the foot of the pump with a net before being drawn up the pump into the transporter.

Other harvesting methods

Gill nets, drum nets and shade traps cannot collect enough stock to warrant their use as a harvesting tool, but drum nets and shade traps are often used to sample fish from the ponds. Gill nets tend to leave dark scar marks on the fish, thus reducing their commercial appeal but are sometimes used to collect broodstock from ponds to avoid draining them, as are drum nets and shade traps.

A drum net is probably the oldest known fish trap. A mesh barrel has a funnel inserted at one end. The fish swim into the barrel, or drum, via the funnel attracted by either curiosity or chance and can't escape.

A shade trap is a drum net wrapped in shade cloth. In clear ponds this makes the drum appear to be an attractive daytime hideaway. Both the drum net and the shade trap are simple, non-stressful methods of sampling fish.

Dip nets

Hand-held dip nets are still used to scoop fish out of tanks and sumps, or just to move them about. They are used to harvest once the fish have been congregated. They are the most common method of removing fish from tank-based production systems.

Harvesting methods for crayfish

Two 500 g fish make up a kilogram. To make up the same weight in crayfish you'll have to handle 20 x 50 g crustaceans. The harvesting methods are similarly dissimilar. Because they tend to hang onto anything they can get their nippers around when they're stressed, it has been found that the best way to get your hands on the crayfish is to lure them into a place of confinement.

The baited trap

There are two types of traps: the funnel type whereby the crayfish find their way into the body of the trap via a funnel but have difficulty finding their way out again; and the spring type trap wherein the crayfish are lured onto a seemingly innocent piece of netting which when lifted (sprung) becomes a basket in which the crayfish are held.

There are several proprietary versions of the baited trap. The requirements in a commercial situation are that they are light to handle, easy to empty and bait, and easily collapsible to transport.

You can make your own traps but when it comes to commercial harvesting you need something that's light, easy to handle and compact. A good operator will clear, reset and move onto the next trap in 60 seconds.

The drain harvest

Drain harvesting should be done in conjunction with an external sump. The pond can be drained into a large sock made of a shade cloth-type material. Any crayfish remaining in the pond can be collected from the pond bottom.

Figure 17.3. A popular trap is the open top crayfish trap sold under various names. It is simple to operate and collapsible so that it can be moved around the farm easily, from dam to dam in a farm dam harvest operation as it is reputed to be a better long-term trap than the Opera House trap.

If the kids are home from school they might be interested in picking up the crayfish left struggling in the pond's bottom by the receding water. To avoid this back-breaking exercise you can flush the ponds a few times to pick up the stragglers.

The usual practice is to re-fill the pond until about two-thirds of the pond bottom are covered. Leave it overnight and repeat the drain harvest, collecting in the sock those that leave with the water. Repeat the exercise, this time only covering the pond bottom to a third of its area. After draining the water the next morning there won't be that many crayfish left.

If the pond is dried in preparation for the next crop, any residual crayfish will emerge when the pond is flooded and should walk hungrily into the first baited trap they come across.

Drain harvesting is usually only carried out after trap harvesting has become non-productive or when the grower has suspicions about the population of his pond.

In ponds that don't have adequate predator control the drain harvest can become an invitation for the local crayfish eaters to visit the ponds while the crayfish are vulnerable in the shallow water. Night herons and water rats in particular love these conditions.

The flow trap

The flow trap uses the crayfish's instinctive reaction to walk into a fresh water flow. Flow trapping is popular among the redclaw growers of the tropics and subtropics but the principle works equally well with any crayfish. It is used as a total harvest or as a way of collecting crayfish to fill a regular order.

The trap consists of a ramp down which a steady stream of water is set flowing. The foot of the gradually sloping ramp is in the pond while the high end of the ramp is supported by a container. The ramp has shade cloth nailed to it to provide a purchase for the ascending crayfish and has sides to direct the stream of water. Unless the ponds are adequately protected from predators the ramp should also be covered to prevent the predation of the 'migrating' crayfish as they make their way up the ramp.

There are a few tips for flow trapping. It works better at night; and when the incoming water is from a different source rather than just re-cycling the water from the pond being harvested. Flow trapping works even better if the ponds are drained down to the last, say, third of their depth. This makes the crayfish think their home is drying up and that it's time to move. The fresh incoming water becomes their escape route of choice.

The crayfish pump

A crayfish pump works in the same way as a fish pump. They were popular at one stage but seemed to have dropped out of vogue. The thought of all those crayfish being congregated and tumbled around doesn't do anything for quality control. One-armed crayfish have a reduced market value.

A few tips on harvesting

- *Always starve the fish for at least 24 hours* before you intend to harvest them so you aren't stressing fish with a full belly. It also reduces ammonia output if the fish are to be purged. Some people even fast their fish longer.
- *Be aware that fish have spikes*, especially native species. During harvesting the defensive spikes will be raised and damage can be done to the other fish. If the fish are to be purged and/or sold live the spike marks can detract from the sale value. In poor water they can also become inviting sites for bacterial and fungal infection. Rough handling stresses fish more than normal, thus inviting more collateral damage.
- *Don't harvest more than you can handle in the drag net*, or the fish room for that matter. Unnecessary crowding stresses fish and leaving them sitting in the net while you do a trip back to the fish room will stress them even further.
- *Fish, like crayfish, are attracted to fresh water*, especially native species. It is possible to get them to congregate by pumping fresh water into the pond.
- *Fish will readily congregate for food.* It would be possible to slip the net around them after they've been enticed into the netting spot by scattering a few pellets on the water. Emphasis on the 'few pellets' in regard to fasting, as mentioned above.
- *Sedation.* Harvesting will be one of the highest stress levels for the fish and some growers sedate the fish in the transport vehicle so they do less damage to themselves and the fish around them. Sedation with a registered anaesthetic will minimise damage during harvest and ensure they are harvested in a rested state. If the fish are killed in a rested state the shelf life of fresh product will be

increased significantly by reducing gaping of the flesh, delaying the onset of rigor, reducing blood spotting, improving colour and appearance, reducing bruising, improving muscle texture and improving consistency; all worthy attributes from which your product would benefit.

- *The quick chill.* When fish are harvested they will thrash about and try to escape. You can't blame them for that, but during this high activity they generate lactic acid, just as we would under the same circumstances. This tends to taint the flesh if the fish are to be killed at that point for processing. Any harvesting method under these circumstances should be prompt and the fish chilled immediately. Fish destined for the live trade purge any acid build-up in the comfort of the purging tank.
- *Match temperature parameters.* If you're going to purge the fish or crayfish, be aware of thermal shock when moving the harvested stock from the ponds, especially in the case of young fish. Pond or tank pH should be, as much as is practicable, matched to the purging water.

GWQEHN says:
The closer your fish get to market size the closer you move your bed to the ponds.

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18

Post-harvest handling

After harvesting, fish will require special attention to ensure they retain their quality. This chapter covers:

- preparation, transportation, treatment and purging of live fish and crayfish
- procedures for fresh chilled fish.

Live fish and crayfish

Live stock will need extra care as they not only have to be purged in your facilities but will be transported over long distances to a holding distribution point then held at the restaurant awaiting selection as *poisson du jour*.

Preparation

Before you even consider transporting the fish to the post-harvest handling area on the farm it should be prepared to accept the fish. If you're going to follow the treatments suggested below, the water should be made ready but that's not all.

If the fish or crayfish are going to be purged in a flow-through system, the preparation is quite simple. However, if they are going into a bio-filtration system, the bacteria will have to be fired up to a level of activity that can take the shock of the increased load. The bacteria will soon breed up to handle the extra load, especially at temperatures above 25°C, but there has to be a base from which to build from. Holding a few fish in the system constantly or feeding an empty system with small but regular applications of fish food usually maintains a population of bacteria that can be stoked up when the need arises.

Should it be practical to close the system down for a length of time for any reason, say over a lengthy non-harvest period, remember that you will have to fire it up and get a healthy bacteria colony established before the harvest season.

Transportation

After getting the fish out of the water it is important to get them as quickly as possible into the comfort of the fish room.

Pond mud tends to be acidic and if the fish are being seine netted this mud is stirred up and dragged into their gill cavities. Oxygen becomes a major factor as the fish are going to be stressed by the whole operation. Some live fish tanks have oxygen bottles attached to a line with an air stone delivering a steady flow of pure O_2 to the tank. Where power is available at the ponds the transport tank can be aerated by air delivered from an air pump via a line and air stone.

Figure 18.1. Transportation should be quick and done in clean oxygenated water. Note the pump fitted to this eel transporter so that water exchanges can be carried out when necessary to maintain water quality.

Another way of ensuring the fish have ample clean aerated water is to flush the holding tank with clean water from a nearby pond or other water source while you've got fish in the transporter tank and are continuing the harvest.

Crayfish, being able to survive out of water, don't need the same transportation facilities, but they do require special care. They should be kept moist, or at least prevented from drying out, and cool. As most crayfish farming is carried out in warm temperate to tropical climates, harvesting should be done during the cool of the day, either morning or evening.

Treatment

The treatment for fish and crayfish in the post-harvest stage is not dissimilar; after all, you're doing it for the same reason: to remove external parasites and to separate the fish from any other pond life that has been captured during the harvest.

At all times during this treatment stage, ensure that the fish have access to adequate levels of dissolved oxygen.

Treatment of invertebrates

Invertebrates that come in with the fish can be removed by spraying a light coating of diesel oil or kerosene on the surface of the water. The air-breathing invertebrates will be suffocated by the floating oil or kerosene and can be skimmed off leaving the fish beneath the film. Once the invertebrates have been removed the fish can be placed in a clean tank.

Parasites

Parasites may be present on the fish. In the case of freshwater species many can be removed by giving the fish a salt bath. The way the authors do it is to fill a tank to a third of its depth with freshwater and add enough salt to make the water saline (20 ppt), or 20 g of salt for every litre of water. In the case of a 3000 litre tank that would mean adding 1000 litres of water and 2 kg of salt. Try to get dairy salt. It's finer and dissolves more quickly. However, butcher's salt will be OK, and it's a lot cheaper if you're using large amounts. Once the salt has dissolved completely in the water the treatment can begin.

The freshwater parasites, being small in relation to their surface area, will rapidly absorb the salt into their system by diffusion, which will cause them to die and drop off. The fish, however, can cope with short bursts of salinity at that level. The usual 'hot' dip duration is 5–10 minutes, but if fish show stress before then it's a simple matter to add more water. By raising the level to two-thirds it will dilute the solution to 10 ppt. By filling the tank you can lower the salinity to 6 ppt to 7 ppt; a level the fish can handle quite comfortably as a long-term bath.

Crayfish also carry protozoan parasites and should be treated the same way.

Some fish are catadromous (a species that moves from freshwater to saltwater to breed, e.g. eels) or anadromous (a species that moves from saltwater to freshwater to breed, e.g. salmon) and salinities as high as seawater will not disturb them unduly.

However, if you find a more determined parasite such as gill or skin fluke you may find yourself having to treat the fish with something more lethal such as formalin. This treatment is dealt with in chapter 15.

Purging

After being treated for parasites, the fish will have to be purged. The smart operator will have stopped feeding a few days before harvesting in which case the shock loading on the purging system will be minimised. However, purging means more than allowing the fish to just evacuate their stomachs.

Fish will pick up what are called 'off-flavours' from the water. Should the growing water have any contaminants they will be absorbed by the tissues of the animal, particularly the marbled fat in the flesh. This is not restricted to pond-reared fish and fish raised in re-circulation systems will pick up the flavour of the water. Water treated with purification mechanisms such as ozone and protein skimmers will remove much of the 'off-flavour' agents.

In open pond systems ingredients found in blue-green algae, geosmin and 2-methylisoborneol, are the main culprits but sulphides and methanes from the pond substrate will also find their way into the flesh of the fish causing 'off-flavour'.

The cure is to hold the fish in clean water until the 'off-flavour' dissipates. (How do you know? – by test-eating a fish.) This can take up to a couple of weeks in extreme cases.

Purging in the ponds

Purging can also be done in the ponds. Exchanging water so that the offending elements are removed is one way. You can still feed the fish but care must be taken to ensure the pond water remains healthy.

It is also possible to 'drop' the blue-green algae from the pond by the use of copper sulphate. The treatment normally used in channel catfish ponds is to take the total carbonate hardness (alkalinity) and multiply it by 0.01 mg/L. That becomes the maximum treatment rate they would use for the copper sulphate. In other words if the total carbonate hardness was 200 mg/L (200 ppm) they would multiply 200 by 0.01 and come up with 2 mg/L and that would be their dose rate for copper sulphate.

The reasoning behind this is that if the water has a low alkalinity there's a greater opportunity for the copper to precipitate very rapidly as copper oxide, which can be toxic to fish. The treatment rate can only be safely increased as the carbonate hardness increases. If you have a low carbonate hardness and you put in a high dose of copper sulphate you can kill the fish. So you've got to be sure of your dose rate. US catfish farmers have found this to be the only treatment that's effective against off-flavour in the ponds, but even then it's not always effective.

As off-flavour is also a major problem in the culture of Australian native fish the above information could have some positive application here. However, copper has always been regarded as a dangerous element to have around fish and as there is a huge variation of the copper tolerance between species it would be essential that some preliminary tests be carried out on a small sample before placing the entire crop at risk.

Remember the above procedures are carried out in earthen ponds. Copper, when not able to react with the soil is potentially more toxic to fish. Should it be used in re-circulation systems, or situations other than the traditional clay-lined ponds, extra care should be taken so that the dose rate the US catfish farmers use doesn't reach lethal levels. However, phytoplankton should not be present in a housed re-circulation system.

pH and temperature levels

The water into which the fish are purged should be reasonably close to the pond water in pH and temperature. As the pH of pond water will be influenced, if the ponds are carrying high levels of algae, by the phytoplankton activity it isn't always possible to match the pH reading closely. Trial and error will let you know how far you can go in this regard but harvesting fish from water with a pH of nearly 10 and dropping them into a purging system running at a pH of 6 should be avoided.

As a rule of thumb, fish can tolerate a thermal variation of 1°C for every 2.5 cm of body length. Use this rough estimate by all means, but the more comfortable you can make the transition from pond to purging system, the less prone to stress the fish will be, and stress is the fish husbander's worst enemy.

Once the fish are in the system, the water temperature can be raised to suit the preferred operating temperature. However, be aware that any temperature movement will change the density of the water and the pressure at the gills. Unless the water temperature is raised carefully and accompanied by vigorous aeration, gas bubble disease (nicrosis) can occur, just as it can happen to a diver rising too quickly.

Be conscious of the lower and upper critical temperature limits of the species being purged. Water temperatures should be kept within the comfort zone of the species. For instance silver perch growers prefer to have their purging temperatures between 16°C and 20°C while barramundi growers prefer to have their purging levels sitting between 25°C and 28°C.

The bottom end of the range will slow metabolism and activity without putting undue stress on the animal. It will also reduce bacterial activity. The high end of the range will hasten metabolism, which will advance the purging process. Stress in the system will have effects on the fish other than compromising their immune system. Under adverse conditions silver perch are prone to fin nipping and bunting. If they become a bit hyper they can be slowed down by lowering the water temperature to the bottom end of the range but don't go overboard. Always change water temperatures gradually, accompanied by plenty of aeration.

Crayfish purging

After collecting the crayfish they should be graded into the sizes that you have decided on as your market lines. This can be done before or after the salt bath.

Some growers purge in tanks of water while others use a spray room in which the animals are kept in slotted trays allowing the water to run through. The exponents of both methods swear by them. Growers have been known to have a little bit each way; holding the crays in solid water for a few days and moving them to a spray room for long-term storage. All three methods seem to work. A lot depends on the health and condition of the crayfish when they go into the purging/holding room in the first place.

Aeration is crucial. Solid water systems will need to be managed in much the same way as a fish purging system. The spray system allows the crayfish to extract oxygen from the atmosphere.

It is generally accepted that the holding water temperature gives the best results when held between 8°C and 12°C as it slows metabolism reducing attrition and weight loss. However redclaw, being tropical animals, are better held at higher temperatures. Dr Clive James of the Walkamin Research Station (Qld) suggests the best purging temperature for redclaw to be between 15°C and 20°C (personal communication, 2003).

You will be surprised how tightly crayfish can be packed if they are going into a good drip room but one thing that has been noticed is that, overall, well fed aquaculture stock will cope with handling and packing better than wild caught stock.

Management

Keep the purging room clean; and keep an eye on it. Develop a manual for the procedures you have established and follow it. Don't presume that just because the various motors are running, that the water is pumping, that the temperature and water quality is right. Listen for an irregular beat from a motor; run a max–min thermometer and monitor the temperature and the water quality in holding systems. Get a feeling for how the room should smell and check for blockages and other things that can go wrong. You'll soon learn to recognise the tell-tale smell of ammonia, especially around crayfish.

Hygiene

Hygiene is important and to ensure that it becomes routine you should designate a particular day each week for stocktaking and regular maintenance.

Records

Keep a purging room book to record the flow of product through the system. Work out a method whereby you can record and follow the progress of the produce from individual ponds. This will be helpful if you are suffering mortality in the unit and are trying to trace the cause. It will also enable you to rotate your stock and provide records should you have to trace product for any reason related to post-sale events.

Having purged animals will enable you to enter the market with a top quality product at any level you choose, and to ask and receive top dollar for the extra service you've provided.

A less obvious advantage gained from purging live stock is that you get to road test your crayfish before they travel. There is no more frustrating argument than the one that starts, 'But they were OK when they left here.' No one wins: the buyer has got a tank of dead and dying product on his hands and you've got this suspicion that everything's not quite right. If you've held the stock for over a week without loss you can be reasonably confident that the problem doesn't lie with the fish and you can start checking what happened to them on the way to market; or in the holding facilities at the point of sale.

Fresh fish

The procedures for fresh fish, or fresh chilled fish if you like, are simple. Get them iced down as quickly as possible. This means getting them into an ice slurry as they come out of the water. The Atlantic salmon farmers in Tasmania pump the fish from the pens

Figure 18.2. These salmon are being harvested at the wharf and loaded straight into an ice slurry to ensure stress-free freshness.

straight into a bin of crushed ice and keep them covered at all times until they go into the processing works. You just can't have too much ice around fish.

Ice-making machines

In out of the way places it will be cheaper to have an ice-making machine on the farm. They aren't that expensive and will produce cheap, clean ice for when you need it.

Not having to ration ice will ensure you use it liberally and keep your product in prime condition for as long as is possible. Quality and extended shelf life is essential if you are to hold your position in the marketplace.

Processing

It isn't within the scope of this book to deal with processing fish or crayfish for market other than to point out that once you take that step you come under another set of licensing authorities and regulations. Your Fisheries or DPI Extension Office should be able to point you in the right direction.

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19

Marketing

This chapter covers the vital areas connected with getting the best price for your stock. Topics include:

- market research
- product range
- market entry points
- presentation and packaging
- value adding
- the price pyramid
- realities of the market
- promotion; and perhaps the most important
- getting your money.

Marketing should not be confused with selling. How many times have you heard people say, as they head for the nearest commercial centre with a tray load of poly boxes full of freshwater crayfish, that they're 'off to do their marketing' when in fact they're going to town to sell them, in some cases to whoever will take them off their hands. Selling is exchanging goods for cash and marketing is finding/creating a need for a particular product. In most cases the transactions we call marketing will be exchanging goods for cash. However, even though we mightn't be mounting a full-scale marketing campaign we'll always be beating the drum for our product and our label.

In one sense, as growers, there is little control we can exert over the price of our product on the open market, but we do have control over our cost of production. As the amount of time and energy the farmer has will most likely be limited, it would be best spent on items that are going to give the best return. The cost of production is as important in determining the margin for the grower as the price he or she will receive. Efforts directed at maximising efficiency and minimising the cost of production will always be of advantage to the farmer.

That's not to say that you roll over for every one who phones or comes to the door and offers you a price. If you concentrate your efforts on the quality of your produce and the reputation of your operation it's likely that the price offered will be a premium.

Market research

An agri-banking finance director with one of the major banking chains used to stun gatherings of aquaculture hopefuls by saying that, 'No one ever made money growing fish'. He would repeat the statement in a Keatingesque manner in a lower, faraway, tone after a short pause. 'No one ever made money growing fish.' After waiting a few seconds while the audience regained colour in their cheeks, he revived them completely by telling them that it was only when you *sold fish* that you made money. Everyone would start breathing again and he would continue with what the finance industry required of a business plan.

In reality, this chapter should be at the beginning of the book. The first thing that should be established is that you are going to be able to sell the fish, crustaceans or shellfish profitably. If you can't do this, don't grow them. You can see why we left this until now: too many of you wouldn't have read any further. When doing your market research, take into account the following aspects of the market.

The size of the current market

This sort of data is not readily available. There are plenty of data on production available from the Australian Bureau of Resource Economics (ABARE) but very little work is available on what seafood consumers are buying, the regions in which they are buying it and in what form they are buying it.

Growers' associations are a starting point, although they may not welcome the entry of a new competitor. You'll soon pick up the problems other growers are having moving product and whether they consider there's room for more growers.

Establish if there is an international market for the species you're considering.

Is there growth in the market?

If 10 000 tonnes a year of a particular seafood are being imported then the opportunity exists to take a share of that market with locally produced fresh product. Maybe the local growers can't produce enough. Maybe the local produce is too dear. The lament of freshwater crayfish dealers, particularly with yabbies, is that they can't get enough product to satisfy demand. But then, how much is enough?

Can a market be created?

Silver perch didn't have a following outside the inland angling community until they were brought into Sydney's Chinatown and introduced as a live freshwater option that suited Asian cuisine. Jade perch are another species that have been 'discovered'. Other species, species quite suitable for culture could very well be awaiting discovery. The US has a catfish industry that produces 250 000 tonnes annually, yet as far as the authors know, no one has had a serious go at our catfish as a culture option. The few boxes that find their way onto the market attract the same sort of buyer interest as carp. Could a market be created for catfish should they prove to be a culture proposition?

What are the limitations to the market?

For instance: any species sold into the live fish trade would be limited to the capacity of the live fish tanks that are available at any given time.

What is the depth of the market?

Some species may have a niche market that will collapse under pressure from farmed product. For instance: abalone currently hold a high value as quotas limit their supply from one of the world's remaining wild fisheries. If farmed product comes onto the market in volume, the value may fall.

Take another instance, that of Murray cod, which were selling at over $30/kg for wild caught fish in Sydney in the late 1990s, yet it only took the first wave of pioneer Murray cod farmers a few years to flatten the market to around $10/kg. Thorough market research would have revealed that during 1996 from January to the end of August, when the season closed during the breeding season, the average monthly price of cod offered through the Melbourne Wholesale Fish Market fell from $23.20/kg to $13.00/kg. The rot set in properly during June, July and August when the offerings jumped from less than 10 boxes a month to 35, 54 and 110 boxes respectively. The market never recovered and the real crunch came the following season when an offering of only 49 boxes flattened the market to an April average of $4.05/kg.

Is the market growth sustainable?

Growth projections are fine but where do they stop? Atlantic salmon growers felt the growth phase was going to go on forever, until it stopped. New markets are being found for salmon, and the industry is undergoing rationalisation but it's been a painful period in the industry's history.

Statistics are useful but they don't tell the full story. There's no substitute for standing at the seafood counter at markets and watching what people buy and listening to the questions they ask about seafood. If a fishmonger has some live crayfish on display and the generally feeling is, 'Oh, I couldn't put them in boiling water', then you'll know that selling live crayfish to the general public is not a proposition, or at least not at that outlet.

Ask the stallholders during a quiet moment what their best sellers are, and how people like to buy their seafood: as fillets, whole plate-size fish or in steaks?

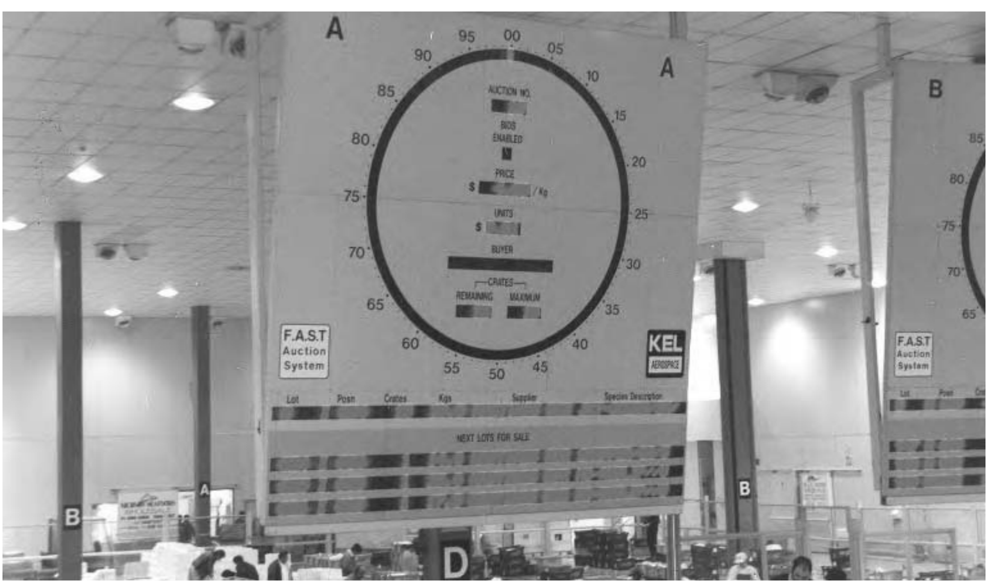


Figure 19.1. Under the Dutch auction clocks at the Sydney Fish Market huge volumes of fish move very quickly. A visit to see how seafood is sold should be on every prospective fish farmer's agenda.

Repeat the exercise at supermarkets and see what people buy at the seafood section. Watch what processed lines are moving off the shelf. Ask the manager what the best sellers are.

Visit wholesale fish markets. Anyone who is seriously considering entering the seafood business should go to their capital city wholesale fish market and watch how the bulk of the seafood is sold. If it doesn't happen to be Sydney, shout yourself a trip to the Harbour City to see how it's done at the nation's premier wholesale seafood clearinghouse.

Talk to wholesalers and distributors. Ask them what they look for in a product. Don't try to impose your will on the market; find out what the customers want and give it to them.

Product range

It is always a commercial advantage to be able to liquidate your stock at any given time. For instance in the commercial life of barramundi they have market value as fry of 25 mm, as fingerlings of 30–50 g, as plate-size 'baby' barramundi of 250–350 g and as 2–3 kg fish that can be dressed out as fillets or served up as a banquet fish. The ability to sell product at differing times gives growers the flexibility to restructure their growing program if the season or market trends aren't following the pattern laid down in their business plan.

Crayfish have similar selling options. They can be sold off the mother's tail as 20 mg hatchlings to stock grow-out or nursery systems. They have market value as bait or seedstock at sizes up to 35 g. Market sizes for table fare range from 35 g to as large as they grow, with the most popular sizes being between 50–90 g for yabbies, 70–120 g for redclaw and 250–500 g for marron. There's even an option to sell unusual coloured ones to the pet trade.

Market entry points

Being seduced by the retail price is a common weakness in marketing plans. Retail is what the consumer pays for the product but there are many steps between the pond and the consumer, each of them bearing a cost and a margin. The rule of thumb is the closer the grower can get to the consumer, the higher the price; and the greater the level of service required.

Don't kid yourself: service costs. And it can cost more than money; it costs time; and if you don't deliver on time, it costs you your reputation. If you don't like dealing with the public with all their demands and foibles keep your distance from the consumer.

The market entry points are as follows.

The wholesale fish markets

The wholesale markets are the clearinghouses for all forms of seafood, and while they can be generous on any given day they will indicate the bottom end of the market: the floor price. That being the case, they will also indicate the base price for any particular species, not only on the day but also in general.

Sydney is regarded as the seafood capital of Australia and the Sydney Fish Market (SFM) has developed a reputation as reflecting the base price for seafood in Australia in much the same way the London Metal Exchange determines the base price for metals on an international scale. The SFM offers an excellent service including historical records going back several years and real life prices as the daily auction progresses. Their website address is www.sydneyfishmarket.com.au. Melbourne historic prices can be sourced through the C. H. Smith Pty Ltd website: www.chsmith.com.

Payment is secure and prompt, usually within seven days. However, market dues and commission will be deducted from the price, and they can be significant.

The wholesaler

The wholesaler is the person or company that buys on the auction floor. They also arrange private treaties with commercial fishers and farmers to take their produce direct. They are one step closer to the consumer but still at a level subject to daily market demands and fluctuations.

The prices offered by them, as wholesaler, would not be subject to the same charges as those incurred by selling on the auction floor but there may be a compromise between the auction price and the dues that would have been incurred. Payment is as secure as the wholesaler's standing. Established wholesalers will not risk their reputation by not paying, but beware of newcomers to the industry who may find themselves out of their depth very quickly in a perishable goods market.

The specialist product buyer

The specialist product buyer is another wholesaler but one specialising in particular product lines. For instance you might come across someone specialising in venison and wild boar distribution, or kangaroo and emu cuts, or better still, farmed seafood distribution. This operation would have a vested interest in a long-term commercial relationship with the producer, in seeing a fish farmer succeed if for no other reason than to get more produce for their catalogue. The success of the respective operations is linked and offers an attractive option.

Having said that, fresh food distribution is not always linked to the mainstream seafood marketing operations and like any business sector, has a failure rate. Ensure you have a clear understanding of the financial side of any arrangement you enter. A rule of thumb is that you don't deliver the next consignment until the previous one has been paid for.

The retailer and the food service industry

The retailer and the food service industry brings you only one step away from the elusive consumer, but also extremely exposed to the vagaries of the wholesale market and the whims of the consumer. Servicing the sector becomes a logistic nightmare with dozens of drop-off points in suburban and city commercial and shopping centres.

Servicing these clients can also be a headache. Every phone call on Friday afternoon could be from the customer who either under-ordered or forgot to order on Thursday when you were writing up the manifesto for Friday's deliveries.

You're also in the high-risk area for payments. The food service sector is notorious for failures and the consequential delinquent accounts. Make sure of the proprietors of the business you're dealing with and secure any credit arrangements, but often this is not enough. One way around it is to install a credit card facility and be prepared to forfeit a bit of your margin for financial security.

The retail sector is also not without its downside. Supermarket chains will want assured food safety standards, assured supply and assured quality. For this they will want to pay as little as possible for the privilege of using their display space for your product. Smaller operators can buy product at the market or through their regular distributors. Gaining their confidence may take some effort; even then you only have to let them down once to destroy all the good work you've put in.

Local outlets

As a consumer, fresh seafood options in rural areas can be limited. If the farm is situated in an inland region with market potential there could be an undeveloped market waiting for someone to service it. Taking into account food safety and other business issues, it may be profitable to set up to sell direct to the public in regional areas.

It's certainly easier to chase your money up locally and the consumer is used to paying cash.

Tourism and door sales

At last you've got your hands on that ever-elusive consumer; so make sure you know what to do with him or her. This is the ultimate test of the fish farmer's patience and family relationship. The money required to set up a tourist operation can be intimidating, yet it has proven to be a viable option for many farmers. People love to be around water and seeing fish swim in aquaria, not to mention actually catching one.

Do the costings thoroughly. For instance you'll find the toilet facilities will need to be ten times better than the ones the whole family shares each morning as they scramble off to their respective daily activities. The cost of laying down all-weather roads for tourist buses may take generations to recoup.

Having said that, catering to tourists is a legitimate form of marketing and the margin on tractor hats and T-shirts is healthy. Most tourist farms started out as fish farms and the tourism became an adjunct. If you're going into the aqua-tourist industry think tourism first and select the site with that in mind. There are associations and government advisory bodies that will help you to get started.

Export marketing

Export marketing is an option, but not for the beginner. The authors don't know how many times they've heard: 'I'm going to grow yabbies and export them to Sweden, or Japan.' There's nothing wrong with that in itself but in most cases the statement is made without any understanding of what's involved.

Before you go down the export track make sure you have a full understanding of what you're getting yourself into. Talk with Austrade, other government bodies and people experienced in exporting seafood to find if you have the resources to enter the marketing chain at this point.

One seafood operation in Darwin did their costings and found that it would take half the outlay to send a refrigerated container to Singapore as it would to southern

Australia. But they had to wait till they had the production to fill the container. Then they had to be assured of their money.

Presentation and packaging

Presentation

The three Golden Rules of marketing are Presentation, Presentation, and Presentation. Buyers are impressed by what they see. People judge from appearances. (They may change their mind later if the product doesn't match the label, but that's another story.) They can be turned off by poorly presented packaging.

Presentation has a cost and this should also be taken into account when deciding on the level of marketing your operation is aiming for. Fancy labels are great to impress buyers deciding on what to buy for a supermarket shelf, but chefs only need a clear definition of what's in the box, where it came from and what's the phone number to re-order, or blow the tripe out of the farmer for a crook batch. Labelling will also have to address food industry compliance issues, such as being part of the food safety audit chain.

Packaging

Packaging will vary from species to species and destination to destination, but the main considerations are:

- the quality of the product;
- the information on the packaging in relation to delivery and contents;
- the clarity of the labelling; and
- the ruggedness of the packaging.

Seafood has a reputation for rapid deterioration and should be packaged in a way that maintains freshness and extends shelf life for as long as possible. Ice is cheap and excellent insurance against deterioration.

Figure 19.2. Presentation. Presentation. Presentation.

Shifting live product presents a different set of criteria. Crustaceans can be transported 'dry' as long as temperatures aren't allowed to reach extremes. Finfish can be sedated to lower their metabolic rate while in transit. Live seafood is regularly exported to maximise the opportunity presented by live premium prices offered. Abalone, rock lobster, yabbies and Murray cod are sold as table species and there is a vigorous world trade in live aquarium fish.

Joint marketing

Many aquaculture sectors, especially new ones that haven't reached anywhere near the saturation point of the market, may find they are unable to satisfy market demand. This situation sounds ideal at first glance. However, potential customers may be turned off the product due to the poor supply. Yabbies are a case in point. Growers are continually saying they can't produce enough for the market.

There may be an opportunity to market in conjunction with other growers in your district. There are real benefits from presenting a united front to the buying world: continuity and quantity would be enhanced; quality control could be standardised; and markets would become more stable.

Secondary benefits would be that technical information can be shared and buying power would be increased. The journey is hard enough as it is and a few mates might brighten the weary road.

On the other hand the relationship may crack under the pressure if the operation becomes complex. Keep it simple and don't overreach the organising or production capacity of the group. The success of a growers' co-operative depends entirely on the ability of the people managing it. In unity is strength; but only when those united know, and agree on, what they're doing.

Value adding

There has been a lot of talk about value adding, or processing. As the name implies, its thrust is to create a higher value. It has its benefits and its drawbacks. Both have to be considered to decide if value adding is worth undertaking.

Kinds of value adding

Value adding comes in a variety of forms in the aquaculture industry.

Tourism

Tourism is actually a value-added process. Take a catch-your-own trout farm. The product (fish) can be sold at somewhere better than wholesale prices but a little bit under retail and the buyer harvests the crop. While the parents are doing that their kids are feeding your trout for you and buying the feed from you at 1000% mark-up.

Live product

Ironically the best prices are paid for live seafood so the value-adding effort can be productively spent on keeping your production, purging and holding systems up to the mark.

Figure 19.3. Live marron (left) and yabbies on display at a Hong Kong supermarket.

Processing
When most people think of value adding, they think of processing, that is, filleting and butchering fish, smoking, crumbing, putting into fancy packaging, and the creation of products such as seafood pate.

The benefits of value adding

Value adding can have some real business benefits, as shown below.

Brand image exposure
By getting the product out into a wider marketplace, the farm's brand name receives wider exposure. This can be of long-term benefit and attract new customers, which are real advantages that don't necessarily show up immediately on the Profit and Loss statement.

Wider market penetration
Altering the nature of the goods increases the product range and market options for the farmer's products, expanding sales. For instance: trout farmers sell fresh product but they also pick up those customers who want a smoked product. Atlantic salmon is presented in a range of products from fresh to smoked and in several different cuts including straight-cut and angle-cut steaks, cutlets and fillets. The packaged range comes in a range of flavours from modern cuisine to the traditional but time-consuming gravalax.

Extended shelf life and quality
Processing and packaging can extend shelf life, enabling the producer to grow product when the growing time is good, and to dribble it out to the market over a longer period

of time. For instance the condition of shellfish has a peak in the season and mussels are harvested at the peak, but can be kept for sale later in the season after the crop has spawned and gone off condition.

Take advantage of seasonal prices
Prices for raw material are generally lower at some time during the season, usually at the peak of the season when in prime condition. Processing product at that stage for sale later in the year can be to the farmer's advantage.

Costs of value adding

Value adding is not all beer and skittles. Don't take it lightly. Processing comes at a cost and requires a capital outlay. Food safety compliance has to be considered. You must carry out thorough costings and market research before tooling up for processing. It is a huge obligation. There may be processors already in the seafood industry who are already able to process your product, which would get you off to a flying start. With the extended shelf life your product is more exposed than if you were just sending them into the fish market.

Measure benefits against drawbacks

Value adding is also cost adding and there's no point in attempting it unless the price received for the value-added product creates added value to the grower. In other words, you've got to make more profit from the venture by increasing margins or expanding markets to accommodate farm extension.

Prerequisites for value adding

Think hard before you consider value adding. As well as having the cash or credit to undertake it, there are other prerequisites. Items that should be considered are:

- sufficient raw material: the most obvious detail to establish is whether or not there is enough raw material to keep the plant operating profitably;
- sufficient margin and/or increase in market share to warrant the extra effort and cost;
- sufficient shelf life to ride market ebbs and flows; and
- suitability to processing of the produce being grown.

Over the years the authors have watched the abalone production industry. Many of the licenced divers were well cashed-up and wanted to invest surplus capital. A logical step was to go into processing and several facilities were established: some quite impressive. Abalone divers tend to appoint professional managers to oversee their processing operations and it's the managers' jobs to look at the profitability of the value-adding operation. Their concerns are that the processing works tie up a very significant amount of capital, yet are only operating when abalone is being harvested. All this flash gear will spend a lot of time being unused, and overheads keep on accumulating. Whenever you talk to the managers they are continually looking for options to keep using the plant between batches of abalone: they talk about abalone sauce, retortable packaging and alternative products. A message comes through: value adding may add to the return from the abalone, but when the plants are looked at as profit centres in their own right, irregular or insufficient supply does not add to the processor's profits.

The price pyramid

The biggest question in marketing is *How much can I or should I receive for my produce?* The answer is simple: whatever the market deems to be its value on the day. Glib? Yes. Honest? Yes. Helpful? No. If there were any hard and fast rules to this figure it would make life too easy and Malcolm Fraser isn't the only great philosopher to deduce that life wasn't meant to be easy. However, with an understanding of the forces influencing the market, growers can come to grips with its realities in order to make decisions with which they can live.

The price pyramid, in simple terms, can be used as an analogy to describe the influence of supply and demand in relation to the market perception of value and, consequently, the price offered the grower for his produce.

Demand and market perception will provide the floor price of the produce being sold while the supply, combined with the market perception, will set the ceiling price.

At the top of the pyramid we have produce that is high in value because of its flavour, cultural proclivity and/or scarcity either locally or internationally. You know you've pulled the wrong rein when you sit down at that flash looking restaurant with 360° views of Sydney Harbour or the Coral Coast Rainforest and the waiter flicks a napkin as big as a bed sheet over your knees. The food arrives on a tractor hub cap and consists of an anchovy and a snow pea but you're sitting at the top end of the pyramid and if they're serving the seafood you produced at least you'll be able to afford the tip. Rock lobster, sleepy cod and abalone are examples of produce at the higher end of the price pyramid.

Figure 19.4. The price pyramid.

The middle section of the pyramid is made up of that produce which has a good following because of its supply, cost of production, national or international appeal and flavour but the supply factor keeps the price in the middle range. Prawns and freshwater crayfish are examples of seafood at the upper middle range. Pink snapper and bream would be examples of the lower middle range.

At the base of the pyramid is the produce regarded as having less demand and an abundant supply, such as carp. Most of the fish that makes up the base of the price pyramid are imported white flesh fillets that make up the bulk of the seafood eaten in Australia, most of it served in batter with chips. When you order your next fisherman's basket pub meal you can bet that very little of it is produced locally.

The retail sector operates under the same pressures but may have different mores. The leaning is towards fish pieces rather than whole fish. You just have to have a look at the seafood counter of your local supermarket to see this.

Another way of looking at the price pyramid is to view it in relation to your chosen species. The peak is where the best prices are, but the requirement for quality is extreme and the competition to get into that end of the market is fierce. It's a very narrow market up there at the pointy end of the pyramid.

The middle range market is wider but still cramped. It's the chequered tablecloth market. A bit like mutton dressed as lamb. The customers want quality meals in interesting surroundings but there are more restaurants in this group and price is more of a consideration.

Down at the base the quality standards are less imposing but food safety issues still have to be considered. These are the restaurants and cafes that cater for the growing number of people who eat out rather than cook.

The realities of the market

There are several factors bearing on where in the price pyramid a given kind of seafood will reside. The irony of all this is that the price is not always set by the flavour of the fish and there are factors other than supply and demand influencing prices. Some of them are listed below.

Influences of ethnic preferences

Some seafood has a cultural following. Chinese and Vietnamese communities like silver and jade perch and Murray cod. The Jewish community requires a freshwater scaled fish for the traditional gefilte fish. New arrivals from Eastern and Northern Europe and Asia are used to eating carp.

Positive regional preferences

Black bream is a popular fish in Western Australia. Victorians were raised on flake. Any seafood restaurant worth its salt in Sydney will have baby snapper on the menu in season.

Negative regional preferences

Until recently, flathead was regarded as a low priced fish in Melbourne, probably because it was so easily caught in Port Phillip Bay. It found its way onto restaurant menus because of its value to the proprietor and popularity with the customers and it's not the bargain it once was. Or maybe there aren't so many being caught.

Export parity

Some species are relatively plentiful but their international demand keeps the domestic price high. When the Emperor of Japan died and the population gave up luxuries for a year in mourning the local price of lobster plummeted. Abalone would be the perfect example. Remove the Asian demand, as happened with the recent SARS outbreak, and you wouldn't be able to give them away.

Presentation

Live crustaceans bring a higher price than cooked or fresh crustaceans. Live fish attract a premium over gilled and gutted.

Catering trade preferences

Some species have developed a following amongst the catering trade for their ease of handling, shelf life and either bland or strong flavour. Orange roughy and butterfish spring to mind as examples at both ends of the price range.

Marketing's six commandments

1. Never try to market a product that you don't have.
2. Target the most profitable market, not necessarily the one with the highest prices.
3. Image is important, from brochures to packaging to transport to the clothes you wear.
4. Never let a customer down.
5. Word-of-mouth is the best advertising.
6. If your product is not top quality, marketing is a waste of time.

GWQEHN says:
Ignore marketing's six commandments if you must. Everybody else seems to. But do it at your peril.

Promotion

Promotion falls into three categories:

- promoting seafood in general
- promoting the species, and
- promoting your own operation and brand image.

The seafood industry peak bodies will spend time promoting seafood through campaigns based on themes such as 'seafood is brain food'. Growers' associations will spend time and money promoting a particular product, such as the Atlantic salmon campaign based on the 'As Simple As Salmon' recipe booklets. As a producer, you may be asked to contribute to these types of promotion, or you may already be doing so through membership dues, but when it comes to putting your own operation in the limelight it's up to you.

Freebies

Media outlets are always looking for content and aquaculture sells, especially if you have something unusual like an eel farm, or have made some major breakthrough such as having bred a new type of crayfish. Landing a big export order should see the producers of the 'Landline' show some interest. Rural and city newspapers, magazines, especially trade magazines, and radio programs dealing with local and rural issues are all likely prospects for a story about your operation if it's something different or new.

Food fairs

Food fairs and shows are always good ways to gain exposure to the people who are likely to be interested in your product. If your client base is to be found among other farmers then farmers' field days and alternate farming field days will bring you into contact with prospective customers.

Brand image recognition

Brand image recognition as practiced by Coca-Cola is probably out of the reach of most fish farming operations, but there's nothing stopping you working with seafood outlets to push your product and your brand.

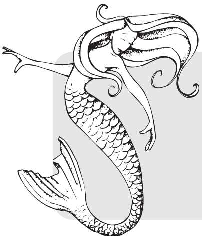
Get your money

It has been said that seafood trading is the 'purest form of capitalism'. Not only let the buyer beware, but the seller has to beware as well.

The restaurant business, although, or probably because, it trades in cash, is notorious for bad debts; and this has a tendency to flow along the chain.

Fishmongers at the market are governed only by their necessity to stay in business, but as they tend to do this quite successfully there is a much reduced risk in trading with them.

Wholesalers, as the link between the grower and the restaurateurs, can be a risky area and their reputation should be checked out around the traps, or as we say in aquaculture, 'around the ponds'.



GWQEHN says:
Any mug can stand on a street corner and give money away.

20

Getting started: choosing the right option

This chapter is very important as it asks you to consider very carefully how you are going to go about fish farming and what options are open to you. It will cover:

- your inputs
- aquaculture production niches, and
- how to choose what species you can grow.

It's difficult to get going if you don't know where you're going. That's why we've been spending time on the basics of aquaculture before we sit down to plan the shape our aquaculture venture is going to take.

In many cases people starting up in aquaculture already have a property and fish farming is to be incorporated into the activities on that site. In these circumstances, the location and resources that already exist on the property limit the options. If that's not the case, then the prospective fish farmer has a wider range of options but must still consider the same factors when deciding which course best suits his or her personal skills and financial resources.

Over the previous chapters we've looked at enough of the key elements of aquaculture for you to have a grip, tentative as it may be, on the levers that control aquaculture. We're now going to take our first cautious journey. We're going to plot the course we intend to follow.

Your inputs

A fish farm can be as complex or as simple as you wish it to be. Before you work out what you might do, you should determine what you can contribute. A potential fish farmer should take into account the following factors:

Personal skills required

There is no point in overextending your personal skills. Meeting a challenge is one thing; creating one is another. For example, if you are one of those people who just aren't able to come to grips with the operation of a computer, don't incorporate one in your procedures. This will make recording tedious and time consuming, but of course you can always pass that role off onto someone else, someone from the computer generation.

Try to avoid the trap of doing everything yourself. It doesn't pay off in the long run. Be prepared to enter strategic alliances with key industry people such as marketeers, seedstock suppliers and feed manufacturers or nutritionists.

Time available

Don't underestimate the time required to devote to your business. Aquaculture is unforgiving and you will find that stress on the operator is just as threatening to your efforts as stress on your stock.

Don't be ashamed to dry run some of your functions to get an idea of how long everything takes. Ideally, the Fisheries Extension Officers would be running hands-on workshops for people coming into the industry, and it is probably fair to say for a few of those who have already invested their dollars.

Better still, if you could work on someone's farm for a season, or even just through some of the high activity periods on the farm such as harvesting or breeding, you would get a better idea of what's involved.

Part of your business plan should be to write an operations manual. This will allow you to estimate the time each task takes to carry out. This is an essential part of costing.

Financial requirements

Don't leave yourself short of cash. Plan your capital and operating expenditure thoroughly. Allow for contingencies; 20% is a common figure used by business planners. The most common planning trap unwary farmers fall into is to allocate projected profits to cover capital and expenditure costs. If, for some reason beyond your control, the expected cash flow is not forthcoming – a lousy season or a shortage of seedstock – you could well find yourself unable to fire up for a second season, or even the second half of the first season.

Aquaculture production niches

The basic idea of fish farming is to stock your ponds with the smallest practical size fish, paying the lowest imaginable price per tail, grow them to a marketable size as economically and quickly as possible and sell them at the highest attainable price.

There are stages along the aquaculture production chain. In many cases the prospective fish farmer is restricted logistically to a particular stage by such elements as the amount of water available, or the distance from market. It is important that the prospective fish farmer chooses the stage that best suits his or her overall capabilities.

At the end of each stage the product has a market value and, like a night at the pokies, you can cash your chips any time you feel that there's nothing more to be gained by playing on.

We've already looked at the five stages of a fish's life. What needs to be done now is to consider seriously the resources, skills and time involved in each one and how much of these three key elements you have to devote to your operation. Be honest. The aquaculturists' graveyard is full of people who have kidded themselves in this regard.

Look at the stages in relation to which one or ones you wish to be involved in. It may be that you can enjoy aquaculture by concentrating on the one that suits your skill-base, your time frame and your resources. To refresh your memory the five stages of a fish's life are:

- the hatchery stage;
- the nursery stage;
- the grow-out stage;
- the processing stage; and
- the marketing stage.

If we look at the hatchery stage as the pumping of seedstock into the ponds we can look at the marketing stage as the pumping of dollars into the industry. Neither can exist without the other. They're not referred to as the bookends of aquaculture for nothing. Remove either one and the bit in the middle falls over.

How do you choose what species to grow?

There is a set of criteria, by which a prospective aquaculture species may be evaluated before becoming eligible for consideration.

All too often fish farming ventures are launched on a wave of current market euphoria only to become wrecked through ignorance of these basic rules of aquaculture. If the market value for a particular species is high it is because the supply is lower than the demand. This would suggest that they are difficult to culture. For an example of a floundering aquaculture based on high market value, look no further than the 30-year-old marron aquaculture of Western Australia that can hardly keep the local market going at prices of upward of $30 per kilo! Allied freshwater crayfish such as yabbies and redclaw are produced by the hundreds of tonnes and attract prices of $10 to $15/kg. Who do you think is better off, the redclaw and yabby growers or the marron growers?

Check the following features in relation to the stock you want to grow, or against the options open to you.

Ready market acceptance

In reality having a ready market is the first thing you should check. There's no point in growing something you can't sell. There is a proviso to this: the particular species may have a market appeal that hasn't been developed; or it may only have a niche market that will handle a limited amount of product. We'll discuss this aspect later.

Fecundity

Can the stock be bred in numbers sufficient to support a grow-out stage? If the answer is 'No', ask why this is so. If it is because the species is a naturally poor breeder then everyone who grows that species will have the same trouble with seedstock supplies. However, if it is a technical problem, the seedstock blockage may be removed one day as a limitation on production. If the price has been kept high because of limited supply then rush of seedstock is likely to generate a rush of production that could have an adverse impact on the markets.

An example is the development of hatchery technology for abalone. Abalone can be conditioned in a hatchery and spawning induced by triggering breeding cues. This means that should someone want to grow and market 200 tonnes of abalone, all they have to do is build a hatchery and an on-shore facility and, if all goes well, in three or four years time they'll have their first 200 tonnes of abalone. It would take a diver with a 20 tonne quota 10 years to produce the same volume. While it's too early to say what will happen to the abalone markets, once the farms start selling their crops you would have to imagine it is likely that the price will soften.

From another point of view, if you want to get into an aquaculture growth area you will have to grow a species that is fecund. A 2 kg silver perch can supply 500 000 eggs in one spawning. If half of the eggs survive to reach 1 kg, that would be 250 tonnes. Fecundity is important to the aquaculturist.

Hatchery friendly

Not only must the species be fecund, they must be able to be bred under controlled conditions to ensure continuity of supply. If the broodstock can be conditioned, that is brought up to breeding condition in the hatchery, they can be bred at a time to suit the management of nursery and grow-out stages. Timing and predictability are important in a commercial sense.

For example: Barramundi can be bred in captivity at any time of the year. That means re-circulation system growers can have a continuous supply of seedstock. This in turn allows them to be able to grow their fish without having to retard the growth of the stock to ensure a regular supply to the market. This is one reason barramundi have been so successful in re-circulation systems.

Some species only produce one batch of seedstock a year. Native perch and cod and salmonids are examples of this. That batch has to do the grower the whole year. Then there's the added risk that if something should happen to the batch of fry or fingerlings, it leaves the farmer with no seedstock from that point until next breeding season.

Holding stock back is also inefficient. The fish grow fastest when they are young and to forfeit this fast growth to ensure year-round supply isn't good farming. However, by manipulating light and water temperature under controlled conditions, some species can be deceived into breeding out of season to get around this.

The most powerful argument for being able to breed a species in a hatchery is to be able to manipulate the genetic make-up of the animals. The longest lever in aquaculture is the one in the hands of the geneticist. Random breeding in ponds (as is the practice in US catfish aquaculture) doesn't allow the genetic finetuning that will produce the farming genotype that has made the pig and poultry industry so successful as protein-producing industries.

Quick growing

The stock should be brought to market size as soon as possible: preferably in one season. The longer you hold stock: the greater the risk. Most fish are fast growing. It's a matter of relativity. A species that grows to a very large size will reach plate size in a short period, thus allowing the farmer to utilise the quick-growing period of the species' growth cycle. For instance: a Murray cod, with the potential to grow to 25 kg will get to 250 g much faster than a silver perch with a potential mature weight of 5 kg.

Hardiness

The species should be able to tolerate extremes of temperature, adverse water conditions and excessive handling.

While growers in re-circulation systems will have year-round optimum temperatures, farmers in open systems will have to face what the season brings. Every now and then these conditions will be extreme and the fish will have to endure them.

Tolerance of handling is important because grading is an important aspect of husbandry and a species that sulks after handling, and goes off its tucker, or breaks out in a rash from stress, will be a pain in the neck to grow. Handling tolerance will not only make them a better farming proposition but will enable the grower to ship them to market live, especially overseas, thus adding value to the product.

Hardiness should not be abused. Regardless of a stock species' hardiness, extremes of temperature and adverse water conditions should never be allowed on your farm or in your fish factory, where economically practical.

Disease resistance

The species must be relatively disease free. Pathogens are always present and managing protozoan parasites is part of finfish husbandry. However, there are certain diseases for which there are no practical management procedures. *Thelohania* in yabbies is an example. Make sure the species you choose isn't prone to an endemic disease, especially one for which there is no known cure.

Husbandry requirements must be known

There's no point growing a fish for which the husbandry is unknown. A lot has been said of the market potential of golden perch but to the authors' knowledge, despite some worthy attempts, no one has succeeded in growing this nomad of the Murray–Darling Basin. This will provide a challenge for someone no doubt, but for the commercial fish farmer the absence of known husbandry practices is a warning to wait until everything is in place.

Must be able to be fed artificially

It is in the area of feeding that species really show their suitability for domestication. Although natural food is by far the cheapest and best nutrition a fish can have, in an aquaculture situation the grower must be able to feed a supplementary ration. Getting fish to take an artificial food is not always easy. For ages it was thought that Murray cod couldn't be fed artificially and the only cod on the market were those taken by professional fishers. It wasn't until Bruce Malcolm at Uarah Fisheries at Grong Grong, NSW, after much perseverance, established that cod would take a pelleted diet that we started to see cod swimming around in fish tanks in capital city restaurants.

Nutrient requirements must be known

There must be an awareness of more than just the general nutrient requirements of the target species. Each species has its own nutrient profile. The closer the composition of the feed gets to that profile, more of the feed will stay in the fish and less goes out into the water column as unwanted nutrient load. Most professional nutritionists will be able to draw on data that deliver a commercially acceptable diet, but there are still people out there feeding chook pellets to yabbies. That is very bad farming.

Cheap to feed

There is no point in choosing a species that is so expensive to grow that it uses up your profit margin paying for its feed. Abalone feed seems extremely expensive for what it is, but with the current price of abalone, maybe growers can afford it. It's also arguable the industry is paying for a lot of research but that's not what your bank manager wants to hear.

On the other hand, there are yabby growers falling over themselves to feed the cheapest feed. Aquaculture diets that retail for less than $900/t would have to be suspect as a balanced ration for your stock. When you hear some growers bragging of paying less than half that you can only smile politely.

Feed conversion

Fish are naturally good converters but the species must still be able to convert food into saleable product efficiently. This shouldn't be a problem if everything else is in place and the diet is designed to suit the species.

High social density

This is also called 'schooling ability'. Without a propensity to like, or tolerate, crowding, the species can't be held in densities that make it a proposition for culturing. This is not an insurmountable problem. Murray cod in the wild are extremely territorial and an old man cod will dominate a deep hole in the river to the detriment of other fish. Yet with good husbandry they have been held in densities as higher than 200 kg/m^3 in re-circulation units capable of carrying that sort of load.

Research, extension and infrastructure back-up

These are three crucial areas. Being a pioneer is one thing but often the reward is a lonely tombstone out there on the aquaculture trail. Before you take on a species find out what research has and is being done on it in the way of three key areas: husbandry, diet and genetics. Infrastructure support is equally important. If specialised equipment is required, make sure it's readily available and there is a service provider that comes with it.

Probably the most important, and often the most overlooked, is the existence of an extension service. The US catfish and crawfish industries were built on the extension service provided by the various state agencies linked to Auburn University's research department. NSW silver perch aquaculture is one sector that has benefited enormously from the excellent extension service provided by that state's Fisheries Department. To a good extent, the Western Australian yabby farm dam harvest owes its success to the Fisheries Extension Officers who delivered the Code of Practice that underwrites that successful industry.

What species are available? See chapter 23.

Summary

The approach most novices take to aquaculture is: 'If I start with the smallest possible size juveniles and grow them out to the largest possible size table fish I'll make lots of money.' Welcome to the aquaculturists' graveyard. The specialist skills required to run and hold together an operation that ranges from seedstock production to marketing demands a broad base of technical and management skills as well as capital. Aquaculture is hard enough as it is without overloading the exercise with a whole lot of highly technical, often unnecessary and mostly unprofitable structure. Analyse your situation thoroughly and honestly.

Most of us will be able to grasp the principles of aquaculture and cope with the pressures of management; and a good deal of the well-watered country in Australia is suitable for one form of aquaculture or another, not to mention the 35 000 km of coastline and a marine zone larger than the continent itself, so there is no reason that a carefully planned operation should not succeed. Many operations will have the resources to cover more than one aspect of aquaculture and there is no reason not to do this. The trick is not to overextend your resources: both physical and human.

The *Oxford English Dictionary* defines niche as: 'a place among memorable persons'. On past performances, anyone who is able to make a success of fish farming deserves a niche in Australian aquaculture.

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21

The law

The law impacts on aquaculture in many ways. This chapter will cover:

- tenure, planning/development approval
- permits, environmental impact statements and environment management plans
- aquaculture licences, notifiable diseases, and
- food safety.

Aquaculture is one of the most regulated farming activities you can take on. What species can be grown where, environmental impact, translocation issues and where you can and can't farm are all subject to regulation. It's often been said that if the Macarthurs had been faced with the regulations fish farmers are faced with, we would never have had that century-long ride on the sheep's back. However, don't despair. As daunting as they seem, most of the regulations won't restrict your entry into commercial aquaculture.

Further to that, most Fisheries Departments have a designated Licensing Officer at head office and regional facilitators to help you through what, to the first-time applicant, can appear to be a maze. Extension Officers are also trained and experienced in making permit applications and their assistance should also be sought. Growers' association members will have plenty of horror stories to tell but they'll also know the ropes.

When it's all said and done, aquaculture is just one stakeholder in the environment and it's in the interests of every fish farmer that our industry is environmentally sustainable. It is important to be aware of the rules, regulations and requirements right at the outset, as rules can make a fundamental difference to the kind of aquaculture you can undertake and whether or not you are successful in starting.

Quick overview

The first part of this chapter provides a quick overview and short comments to get you through the process. If your interest is growing fish, read that, and skip the second part. If you are about to enter into the realm of getting licences, permits and so on, and want to get an idea of why the laws are there and what considerations might be taken into account when making applications, read the second part.

There are four fundamental pieces of advice:

- *check first.* Before you turn a sod with the thought of digging a pond in mind, find out what entitlements you have to obtain and what rules you have to follow. It would be a disaster to have spent your life's savings on ponds and stock only to find it is illegal to farm where you've set up.

- *keep a diary.* Make a note of every conversation you have in relation to the application: name, contact details, dates and what was discussed. Find out their name and phone number and write them down. If you get advice from the government, which is critical to the success of your venture, ask for it in writing, or confirm it yourself;
- *get help.* Determining what entitlements are needed can be complex. It can also vary from place to place. Each state or territory has different laws and different government departments administering those laws. Advice can be obtained from Fisheries Departments, government business development agencies and fellow growers (a good reason for joining up with an association). Persevere until you find somebody who is helpful; and
- *don't fight City Hall.* You can take on the government, and you might even win, but regardless of the outcome, it will take a lot of time and energy, which would be much better devoted to farming fish. Keep smiling and calm. It will pay off in the long run. Bureaucrats enjoy the good life, love their kids and play with their dog just like you and me. They didn't write the regulations and find them as maddening and frustrating as you but their job depends on having the paper work filled in. Sometimes they don't know what the questions mean and all they need is an answer that complies with departmental policy on a particular issue.

If the application is for a major project it may pay to have a planning consultant carry the load for you.

The principles

A multiplicity of state, territory and local governments have rules that might have an impact on an aquaculture application. Most states will have a lead agency, usually the development or Licensing Officer, and that person's job is to walk the application through the other agencies.

One of aquaculture's biggest problems is that it's new. For new read 'unknown'. If the application is for a species that is already widely farmed, the passage may be smoother than for something that has regional bureaucrats scrambling for the rule book.

Acquiring tenure

Once you have an idea of what you want to do, the first step is to select a site where you will establish your aquaculture venture. You can't start any of the rest of the approvals process until you can relate your application to a place.

Depending on where you are, the nature of the ownership of the land: tenure, may vary.

In developed areas almost all of the land is freehold. Freehold land is alienated from the Crown, and ownership is established by having a title. Neither of the authors are aware of freehold title ever being issued for marine areas, so this is a kind of tenure almost exclusively confined to terrestrial areas. Much of the inland grazing land is also leasehold.

Having a title to freehold land does not give you unencumbered rights to the land. In almost all cases, you don't own the minerals in the soil below. Very importantly, you don't own the water moving over or under the land. There may be easements over the land that limit the types of structures you may put in parts of the title. There may be covenants on the title preventing some kinds of works or constructions. These are all specified on the title document. In addition, there may be heritage areas or sacred sites, which cannot be disturbed.

In some places in Australia there is a modified form of freehold, generally referred to as 'Aboriginal freehold'. Usually, the owner of Aboriginal freehold is some kind of trust or body whose job is to represent the traditional owners of the land, into perpetuity. Almost invariably, Aboriginal freehold cannot be purchased.

It is possible to get a lease to use freehold land owned by somebody else. Basically, a lease is a contract with the owner specifying what you can do on the land, and what the owner receives in return. All the encumbrances mentioned before still apply. In addition, the lease arrangement may contain conditions that further limit what may or may not be done on the land.

The other major category of tenure is Crown land. On Crown land, the land (or title) is owned by the government (usually the state or territory government). Governments have lots of things they want to do with Crown land (for example, establish National Parks and reserves) but in some cases, governments opt to lease the land for private development. Traditionally, the largest areas of privately developed Crown land have been for pastoral uses: running cattle.

Indigenous people owned Australia before European settlement and the introduction of contemporary law. This ownership is recognised as Native Title. If a government has undertaken an action that has given strong tenure to a subsequent person, then it is generally deemed that the original native title was extinguished. Granting freehold title clearly and completely extinguishes native title. However, if the tenure was limited, it may be that native title remains to a lesser or greater extent. It is possible that in some cases, a pastoral lease may only have extinguished native title for grazing, and that native title still exists in that lease for activities such as aquaculture. If you are considering establishing aquaculture on a Crown lease, check.

Most of the sea is Crown land. Most forms of aquaculture that take place in the sea (e.g. sea-cage farming, shellfish farming) require a distinct authorisation to use the site. In the case of marine Crown land, aquaculture leases may be granted for a fixed term with or without the option to renew. These marine farms are usually part of a designated aquaculture zone and will be subject to a Management Plan. Should an applicant aspire to a piece of Crown land not designated as an aquaculture zone, there will be an application process to establish whether or not the site should be given over to aquaculture. The process is usually lengthy and stressful.

The general categories described apply across the country, but details vary between states and territories. Access to land is one of the most fundamental rights in aquaculture, so it is essential to make sure all is kosher.

Planning/development approval

What you do on your property may have implications for what happens outside the property line. If you cook crayfish, a smell might waft into your neighbour's kitchens, which your neighbour might like, or might hate. If you build a big dam on a hill on a property line, the underlying hydrography may change, influencing the kinds of plants that will grow next door. Having water lying around might provide a habitat for pests such as mosquitoes. Impact on neighbours can extend to matters of social acceptability, for example: a north coast of NSW aquaculture application was granted but the neighbours kicked up a stink when the 200 hp of paddlewheel aerators started slapping the water every night from 11 p.m. right through until 7 a.m.

To keep everybody happy, a set of rules has been developed for most areas that generally go under the name of a 'statutory planning scheme'. The usual approach is to divide a given area into zones, and to define what kinds of activities are appropriate in those zones. Statutory planning schemes may cover all the land in a given area, or depending on the local rules, may not include any Crown land. Statutory planning schemes generally focus on dry land, but in some instances, they extend some distance out to sea. You'll have to check.

Usually statutory planning schemes work on two levels. The first level operates through broad-brush 'land-use objectives' which define general themes for a large area. These themes are addressed in much more detail in the second level, the local Control Plan. Control Plans usually zone up areas and define the uses to which a zone might be put. They specify which zone might become a shopping centre, whether or not a 'noxious trade' might be undertaken, what area will be used for dwellings, and so on. It is generally at the level of the Control Plan that the fish farmer interacts with the system.

In a Control Plan, the zones usually have a certain theme, for example, a zone might be called 'rural living' indicating it is a place, mainly for homes, but where people want to run a horse or two, dig a vegie patch out the back, and to have a view of scrub or pasture around them. The residents don't want to see too many buildings or hear industrial noises. Another zone might be for noxious trades, where people can undertake a business that creates a stink, but there are no neighbours to complain. And so on. The local government authority usually administers the statutory planning scheme.

In each zone there will be activities that will be declared 'as of right', that is, no specific permission is needed to undertaken them. In our previous example of rural living, an 'as of right' activity might be erecting a chook pen, or keeping a horse. There will also be activities that are specifically banned. Going to our example again, a banned activity might be building a factory, as it is out of keeping with the general conditions of rural living. So now we have two lists: 'as of right' and 'banned', but there is likely to be a whole suite of other activities not mentioned on either list (very probably including aquaculture). To obtain authorisation of the unlisted activities, permission must be sought through a 'consent' activities process. You usually have to put up a sign indicating your intentions, and interested or objecting parties have a specified period to make submissions to the planning authority, where a board considers the matter. Permission, if granted, comes in the form of a permit, but it's usually not just that simple: the permit can come with conditions that will limit what you may or may not do.

Failure to comply with Control Plans is considered a serious offence. If the planning authority discovers the breach (and there is always a nosy neighbour to inform them) they generally not only take you to court, where you may receive a hefty fine along with a black mark on your record, but they usually make you return the land to its previous condition, that is, fill in ponds, tear down structures and so on.

Effluent

If waste water from an aquaculture operation is discharged into public waterways its quality will be subject to regulations that will be reflected in licence conditions. The trout farmers operating flow-through systems are subject to a phosphate cap. In other words there is a limit to the phosphate they can discharge over a given time. These farmers have been able to stay under the cap and increase production by increasing the efficiency of their husbandry and their diets.

If the aquaculture waste discharged is to be onto the applicant's own land it shouldn't be subject to any conditions.

Some re-circulation system operators discharge into the sewerage system and pay their dues like any other factory operator. Others discharge to an irrigation or hydroponic situation.

Large projects will be required to submit an Environmental Impact Statement (EIS) with their application. These can be quite costly and prawn farmers along the Queensland coast opposite the Great Barrier Reef can find themselves facing a bill of over $250 000.

If a farm discards water at all, it is effluent. In almost all jurisdictions in Australia that will mean the farm needs an effluent licence. If the public at large is of the opinion the effluent is likely to be a serious polluter (wrongly or rightly) this could be a show-stopper. In both cases, a proponent for a fish farm should do their homework, have credible estimates of the pollution potential of their farm, and have plans for ways of treating their effluent.

Environmental assessment

Should the application involve significant impact on the environment, such as laying water intake pipes through sand dunes or major effluent discharges into public waterways, the application will be thrown open to public scrutiny. Environmental assessment is a process applied by government to assess the environmental impact of a development, and the degree of public acceptance of the development.

The developer is required to describe the nature of the proposal in written and/or electronic form. The description is then put on public display in a public place (such as a library or a town hall) or on the web. Comments are sought from the public. Comments submitted might reflect a degree of technical expertise or might just express an emotional gut feeling. In a democracy, both have legitimacy. The Minister responsible, assisted by his staff, will then make a decision as to whether the proposal should go ahead as described, if it should be rejected, or if it can go ahead subject to specified limitations and conditions. (This approach has some similarities to the statutory planning public consultation process.)

The system of environmental assessment can vary a little from jurisdiction to jurisdiction. Sometimes there is a two-tiered system: a short easy version of the process may only be required, or if the proposal is a major one, a drawn-out consultation period might be required. Sometimes the developer can get two bites at the cherry, that is, they may be required to note any concerns that the public has mentioned, and make suggestions as to their legitimacy and/or how the concerns might be allayed. In different states and territories, the name for the process can vary a little, it can be called an Environmental Impact Statement (EIS), an Environmental Effects Statement (EES), or even something as different as a Public Environmental Report (PER). But the general idea is the same.

Formal environmental assessment is usually only applied to developments of a significant size. For example, a 4 ha yabby farm would be unlikely to be required to undergo the process. However, a 400 ha prawn farm may well be required to undergo full-blown environmental assessment. In most instances an assessment is required when the Minister responsible thinks it is required. To some extent, value judgements are involved, and this adds uncertainty for the proponent.

Usually the process is formally triggered by the submission of a 'Notice of Intent', or similarly named document. The 'Notice of Intent' provides the Minister (or the staff advising him or her) with information to make a decision on whether or not some degree of environmental assessment is warranted. It is generally the responsibility of a developer to submit the notice. Pretending that nothing is happening and not submitting the notice is inviting trouble: there are plenty of people out there who are ready to complain about any malpractice. Failing to provide the notice could ultimately stop the proposal.

Environmental Management Plans

Many Government agencies are requesting that developers produce an Environmental Management Plan (EMP) before other licences are considered. As well as establishing *bona fides* for the public at large, the EMP is something developed by the farmer for their own use.

There is a specified series of steps that must be followed in an EMP:

- the various environmental issues (that is, potential impacts) are identified. Examples might be effluent control, what to do regarding fish disease, escape of farm species with impact on wild ecosystems, and so on;
- the plan is documented to address each of these issues;
- the plan has to specify how success or failure can be measured and how often it will be measured; and
- the plan also has to specify what the contingency action is, if the first part of the plan is found to have failed.

Each of these steps has to be incorporated.

EMPs can vary in size. A comprehensive EMP might be a book. For a small fish farm, it might be possible to get it all in a table on one page of A4.

The advantage of going down the EMP track, is that it lets the farmer decide the best way to deal with a problem, instead of having a solution forced upon him or her. If a solution is forced on him or her, it might not be suited to their particular farm.

If EMPs are going to work, the farmer must adopt the concept wholeheartedly, and incorporate it in the basic workings of the farm. It should not be an add-on bit of paperwork just undertaken to keep people quiet.

Illegal species

Australia has a history of importing hardy species, letting them into the environment where they go feral. The rabbit, prickly pear, feral cats, the cane toad, Undaria seaweed, blackberries, carp, foxes, water hyacinth, tilapia... The list goes on and on.

In an attempt to prevent recurrences of these environmental tragedies each state and territory has developed lists of unwanted species of plants and animals. The plants are generally termed 'weeds' and the fish declared to be noxious under fisheries legislation. It is irresponsible to attempt to farm any of these species. Not only does it create an environmental risk, but also throws the practice of aquaculture into disrepute.

The trouble is, the very features that make a species good to farm, also pre-adapt it to going feral. Some of the species proven to be pests in Australia form the basis of aquaculture industries elsewhere. (See chapter 23 for more information on species.) Don't fall for the temptation. European carp were brought into Victoria with the intent of farming them.

Aquaculture licences

In most places in Australia, it is illegal to undertake commercial aquaculture without a specific licence or permit. This is usually in addition to a specific lease or permit to occupy Crown land.

It is not uncommon for farmers to point out that they don't have to have a licence to farm cows or farm chooks, and they want to know why aquaculture is different. Much of the aquaculture-specific law in Australia has evolved from fisheries law. Australia is perhaps the most successful nation in the world when it comes to managing its wild fisheries, and a key part of the management arrangements have been making a distinction between commercial fishers and recreational fishers. To make this work, different licences are needed for people who fish to feed themselves and those who sell fish. Every person who sells just-harvested fish has to have some kind of licence, hence the aquaculture licence. There are other good reasons for having an aquaculture licence:

- It helps to control farming of species with potential to harm the environment.
- It gives a level of control over the spread of disease, and assists to ensure that aquaculture is undertaken in an environmentally friendly manner, and can be seen to do so.
- Licensing also provides an income-stream for government and this is not completely bad either, as moneys are allocated to industry advocacy organisations and into coordinated research to benefit industry.

For historical reasons, fisheries agencies are generally given charge of issuing licences for aquaculture. Often, they take the position of the 'lead agency' for aquaculture and facilitate the acquisition of other legal entitlements.

Notifiable diseases

Some states and territories have legislation that provides for notifiable diseases. These are diseases that are so virulent that immediate government action might be needed if they are found to be present in an area. In the case of land-based farming, foot and mouth disease provides an example. In aquaculture there are similar types of diseases, with white spot and yellow head in prawns offering prime examples. If those diseases got into the country, it would be devastating for the prawn farming industry.

Every farm suffers from low level endemic diseases and has the occasional fish mortality, but if significant mortality occurs, the only responsible thing to do is to contact the local fish health authorities and get them to come and look at the sick stock.

Goods sold

This book is about aquaculture, not the ins and outs of marketing the produce, but mention should be made of quality control. In Australia there has been increasing government focus on maintaining quality of food. This is to maintain our credibility with international trading partners who would like any excuse to impose non-tariff trade barriers and provide an edge for product from their countries.

There are other standards that are becoming increasingly important. A significant and growing segment of the market wants to be sure that the products they buy are clean and green. It is not good enough just to say it. To prove it to customers there has to be some third party standards that are audited by non-involved parties. Quite a few standards have been developed, and it would be crystal-gazing to say which will become pre-eminent, if any. However, in the prawn industry there is increasing acknowledgment of the ISO 14001 standard and in the future this may become an intrinsic part of management of any farm.

Growers' associations are also developing Codes of Practice in relation to food safety to assure the buying public that they, as an industry, follow safe food and sustainable environmental practices. This reassures the public and provides the industry with a yardstick by which members can measure their responsibility to each other – this is an industry in which they may have hundreds, if not millions of dollars invested.

Threading the maze

It can be very complex working out what licences/permits/entitlements to seek, who to seek them from and when to seek them.

Most state and territory governments have a business development agency and they can assist with the general requirements for licensing. Most have a website that you can access to find out what licences are needed.

Getting approvals for aquaculture can sometimes be difficult. For some reason it is often thought of as 'new' or 'unusual' and people working in government departments often don't know what to do about it. In some cases a 'Catch 22' situation arises: one government department won't give out an entitlement unless all the others have first, and if all the departments take that approach, nothing can happen.

In the bad old days, fisheries agencies used to sometimes take the line that protection of the wild fisheries was their role, and if anything in aquaculture might provide an opportunity for persons to do something that might damage the fisheries, then they should oppose it. Nowadays, most fisheries agencies are more positive and contain staff keen to see aquaculture develop. They often offer a service of either pulling the strings together themselves or advising proponents on how to do it. Some are working towards having a 'one-stop-shop': a central point where all the applications can be made in one place. The authors wish them good luck.

To find the best person to assist you to thread the bureaucratic maze, get on the phone and ask around the fisheries agency staff till you find somebody sympathetic, then use their skills as much as possible. Other fish farmers may be able to point you in the right direction too.

The licencing/approvals process may seem like a real pain, but it is not all bad. Once whatever level of environmental assessment has been undertaken, and licences have been obtained, the proponent can stand up before all and sundry and tell the world they have undertaken due diligence. This provides an edge, not only when dealing with potential detractors, but also in the marketplace.

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22

Management and administration

We are not going to tell you how to run your business. However, there are certain aspects of any commercial operation that should be considered before embarking on an investment. Topics covered in this chapter include:

- developing a business plan
- what you want from your venture, is it possible, why, when and how would you do it, and what it is going to cost you
- keeping operational, stocktaking and inventory records
- key performance indicators
- writing your own manual, and
- going about an R&D program.

Developing a business plan

The long-awaited bottom line: the business plan. You've been very patient. The rewards of aquaculture await you, but only if you abide by the rules. A liquidator was once heard to comment that he had seen a few well-run operations that had failed, but never a poorly run one that hadn't. The moral of the story? There's no guarantee of success but there's a guarantee of failure.

Aquaculture can be described as a maze, a minefield or a bottomless pit into which you pour your life savings. It can also be described as the future of healthy protein production for human consumption. The difference between the two pictures is planning.

This chapter is about planning.

What do you want from your venture?

The very first thing to decide is what you want financially from the venture. Whether you need $50 000 a year to live in the manner to which you are accustomed, or $1 000 000? Remember that when you go into business there's no one handing you a pay cheque at the end of the week. There's no one paying your superannuation contribution. There's no one picking up your workers' compensation tab. There's no one saying 'Take a month off, I'll look after things while you're away.'

And everyone you deal with, outside your client base, will want to be paid for what they do for you or what they supply you. However, your client base may be reluctant to cough up what you feel they justly owe you. This is life outside the comfort zone.

In effect, you write the bottom line first then fill in the bits above to determine what has to be invested in infrastructure and operating capital to achieve the desired outcome. Working backwards if you like.

Once you've decided what you want in the way of income from your venture put the figures aside for the time being.

What is possible?

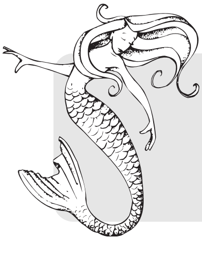
The next thing you will have to decide is what your operation is going to be. What it *can be*, not what you want it to be. This is very important. It should not be of a greater scale than your resources and management capacity can support. Below is a checklist of things to consider when taking this vital decision.

Don't make a final decision at this stage; just list the possibilities. Consider such items as:

- the available water: its quality and quantity;
- the management capacity and the timetable to be devoted to the operation;
- the critical mass required to ensure sustainability and profitability;
- the lifestyle expectations of all those involved;
- the negative influences of the farm situation that relate to production and marketing: the species to be farmed, the extent of the operation,the point of market entry;
- the feasibility of each aspect of the options examined;
- the infrastructure, services and marketing support available – vet services, supplementary food supply, transportation; and
- the availability of technology and the research resources.

For instance: that property you see advertised between Hay and Balranald may be attractively priced and have a licence to pump water from the Murrumbidgee River but if it's a four hour round trip to town, half of it over bush tracks that are closed every time it rains, and the power supply is subject to brown-outs because it's at the end of the line, it will soon expose any weakness in your plan. It may even be the weakness.

Don't let your dream to become a fish farmer override commercial viability and common sense. Talk to industry leaders. Their story is usually one of setbacks, perseverance and long backbreaking hours of sheer hard slog.



GWQEHN says:
Too many people try to make aquaculture what they want it to be rather than what it is.

Why would you do it?

Having listed the possibilities for your farm, you now have to decide which ones you'll take up. The easiest way to go about this is to ask yourself 'Why?' Why you would and why you wouldn't follow a particular path? Ask yourself which option is going to provide the most efficient and rewarding return on outlay and effort in both the long and the short term.

This is sometimes referred to as the SWOT analysis:

- **S**trengths
- **W**eaknesses
- **O**pportunities
- **T**hreats.

The checklist should focus on the Strengths and Weaknesses of your own operation and the Opportunities and Threats of the industry.

For instance the Strengths and Weaknesses of your business should evaluate such items as:

- technical knowledge and experience of the assembled management team;
- the resources available to the operation such as a well-situated site with copious water, an ideal climate and proximity to markets;
- business and sales experience; and
- a capital base that is sufficient to deliver the outcomes in the business plan after taking into account any contingencies.

On the other hand, the Opportunities and Threats evaluation should consider such items as:

- market depth, trends and future prospects;
- the strengths and weaknesses of the opposition; and
- the international market – the prospects for your product and the likely threat from imports.

Be honest with yourself here, and in all parts of this process. You can lie your head off to your bank manager, your accountant, your solicitor, your spouse, and your lover but don't kid yourself. Aquaculture has a nasty habit of exposing prevaricators and self-deluders. The aquaculturists' graveyard is decorated with their headstones.

How to achieve the goals you've identified

Now we move on to the 'how to' part of the plan. Having decided on the goals of the aquaculture operation, it is now time to look at how they are to be achieved. Plan this part well because this will be your Business Plan: your road map. You may be able to take a detour or two along the way, in fact you may be forced to, but it is very difficult to totally change direction.

If while compiling your Business Plan you discover aspects of the previous two steps that don't pan out as you thought they would, be prepared to retrace your steps and take a different view of the overall situation. Re-think the whole operation if you have any doubts. You still have the luxury of changing your mind at this stage whereas once you're halfway into the season this may not be possible.

GWQEHN says:
Aquaculture is rewarding, otherwise we wouldn't be here, but it is unforgiving, totally. Don't take any unnecessary risks.

When?

The big question now is when is it going to take place and when is the money going to start rolling in? Unless you have invested in a climate-proof indoor system, the seasons are going to be your timetable. There's no point in fighting them. *Time and tide wait for no man.* Make sure the timing of the establishment of the operation matches the season. For instance there's no point in having your yabby hatchery pumping out hatchlings in March when the season's nearly over nor starting to build your prawn ponds in December to deliver a crop the following autumn.

The other important part of the 'when' question is 'When am I going to need the money for outlays?' Matching the incomings and the outgoings – the cash flow budget – is critical to the financial survival of your aquaculture venture, especially in the first season when everything that can go wrong usually does. For instance budgeting for a cash flow from early sales to purchase feed to finish off the tail end of the crop is a high-risk strategy.

Divide your season into months and list your outgoings and income for each month. Your bank manager will want to see this and you'd be well advised to have a handle on it yourself so you can gauge the amount of cash you'll require to fund the capital and operating outlays.

The outlay

Starting from scratch, the following checklist will help you determine how much you're going to need to set up and get through the first and subsequent seasons. You may already have some of the items on hand and being able to find a multiple use for farm infrastructure will reduce the overall cost of the integrated operation.

Capital costs

These are the costs involved in setting up the fish farm. Some of these items aren't immediately tax deductible but can be depreciated over a set period or on a sliding scale. Your accountant will be able to advise you on the most advantageous way to structure your depreciation schedule.

However, it may be that some existing structure is being modified or repaired to accommodate its use on the fish farm. It is likely in this case that the expenditure can be claimed against the income earned from aquaculture for that year.

The check list

- Purchase of property
- Survey of Land Form

- Permits and approval fees
- Water
  - (a) procurement
  - (b) movement
- Ponds
  - (a) design
  - (b) plumbing
  - (c) construction
  - (d) protective netting
- Infrastructure
  - (a) on- and off-farm vehicles and transport-related equipment
  - (b) harvesting equipment
  - (c) holding/purging room
  - (d) processing room and allied equipment
  - (e) packing room and allied storage space and equipment
  - (g) office and allied equipment
  - (h) monitoring equipment
  - (i) hatchery and allied equipment
  - (j) power
  - (k) staff and management accommodation
  - (l) staff amenities

Operating costs

Leave room for contingencies and be generous with estimates. You can't pluck funds out of mid-air halfway through the season, and if your cash flow from the ponds is late coming on-line you could find yourself with insufficient funds to finish off the crop.

The checklist

- General operating costs
  - (a) repairs and replacements
  - (b) fuel and vehicle repairs
  - (c) water and water movement
  - (d) light and power
  - (e) feed and fertiliser
  - (f) seedstock
  - (g) medication and veterinary services
- Workforce costs
  - (a) feeding
  - (b) plankton production
  - (c) water quality management
  - (d) harvesting
  - (e) holding and purging
  - (f) processing and packaging
  - (g) delivery
  - (h) hatchery
  - (i) maintenance

- Management
  - (a) daily overseeing and problem-solving
  - (b) planning and decision-making
- Selling and marketing costs
  - (a) samples and out of pocket expenses
  - (b) travelling and accommodation
  - (c) advertising and promotion
  - (d) staff
- Research and development
  - (a) cost of technology and consultancy fees
  - (b) structural costs
  - (c) operating costs
  - (d) off-farm research
- Administration
  - (a) government paper work, record and account keeping
  - (b) insurance
  - (c) phone and postage
  - (d) stationery
  - (e) legal and accounting fees

Income

Be conservative with yields and harvest timetables. Remember those that have gone before you.

The checklist

- Sales
  - (a) product
  - (b) secondary product
  - (c) by-product
  - (d) surplus seedstock
  - (e) pet trade
- Services
  - (a) consultancy fees
  - (b) open days
  - (c) secondary services and hire of equipment
  - (d) technology
- Tourism
  - (a) product sales
  - (b) by-product sales
  - (c) food and entertainment
  - (d) souvenir sales

GWQEHN says:
Of course, there's always the option of not bothering with all the tediousness of keeping track of your business. It will probably save you many sleepless nights of worry until your bank manager phones to tell you it's all over.

Cash flow

The cash flow should be set out on a spreadsheet covering three to five 12-month periods so that you're able to budget your expenditure to match available funds. Nothing is more disastrous than running out of operating money during the season. To start with you can't buy feed which means your stock don't grow; and if your stock don't grow you lose more money which puts more pressure on your cash flow.

The next three to five years are crucial. Beyond that is only crystal-gazing. Project the figures you have at hand. Before the five years have expired there may be several changes in circumstances that make your projections obsolete. Should this be so, at least you'll be able to plot the variance points and take corrective action.

Operational records

Operational records, in fact records of any sort, are among the most useful tools available to the fish farmer. Yet they are one of the most constantly ignored. It is from the pond records that trends can be traced and events linked. Operational records generated at the workface can be entered into a computer program from where an instant picture of the progress of the production and the business can be called up. Guessing and memory are just not on.

Some records are based on observations and others are based on recorded measurements. Both are important. The ponds won't collapse if the records are missed for a day

Figure 22.1. Operational records can be a simple board to help keep track of breeding cycles as in this yabby hatchery.

or two, and there will be periods when the monotony of the measurements make the whole operation seem a waste of time, but they should be continued as they reflect the conditions under which your ponds have performed.

Some measurements need to be done on a daily basis and some on a weekly or even wider time span.

Some records will deal with the stock and some will deal with water conditions while others will deal with what goes into the pond such as food and fertiliser. All are related in the long run and share equal importance although some, such as DO and pH levels, are obviously more critical than others.

Get used to carrying, and using, a recording device, be it a notebook and pencil or a tape recorder. These tools are an important part of the pond manager's kit.

After you get to know your operation, you will develop an instinct for how it's running without resorting to calibrated measurements. While there's nothing wrong with that, in fact the authors applaud the degree of natural husbandry skills this expresses, they would like to point out that, should something go wrong down the track, the cause may have occurred at an earlier period or under a particular set of climatic or management conditions. It's only by keeping records that the operator will be able to trace the problem back to a root cause with any degree of certainty.

It's also essential in the advent of an insurance claim that accurate sequential records be available to support the claim.

Another failing the authors have noticed is the tendency to monitor and record the values religiously then promptly forget about them. Set aside some management time to interpret the readings. Look for trends as much as upper and lower critical limits.

GWQEHN says:
If you're going to make the effort to take records it seems ridiculous not to interpret them.

Daily measurements

These are the items that can be directly monitored and measured against industry and scientific yardsticks. The importance of some parameters for open pond systems will not be important in an indoor fish farm as the water would not be under the influence of photosynthesis. Similarly, the parameters for a marine farm, either subtidal or inter-tidal are different again. As many of the readers will be contemplating farming in re-circulation systems or open ponds, these systems are discussed under the relevant headings below.

In open pond systems

Dissolved oxygen

Oxygen is probably the most common limiting factor found in aquaculture ponds. Fish cannot live nor metabolise food without oxygen. It also drives the pond's bio-filtration system.

DO levels should be checked a couple of times a day to measure the amount of oxygen in the water and to plot the trend of the movement. The usual time is first thing in the morning and at midday; or, using other terms, before breakfast and before or after lunch. The timing doesn't have to be chronometer true but should follow some sort of routine. Some growers like to carry out the morning test before the sun gets up.

Measure surface and bottom water and note any differences. If there is a wide and/or constant difference mix the water by exchange or agitation to break the thermocline, even if the pH and DO readings don't indicate that your stock are in any danger. The presence of a thermocline indicates temperature variations that will impact adversely on production. This is especially important in crayfish ponds.

For maximum production the DO levels should be as close as practically possible to saturation and if phytoplankton production is high this won't be a problem during daylight hours. In fact it is highly likely they will be well above saturation. The irony is that the easier it is to maintain satisfactory levels during the daylight hours, the greater the likelihood of the reverse being the case after sundown. The slope of the graph will be the warning here: a steep slope upwards under the influence of photosynthesis will indicate a corresponding downward slope after dark.

Some growers only bother with a middle of the day reading. If this is high they know they have ample oxygen dissolved in the water for the stock during daylight hours and that the night readings will be dangerously low so they will have to aerate during the night as the DO falls due to reverse photosynthesis.

pH

pH has a direct and dramatic bearing on the amount of total ammonia nitrogen (TAN) present in the water in the toxic or un-ionised form. It is an extremely fluid element of the pond and will have to be monitored and managed on a daily basis.

You can take pH readings at the same time as you take the DO readings. It is likely that pH and DO levels will share a similar swing: upward during daylight hours, downwards during the night. In cases where there is a good buffering of calcium carbonate (alkalinity) in the water, the swing will be less pronounced.

Either measurement will give an indication of the probable need to run the aerators that night and of the level of plankton production (photosynthesis activity).

Temperature

The water temperature will be useful in several ways and the maximum and minimum temperatures of the pond over a 24-hour period should be recorded. Some growers use data loggers so they can plot the temperature more precisely over the day.

What does temperature tell us? First, it has a relationship, along with pH, with the amount of toxic ammonia that is present in the water at any given time. Second, it has a bearing on the amount of oxygen that can be dissolved in the water. The third piece of information the water temperature tells us is where the ponds sit in relation to the target species' preferred temperature zone, and therefore how much food our fish can metabolise.

Plankton

There are two plankton measurements that can be monitored: phytoplankton and zooplankton. The most common reading taken is for phytoplankton: the bloom of microscopic aquatic plants often referred to as algae. The zooplankton reading has more relevance to growers producing freshwater crayfish or feeding fish larvae.

The implement used to measure plankton density is a Secchi disc. (See chapters 8 and 12 for more information.) The disc is lowered into the water until it disappears from view. The depth at which it disappears is the Secchi disc reading. Readings of 20 cm or less are regarded as dense blooms and steps to reduce the phytoplankton load in the water should be considered, readings between 20 cm and 50 cm are normal healthy blooms, and readings deeper than 50 cm indicate only a minor presence of phytoplankton. Should the pond be rearing fish fry, a bloom of <50 cm would be regarded as being insufficient to support the food chain for the developing fish larvae.

The black and white segments can also be used as a backdrop to the pond life swimming across the field. For instance: black ostracods would show up against the white background and dun-coloured *Daphnia* will show up against a black background.

Figure 22.2. Taking plankton samples is essential, particularly in ponds where the stock is dependent on it for survival and growth. A freshly stocked yabby pond, such as this one, will have juvenile yabbies amongst the filamentous algae at the pond's edge.

Where there's a lot of organic matter or colloidal clay present in the water it will be difficult to get an accurate reading of the plankton bloom. However, you'll generally find that the plankton bloom will be reduced by the lack of sunlight penetration in the water.

Zooplankton can also be measured by catching it in a plankton net either hauled through the pond from the bank or by hand net. Crayfish growers and hatchery operators, generally speaking, have ponds shallow enough to wade so the zooplankton can be measured on foot throughout the pond. This is important as zooplankton, particularly daphnia, move about the ponds in rafts and their presence can be misjudged by a casual appraisal.

GWQEHN says:
There is absolutely no substitute for a genuine lack of preparation.

In re-circulation systems

Re-circulation systems are the Formula One systems of the aquaculture world and as such require a high degree of monitoring. They are working for you 24-hours a day at maximum production levels and warrant a bit of extra driving and tuning to ensure you're getting your money's worth from all those bells and whistles.

Being indoors, a re-circulation system is not influenced by photosynthesis so the water is not subject to diurnal and nocturnal DO and pH swings. However, the pH and DO do move in relation to the biochemical oxygen demand (BOD) and metabolic activity in the system and should be monitored daily. There are devices available that will allow growers to monitor some values constantly and relay the results to a remote terminal.

Another factor to consider when monitoring water quality parameters in re-circulation systems is the safety aspect. The high stocking densities usually associated with these systems, generally between 20 kg/m^3 and 80 kg/m^3, place a demand on oxygen unimaginable in an open pond system with stocking densities nearer 1 kg/m^3. Should any part of the system fail, the life expectancy of the fish in the tanks is measured in minutes, certainly less than an hour. The monitoring probes are generally connected to an alarm system such as a mobile phone so the operator can take the appropriate action in the event of a breakdown.

Electronic monitoring systems will usually be connected to a program that allow the grower to store, graph and print out the results of the monitoring over any period of time they have been taken.

Dissolved oxygen

Being denied the sun's energy, water in a re-circulation system relies entirely on the system for its supply of oxygen. This will be coming from either mechanical aeration or injected oxygen. To operate the system efficiently, the grower should know if the DO falls below a particular level of efficiency in the tanks for any period of time, usually considered to be 85% of saturation in the case of mechanical aeration, although 100% would be better if economically achievable. In the case of oxygen injection the readings should be above saturation level (super-saturated) but at least able to maintain 100%.

The important thing is where the readings are taken. For instance if the readings taken going into the fish tanks are 100% of saturation but only 50% coming out, there would be a deficiency occurring in the tank that would reduce the efficiency of the system. Likewise, if the water going into the bio-filter is, say, 50% of saturation, the nitrifying bacteria would be short of oxygen with which to oxidise the ammonia nitrogen and less efficient than if they had an abundance of oxygen with which to do their job.

GWQEHN says:
Re-circulation systems live on oxygen, you can't have too much.

Even if an automatic monitoring system is testing the DO, it's still a good idea to manually test the readings at various points around the system to determine any oxygen deficient spots.

One of the benefits of a re-circulation system should be its stability. If the water's running through the system and the stocking, loading and feeding regime is constant, it should be steady from one day to the next but the only way to be sure is to monitor it.

pH

Another by-product of the high stocking densities that are found in re-circulation systems is the build-up of acids in the system, notably carbonic and nitric acids. These acids, along with the requirements of the nitrifying bacteria, eat away at the carbonate hardness in the water and can send the pH into a tailspin. While this is a positive as far as the percentage of the TAN that is present as toxic ammonia in the water goes, it can fall below a safe level for the fish to live in.

The pH should be monitored and adjusted daily according to the management protocol of the system.

Carbonate hardness

The pH of the water will be directly related to its carbonate hardness. The test is a simple procedure and a handy value to know.

Its value is also used in the table, along with pH, calculating the amount of carbon dioxide (CO_2) in the system.

Temperature

The water temperature should be stable in a well-insulated re-circulation system. Data loggers that connect to a computer are readily available and will tell growers where their temperatures were at any given time. From a production point of view this is a key measurement.

Ammonia, nitrite and nitrate
While in a well designed and operated system all the critical water quality parameters and key performance indicator values should be stable, there will be times when things get out of alignment for one reason or another. For instance: in a well-run system the nitrite levels, as the middle step in the nitrification process, should be low as the *Nitrosomonas* and *Nitrobacter* colonies work in unison, the *Nitrosomonas* supplying the raw material, ammonia nitrite, for the *Nitrobacter* bacteria. The only build-up in the chain should be either at the beginning, where the bio-filter can't cope with the ammonia, or at the end, where the finished product, nitrate, stockpiles. In nature the stockpile would be used to produce plants. In a re-circulation unit it leaves the system with the water exchange during the normal de-sludging operation. Should the nitrite values be increasing then it's an indication there's something wrong with the system and the source of the malfunction will have to be located promptly.

Most operators take their ammonia, nitrite, and nitrate reading every day. Some twice a day, if they are carrying high loads and managing high feeding rates.

Turbidity is not an issue in re-circulation systems in the same way it is a factor in open pond management. However, some indoor growers like to keep their water relatively clean of organics in solution and Secchi disc readings will alert them to the efficiency of their foam fractionator and ozone units.

Weekly measurements

In open pond systems

Ammonia, nitrite and nitrate
In open pond systems, because the stocking densities and, consequently, the nutrient inputs are so low, ammonia, nitrite and nitrate readings can be taken on a weekly basis. If you run into a problem period you may find yourself checking it daily until the problem is stabilised, either by water exchange, a reduction in the stocking rate, reduction in the feeding rate or a combination of all three.

The cause of the problem is an overload of the pond's BOD or, in other words, you've lost control over the balance and stability of the ponds. Phytoplankton will take up the nitrate as it is produced by the pond's nitrifying bacteria but an increase in phytoplankton activity can often contribute to other problems.

GWQEHN says:
The best cure for water quality problems is to aerate non-stop in combination with water exchange until the problem abates.

Carbonate hardness
The carbonate hardness will not shift as dramatically in an open pond system as it would in a re-circulation unit, but it has the same impact. Keep an eye on it but it should only need to be checked on a weekly basis. It will indicate when the pH buffer is getting low.

General hardness/salinity/conductivity
If you are using water with a pronounced hardness and/or mineral salt content, you will have to be aware that replacing evaporation will increase these values as the water vapour leaves the pond water, leaving the mineral elements behind. Their build-up should be monitored. Weekly readings shouldn't be necessary but you might be surprised how quickly they can accumulate.

Should you feel that these readings aren't changing noticeably on a weekly basis they could be put off to a monthly schedule. However, it's easier to keep the carbonate levels stable with regular applications of lime than large doses delivered on an irregular basis.

Observations

There are some influences that are measured by observation. The results of these can be quantified or left descriptive, such as the weather. Depending on how much importance you give it, anything from the sound of how a motor is running to signs of incursion by water rats can be on the list. You'll soon work out what needs a daily check. It might be the charge of the battery that automatically starts the generator during a power failure. Those that don't require a daily check should be on the weekly or monthly roster.

Stocktaking and keeping inventory

There are two aspects to stock management: operational management and administrative control. Operational management is done on a daily basis and administrative control is ongoing.

Daily stock checks

Develop a method of being able to check your stock daily. Shade traps for fish and yabbies are one way. Move them around a bit to get a wide representation of the ponds. Watching for any difference in the vigour the fish show at feeding is a good indicator. You'll be surprised how quickly you get a feel for this.

Walk the ponds looking for signs of dead stock washed up at the water's edge. This can be part of the other daily routines such as collecting water samples.

Drag a net through the ponds occasionally to get an idea of what's happening on the bottom of the pond. Wade the ponds (the puddle-duck walk) with a plankton and aquarium net to see what's going on in the water.

Long-term monitoring

Knowing what stage your stock are at and where they are on the farm is essential to sound business practice and good farming procedures. Records should be made of stock growth and their movements.

There are two ways to follow these records: from a stock-batch basis and from a pond/tank/cage/raceway basis. A batch of stock coming onto the farm to go into production should be given an identification number. Should that batch be split and stocked in separate production systems their new number should allow them to be traced back to the original batch. For instance: the first intake of silver perch for the year 2004 might be designated 1/02/04, indicating that it was the first batch for 2004 and it arrived in February. It might consist of 100 000 50 cm fish averaging 1 g that are stocked in a nursery pond until they reach 50 g. At this stage they are graded into three grow-out ponds. Their designation would change to something like 1/02/04/1, 1/02/04/2 and 1/02/04/3. This way the stock can be traced to calculate their Key Performance Indicators such as growth rate and FCR. It is essential that these figures be known with a degree of accuracy if you are going to keep tabs on Key Performance Indicators (KPI).

The ponds/tanks/cages/raceways are your paddocks and you should be able to call up the history of the farm and what is happening in each one. It should be able to cross-reference the information with the stock numbers but contain information relating to the pond/tank/cage such as Pond 7 may have a history of anaerobic activity indicating the need to clean out the sludge, or the predator netting around Cage 9 requires repairing.

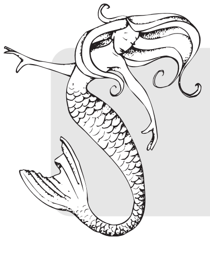
This may sound a bit of unnecessary bookkeeping and if you're a person that shuns records and works from memory so be it, but the human memory is reliably unreliable.

Monitoring stock growth can be done as often as once a week or as infrequently as once a month. Obviously it's not practical to weigh the whole crop and if the fish are easily disturbed the monthly stocktake might be the preferred time span. Take a representative sample to obtain an average, and base your calculations for the whole batch on that. It may be a little bit out, but as long as the sampling method is consistent it will provide meaningful data. The true figure will be revealed when the fish are harvested and a total weight is obtained. Adjustment can be made for mortalities as the season progresses.

Monitoring stock growth has several advantages. It allows the grower to calculate such important operational items as feeding regimes and target harvest dates, and equally important economic items such as food efficiency and fish space. You can't run an economically efficient fish farm unless you have that data at your fingertips.

Being able to trace batches from particular hatcheries or breeding lines is essential if genetic improvement is to be gained.

There are several software options on the market but many presenting themselves as management tools have more to do with determining financial outcomes from a fixed set of assumptions entered by the operator. As there's a lot of work writing a meaningful program of this nature, the cost of a true management tool is quite expensive. Shop around until you find a program that delivers the outcomes you require.



GWQEHN says:
Key Performance Indicators are required knowledge. Don't leave home without them.

Stocktaking crayfish

Stocktaking crayfish can be a bit tricky. The largest, and consequently the fastest-growing animals, walk into and dominate the traps so calculations will be distorted if they are taken as the average. One way of getting a profile of the stock in a crayfish pond is to pull a light dragnet across the pond. This will reveal the make-up of the general population.

In many of these cases it's a matter of making some intelligent guesses at the numbers and average weight, but you'll be surprised how accurate you become over time. The most important thing is to have some idea of how the crayfish are performing, how many are on the farm and where they are.

Equipment

This is straightforward but often overlooked. Many people involved in aquaculture are attracted to it for the opportunity to work with living organisms and tend to overlook the functional aspect of the equipment used on the farm. You'll need to develop a manual for the maintenance of the scientific and mechanical tools used to run the farm. Manufacturers will provide a manual with each piece of equipment and it should be a simple matter to incorporate a farm maintenance manual from them.

Listen for unusual noises coming from equipment. Look for oil, water and fuel leaks from motors, water leaks from valves and pipes, check refrigeration units, expect the worst and follow a routine.

Predator defences

There's no point in building a predator defence if you don't regularly check that it hasn't been compromised. Walk the boundary of your Stalag with the diligence of an Alsatian guard dog.

Key Performance Indicators

One of the world's leading re-circulation system designers and manufacturers offers to guarantee the production outcome from their system based on three inputs: the stocking density, the growth rate and the FCR. From those inputs he can design a system that will deliver the required outcomes.

Every business has Key Performance Indicators (KPI) and it is imperative that the operator be able to refer to these so he or she will know exactly how efficiently his production system is running at any given time. Lose contact with these KPIs and you won't know whether you're in front or behind the game.

A crucial KPI for intensive animal production is the cost of animal space. That is the capital outlay required to produce a unit of production, in our case a fish. One of the largest expenditure items is for the production system, be it an indoor re-circulation unit, a flow-through raceway system or a series of floating fish cages. The quicker, or in other words how often, the fish can be put through the system the cheaper that space becomes.

The poultry industry has reduced the time birds are in the grow-out sheds dramatically. In 1933 it took 80 days to produce 1 kg of live weight poultry. By 1963 that time had been reduced to 42 days and 30 years on it was down to 21 days to produce 1 kg of live weight poultry. It's no coincidence that a KPI, food conversion efficiency (ratio), followed the same trend. In 1933 the meat bird industry average FCR was 4.4:1, in 1963 it was 2.4:1 and by 1993 it was down to 1.8:1.

Just to emphasise the point, in 1933 the live weight at slaughter of the average meat bird was 1.22 kg and it took 98 days to produce. By 1963 the live weight at slaughter was 1.59 kg and it was grown in 67 days. Thirty years later, in 1993 the live weight at slaughter was 2.04 kg and it was grown in 42 days. From this data it can be seen that the poultry grower in 1933 was turning out 4.54 kg for each bird space he had on the farm. By 1963 he was turning off 8.67 kg of product per bird space and by 1993 the return per bird space had become a massive 17.73 kg.

The same economic rules apply to fish farming. Imagine the reduction in the cost of fish space and consequently production costs. Operators who have this information about the performance of their stock will be at the forefront of the industry. KPIs are the best information you can have in this information age.

Growth rates

From growth rates operators will be able to determine essential commercial information such as:

- when they will be able to expect a return by selling the fish they are so busily tending;
- when their marketeers can expect what volume of stock;
- how their feeding regime and diet are performing; and
- whether, by measuring it against previous performances, there are other limiting factors impacting on the performance of the fish.

Food conversion efficiency

On an efficient fish farm food will be the largest single production expense with which you are confronted, therefore the efficiency of the food has to be monitored rigorously and accurately. The FCR is the performance indicator for so many production cost items, not the least of which are growth rate and lean meat deposition. Keep track of what feed you use, whatever it takes. Without this figure you're really only guessing at how much it is costing you to produce a kilogram of fish.

The manual

This volume is a textbook only. It is not a manual. Each farm will have its own peculiarities and each farm will have its own management style. You should be able to write your own manual for your own operation. In fact the authors would go as far as to say it's a test you should voluntarily undergo before you get too far down the track with your fish farming venture. Use it as a means of testing whether you have a grasp of what aquaculture is about and what your role in it will be.

Once completed you could present it to an experienced aquaculturist, Fisheries Extension Officer or even a lecturer if you are doing an aquaculture course. Naturally there are likely to be a few things that aren't practical and a few procedures you've missed, but it's better to discover them now before you get too far into the operation.

The easiest way to get started is to plot the life of the fish from the time they come onto the farm and what you will have to do to ensure their safety, encourage their growth, maintain equipment, harvest and prepare them for market, get them to market, and get paid. All the while, you are administering the whole shooting match: a tall order without a manual.

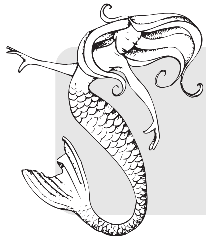
Writing a manual will not only allow you to think through the procedures you will have to follow, but will also allow you to calculate how much time you will have to devote to achieving the outcomes you have set yourself.

Yet another benefit is that it will give you a guidebook to pass on to anyone who works on the farm, be it family member or neighbour helping out while you slip away for a few days hard-earned rest. Should the farm employ full-time or casual labour, the manual will be invaluable.

If this seems a daunting task you may have to ask yourself if you are really ready to take on the responsibility of aquaculture; after all, you are in charge of live animals and part or all of your hard earned savings. This is serious stuff.

You may have several manuals, one for every aspect of the operation. Make copies and have them in plastic folders so they can be used with wet hands. Have a check-off book that has to be initialled and dated by the person doing the operation mentioned in the particular manual.

Naturally there will be updates as the various procedures get streamlined. Put the manual on computer and be prepared to continually modify it as you fine-tune your operation.



GWQEHN says:
It's not what you do right in aquaculture; it's what you do wrong.

Planning a research and development program

Often referred to as 'R&D', research and development is an integral part of aquaculture. Unfortunately there are far too many exponents out there that make R&D the whole purpose of their operation: the Frustrated Academic Syndrome (FAS). The result is usually an aquaculture operation that is more experiment than farm. Allow a budget, both cash and time, for trying something new but make sure the cash flow is assured from the commercial operation before burying yourself in research.

Having said that, the new fish farmer will find himself doing something he's never done before so in that sense it will be all R&D to him. That's fine, but follow the basics until they are second nature to you before you try something that's not in the book. Ask around a bit. There might be a very good reason why it isn't in the book; it might have been tried and failed. Re-inventing the wheel is one thing, re-inventing a square wheel is a waste of time, capital and effort.

R&D requires regular, accurate and relevant recording of the sequence and magnitude of the events associated with the program in order to draw meaningful conclusions from the results and to put the knowledge gleaned into practice.

One of the glaring failures of home-grown R&D has been the lack of replication and control. This has tended to distort the results and consequently the conclusions. One way around this would be to work in a network of fellow aquaculturists, sharing the costs and the results, and applying the thinking of more than one head and set of resources to the problem.

Another would be to identify a particular problem and ask an academic institution to solve it. The matter of funding would be of major importance in this age of user-pays, but government research funding may be available. In this case it is often better to apply for funding through a growers' association or similar representative body. There are many graduates looking for post-graduate work and really not knowing where to start. This latent energy and the grower's need for hard knowledge could be integrated given the right approach – and the right post-graduate.

Associated industries might be of assistance. For instance feed companies might be able to provide a ration, but they in turn will only be interested if they feel they are going to get some worthwhile intelligence from the input. Be prepared to share information as it can only benefit the industry as a whole.

Establish what you want to prove

Before you plunge into an R&D program, you should first establish the economic benefits you will derive from what you are trying to prove. Sometimes it seems a good idea at the time but the gains aren't worth the input. GWQEHN has Her views on the subject and as usual She takes a pragmatic view.

GWQEHN says:
Before you do change anything on your farm you should first ask yourself, how much extra control will it give over the stability and balance of the operation? Then evaluate the cost and the benefit. If the former is greater than the latter – forget it.

The most useful information you can have is how to remove limiting factors from your production system. Try to identify what these are and set your trial to eliminate them from your operation.

Make sure that the trial has a practical commercial outcome. Far too much research work in aquaculture has been focused on matters more academic than aquacultural: more on what fish will do under a certain set of circumstances than actually determining the benefits of the research to aquaculture. Observing the nature of fish, although an important aspect of husbandry, is not in itself farming fish.

The usual pattern of R&D is that it is based on an observation or anecdotal evidence and the trial is the test to see if it is sustainable and commercially viable. The hypothesis may be drawn from another but related aquaculture. For instance prawn aquaculture could well be a valuable source of methodology for freshwater crayfish growers.

Establishing the protocol for an R&D program

Protocol

Once the purpose of the trial has been established, the protocol, or the procedure, should be established. If you believe a particular course of action will benefit your operation, write it down in step form. This will be your protocol for the research. This will be the handbook you follow.

Should you discover halfway through the program that you have made some wrong assumptions, don't be too proud to admit it and change the direction of the research; but if you do, be sure to note the changes and at what point they occurred.

The control

Every trial will have to have a control against which the procedure can be measured. This is usually the normal way the farm operates so that should not be a problem to set up. However, the management of the control situation should be uniform.

The trial

Although the on-farm trial may not be scientifically acceptable under the strict conditions of a PhD submission, it should be relatively uniform with the control situation to have any useful outcome.

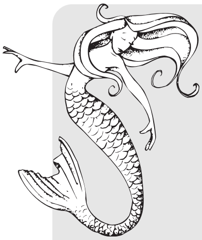
The operation of the trial should match that of the control except for the input being evaluated. Again we are looking for the same maximum possible uniformity in the trial situation as we sought in the control ponds.

Replication

Aquaculture is so dynamic that the more replications you have of the trial, the more likely you are to gain anything other than anecdotal evidence. Having said that, anecdotal evidence, although not conclusive, can be a useful guide and reason for deeper research.

In an ideal world you would have five replications of the trial and five of the control. Comparing production figures from different growing seasons is nothing more than anecdotal, unless of course seasonal variation is the focus of the trial.

There is nothing wrong with R&D work done on less than five replications and many good ideas have sprung from less academically acceptable work, but it would be sound practice to repeat the trials to make sure you're on the right track if the results have been gleaned from less than a comprehensive study. You might even get a colleague or research institute interested in providing support.



GWQEHN says:
R&D presumes that all other things are in balance and that everything has been done to eliminate other limiting factors from the system. There's no point in comparing feeds if the water quality management is so poor that it becomes the major limiting factor on the pond's production. Quite simply, the difference between a good diet and a bad diet just wouldn't show up in the results.

Keep it simple
Test for one thing at a time. Avoid the temptation to roll half a dozen good ideas into one trial. The results will be confusing at best and irrelevant at worst.

Record
Should it have to be said? Record everything you feel may be relative to the trial. Your usual pond records should suffice but you may have some one-offs you want to monitor.

Remember: if you're not good at record taking, train yourself to be. It is as an important part of aquacultural and business management as feeding the fish or taking them to market. Without operational records the rest of the show will quickly decline.

Interpretation
This is the tricky bit. Avoid drawing convenient conclusions. Cross-examine the evidence.

Draw as many conclusions as you like. They may all be true in varying degrees. Follow each conclusion back along its suspected path and look for flaws in your reasoning or the procedure.

Apply the GWQEHN test to each piece of evidence to see if it stands up aquaculturally, and to gauge the positive influence or limitation each of the components would have had on the trial.

Look for items beyond the original scope of the trial. Some of the world's greatest scientific discoveries have been made by accident.

About research – the order

There is an order of achieving goals in developing a species. The first thing that has to be standardised is the method of production: the husbandry. Once the way in which the fish are to be grown has been established, the dietary regime under which they perform the best under these circumstances can be determined. Then, and only then, is it possible to identify and select for the genotype that will make the best-farmed animal.

Far too often the research is around the wrong way. Aware that genetics is a powerful tool, many growers start selecting the best growers. This in itself is not a bad thing, especially when you consider that the seedstock of many of the species we farm in Australia is derived from wild broodstock. However, an unstructured breeding program can lead to all sorts of genetic complications. Genetic development is not just a matter of selecting the fastest-growing fish and keeping them aside to use as broodstock. If that's what you're going to do, find yourself a good book on practical genetics.

Genetics

One of the key purposes in improving breeding lines for farming is stability, or in genetic terms, homogeneity. Crossing out may create genetic diversity, which is what wild stock uses in its genetic armoury to cope with all sorts of environmental circumstances. This is what breeders call heterogeneity. What the farmer is doing is creating a stable environment and he wants all the stock to perform in the same way. Therefore he wants them to be homogeneous.

A key factor in improving farmed stock is heritability. You may be able to select for a trait that is desirable, but find it difficult to pass it on to the offspring because only a small proportion is heritable. Improving a breed can be a long, slow process.

A frequent pitfall is selecting for single desirable traits, such as fast growth rates. Often under this program the pursuit of one highly prized trait is found to be at the expense of other desirable traits, such as disease resistance.

If you wish to invest in this sector of the industry, make sure you know what you're doing and have plenty of time and cash in the bank. A rewarding breeding program can take 10 years to finalise, and even then if someone else comes up with super fish or crayfish before you that 10 year investment has been a waste of time and money.

Nutrition

Nutrition is another area where the science is complex. The authors aren't aware of any home-grown research that has come up with a commercially efficient diet. There have been plenty of successful experiments that have come up with a cheap diet but none that proved to be universally accepted because of their efficiency by the industry at large.

Husbandry

This is the field in which the average fish farmer should excel. No one knows fish like a good fish farmer. Breakthroughs in this area will be rewarded for doing little more than farming well.

Strategic alliances

There's no need to be discouraged. There are good geneticists and good nutritionists looking for good farmers to prove their science. Don't be shy about forming strategic alliances with these people to develop better diets and better genetic lines based on your better farming methods. After all, husbandry is the basis of all improvement.

23

Species

Since we wrote the first edition of this book, the world of aquaculture has moved on. The progress is no more apparent than in the range of species that are proven for aquaculture. In the old days, almost any aquatic species was a candidate for farming, that is, had 'potential'. In the intervening time, experience has shown that some are a lot more suited to commercial farming than others.

The following information covers the basics of each species. In the 'Current market status/potential' box we've tried to be circumspect without drawing too much away from the particular species. We've used 'Established market' or 'Demand' in cases where the animal is recognised universally as a seafood product and is regarded as a commodity. This generally means the grower will have to compete with frozen product from a low cost fishery or low wage farming country on the wider market. Prawns are an example of a species with an established international and domestic market.

However, farmed seafood marketed domestically can be sold live or fresh chilled which lifts it a notch or two in value.

'Niche market' or 'Niche demand' refers to a situation where the demand is considered limited. Silver perch provide a perfect example of a niche demand. Sought for the Asian cuisine through the live fish trade, silvers don't seem to have penetrated the wider seafood market, despite being well received by the white tablecloth sector. Why this is so, and what can be done to expand the market appeal, can't be covered in the space provided in a category box. The readers will have to do their own research into this. One answer could be the cost of production keeps it locked into the high value live fish trade that puts a ceiling on the volume the market will accept.

Of course there's always the species that falls between the two. For instance: southern bluefin tuna has an established market in as much as it's a world commodity. However, there is only a niche supply created by the quota system on the limited resource. In this case we've given it a tick in the 'Established international market' box because even without the 'niche supply' it would be a commodity, as are less prized tuna.

Where we've allocated something an 'Established international market' and a 'Niche domestic market', it means the species has cultural appeal and the followers of that particular culture only have a limited presence in Australia. The obvious one is abalone. Your average Aussie would rather hop into a fillet steak but your average Aussie of East Asian descent would open his wallet very wide for a live abalone. When you evaluate the market status, there are enough Aussies of East Asian descent living overseas to give abalone its 'Established international status' but the limited number living in Australia leave abalone with a 'Niche domestic market' tick.

Abalone

Production system	Land-based mariculture, ranching
Broodstock/seedstock availability	Technology widely available Stock only limited availability
Temperature/water preferences	Most commercial species prefer cold oceanic water
Current market status/potential	Established international demand: niche domestic market
Sector status	Developing

Abalone are marine snails of the genus *Haliotis*. Most of the better-known abalone species are harvested from temperate seas, but there are also various other species, something like a hundred in number, most smallish, that are found in marine waters the world over.

Having a licence to operate in a wild abalone fishery is akin to being able to print your own money. The destruction of wild fisheries around the world by over-fishing, disease and habitat degradation coupled with the growing affluence of the region driving global demand, East Asia, has seen prices driven to ludicrously high levels. It only takes a short stretch of the imagination to decide that farming abalone has a similar potential for profit. The development of technology for breeding and rearing abalone has enabled farming of the species and quite a few well-capitalised abalone operations have been established along the southern coastline of the country.

Although costing several millions of dollars to install, an abalone farm is not restricted by harvesting quotas and can grow as many animals as the market can absorb. For instance, a dive quota of 20 tonnes may be traded for $7 million; for the same investment, an abalone farmer can build a facility that can produce 120 tonnes. Uncoordinated production could lead to downward market pressure on the global market.

Balanced against this threat is the fact that once seedstock can be produced by the million, and economies of scale and improved husbandry and nutritional technology can be brought to bear on production costs, high values won't be required to keep the industry profitable. Abalone meat is already being processed in Australia and it is foreseeable that the wild catch will service the high value niche market for wild-grown product and the processing works will absorb the low cost farmed product.

In Australia and New Zealand most effort has been directed at species found in the wild fisheries. See sections on 'Blacklip abalone', Brownlip abalone', 'Greenlip abalone', 'Paua' and 'Roe's abalone'. However, there are other possible species: see section on 'Tropical abalone'.

To breed abalone, suitably conditioned broodstock of both sexes are required. The gonads of an abalone lie beneath the skin between the muscular foot and the inner edge of the shell. Depending on the species and a few other factors (including whether or not they are in breeding condition) the colour of the gonads can be seen through the skin. Mature male gonads are off-white, and females have green eggs, so a technician with a practiced eye can distinguish the sexes.

Most of the larger species need to be about eight or ten centimetres across the shell before they are sexually mature. When they are ready, mature males and females simultaneously shed eggs and sperm into the water. They do not need to conjugate to breed.

As with all aquaculture operations, site selection is everything. Suitable coastal sites with infrastructure support are seen as prime recreational regions. They are tightly held and access is limited by other stakeholder demands such as yacht clubs, boat ramps and NIMBYs (Not In My Backyard members of the public). In remote areas infrastructure becomes a problem. Facilities are capital intensive, however, as the market demand is above the limit of the current wild fisheries' production quotas the immediate rewards leave margins in which to move during these pioneering days.

If abalone production lives up to its potential, a large volume of abalone will become available on the world market. In due course, this is likely to result in a drop in the value of abalone, in turn reducing profitability. However, in the interim, the businesses that are appropriately placed may well make hay while the sun shines.

Anemone fish

See 'Clown fish'.

Aquarium fishes

Production system	Ponds Aquariums Re-circulation systems
Broodstock/seedstock availability	Most stages purchasable
Temperature/water preferences	Wide range from tropical to cool temperate: freshwater through to full marine water
Current market status/potential	Well-established domestic and international demand dependant on species
Sector status	Mature

Most people, when they think of aquaculture, generally think of growing fish for food, but there are other markets for fish, with perhaps the more economically viable being for aquarium fish. There are lots of reasons why aquarium fish aquaculture is a potential dollar earner: the value of fish depends on its visual attractiveness and/or its novelty so that there is not a great cost in feeding stock. Since most fish are sold small, they are young and it is not uncommon for fish to be ready for sale at three months of age. This is in contrast with an annual cycle required by a lot of food finfish and maybe as much as a three-year growing cycle for species such as abalone. Short growth times means good cash flow.

One problem with aquarium fish is the relatively small quantities in demand. Economies of scale in production are hard to achieve when you can only sell in small lots. On the other hand, this means that a small owner-operator can secure a slot in the marketplace. Many viable aquarium fish businesses have been run from a double car garage. The key is selecting the right species: ideally something not available from the efficient (read that as 'cheap') producers overseas. It should be something easy for you to breed, but difficult for competitors. Selecting a fish that is an Australian native is not necessarily an advantage, as once competitors overseas can get one male and one female, they become competition.

Some aquarium species have pest potential. They may eventually be able to escape into native waterways. In an attempt to prevent this, state governments have prohibited possession of some species. Check with your local fisheries agency to see if the species of your choice is legal.

Arrowana

Production system	Aquarium (re-circulation systems)
Broodstock/seedstock availability	Limited availability depending on local law
Temperature/water preferences	Tropical fresh water
Current market status/potential	Some international demand, potential volume limited
Sector status	Check legality

In Asia, there are species of fish referred to as 'Lucky fish' as they are reputed to bring luck if you keep one in a pool or aquarium at your house or business. If one of those species is gold in colour, it is luckier still. A high quality lucky fish will bring a very, very, good price. In the Americas and Asia, the group of fish are called arrowana. In Australia, we have several species that might fit the description, and they are commonly called saratoga. (See section on 'Saratoga' for more information.) If somebody could breed a line of gold-coloured saratoga, they would be likely to make a fair return on the progeny, that is, before somebody else got hold of one and bred their own.

Artemia

See 'Brine shrimp'.

Asses ear abalone

See 'Tropical abalone'.

Atlantic salmon

Production system	Marine finfish sea cage Freshwater flow-through
Broodstock/seedstock availability	Most life stages available
Temperature/water preferences	Cold water: fresh or marine water
Current market status/potential	Established domestic and international demand
Sector status	Mature

Atlantic salmon (*Salmo salar*) is a native of the higher latitudes of the Northern Hemisphere and were initially introduced into Australia to provide recreational fishing, and then were used for farming. They can be farmed in both fresh and seawater, although freshwater is utilised for breeding and early rearing.

Adult Atlantic salmon can be grown-out in freshwater using traditional inland trout farming technology, that is, in raceways. However, their big success has been in sea-cage farming in protected seawater areas, particularly in Tasmania.

The success in Tasmania followed successes in other parts of the world. For a while, the Australian farming sector managed to remain isolated from competition from other parts of the world. It flourished in an insulated market environment while overseas producers became more and more efficient. Eventually the ongoing trend to globalisation had its impact and Australian suppliers of Atlantic salmon have found it increasingly difficult to compete in a softening global market. At the time of writing the Tasmanian salmon industry was undergoing rationalisation to bring its cost of production into line with the world industry.

Australian bass

Production system	Pond
Broodstock/seedstock availability	Fry occasionally available
Temperature/water preferences	Warm water: fresh through to marine water
Current market status/potential	Relatively unknown as food fish – demand limited to seedstock sales for recreational stocking
Sector status	Pilot

Australian bass (*Macquaria novemaculeata*) is a close relative to golden perch, but has much greater salinity tolerance.

They are a skittish fish, prone to hiding, and making wild runs for freedom if they feel there is a threat around. These characteristics make bass a sought after fish by fly fishers, who regard them as a worthy quarry.

Bass have been bred in captivity and do not present any particular challenges in this area. The market for bass flesh is not strong, so the main application of the technology is to produce young for stocking into private or public waters, with the hope it will boost stocks and enhance fishing.

Australian salmon

Production system	Marine finfish sea cage
Broodstock/seedstock availability	Not available
Temperature/water preferences	Cold marine water
Current market status/potential	Niche demand within Australasia. Used as crayfish bait
Sector status	Undeveloped

Australian salmon (*Arripis trutta*) is a marine species not at all related to salmonids. (See section on 'Salmonids' for more information.) Australian salmon can grow to be big and they are silver, sometimes with spots. In this respect the native species resembles salmon, hence the name. Another name for this species is 'bay trout', so it would seem that a range of people thought it to resemble some kind of salmonid at least.

A species closely related to Australian salmon is the Tommy rough (or ruff), and while this species resembles Australian salmon, nobody has tried to name it after a Northern Hemisphere fish.

To the best of the authors' knowledge, nobody has attempted to farm Australian salmon. Most likely its value in the marketplace is too poor to stimulate interest.

Balmain bug

See ‘Bugs’.

Banana prawns

Production system	Land-based mariculture
Broodstock/seedstock availability	Poor
Temperature/water preferences	Tropical: brackish to marine
Current market status/potential	Established domestic and international demand
Sector status	Pilot

Banana prawns (*Fennerpenaeus indicus* and *F. merguinsis*) are prawns native to Australia that are finding increasing use in aquaculture. As the name suggests, they are yellowish in colour (uncooked that is) and they do not have much in the way of stripes or bands.

Banana prawns have been successfully farmed in Australia. In fact, the life cycle of *F. indicus* has been closed in captivity, so that farmers of this species have potentially fewer problems in locating good genetic lines, and disease-free stocks of post-larvae. Another reputed advantage is that they require a lower protein level in their food. They are also said to feed up in the water column, making better use of the natural resources of a pond.

Low water exchange approaches to prawn farming, such as the ‘Belize system’ have been developed using prawn species with more in common with banana prawns than with black tiger prawns. It may be that banana prawns will do better in these systems.

Banded morwong

Production system	Marine finfish sea cage Re-circulation systems
Broodstock/seedstock availability	Not available
Temperature/water preferences	Cold marine water
Current market status/potential	Demand limiting domestic to live fish
Sector status	Undeveloped

Banded morwong (*Cheilodactylus spectabilus*) is not an aquaculture species in the sense that the life cycle has been closed in captivity, or that they are on-grown or feedlotted, but the species is widely utilised in the live fish trade. They are sold mainly into the Asian restaurant market.

In the wild, the species is found on the east coast of southern Australia, and while it can be found as far north as central New South Wales (one of the authors has fond memories of his youth going on spear-fishing expeditions chasing banded morwong in New South Wales) an important component of supply comes from Tasmania. During transport to market, skill has to be applied to ensure water quality and fish health are maintained.

Neither of the authors are aware of any attempts to farm banded morwongs. One of the authors has kept banded morwong in a fish tank, where they seemed amenable to captivity. Data from the wild fishery suggests that many of the harvested fish are quite old, but the growth rates seen in the fish tank seemed reasonable enough.

Barramundi

Production system	Sea cage Freshwater pond Land-based mariculture
Broodstock/seedstock availability	Good for all stages
Temperature/water preferences	Tropical: fresh through to marine
Current market status/potential	Established domestic and international demand
Sector status	Mature

Barramundi (*Lates calcarifer*) is a tropical finfish that can survive in both fresh and seawater. They breed in salt water, the juveniles go inland to freshwater. The species start initially as males. As they grow larger, the males turn into females. After the barramundi reach almost a metre long, and with the right flood stimuli, they move down to the sea. As a general rule, 'sea' barramundi are silver in colour, and 'inland' barramundi are black in colour, but this probably has more to do with the colour of their surroundings rather than the salinity.

Their hardiness, ambivalence about salinity, the availability of seedstock and the market demand have made barramundi popular for a variety of on-growing technologies. Barramundi are grown in earthen dams filled with freshwater, in re-circulation systems and in sea cages. Plate-sized barramundi, grown under optimal tropical conditions, commonly take a little more than six months to grow and offer good potential for cash flow. However, there are strong indications that the plate-size market is well and truly saturated, and there is a trend to on-grow barramundi to the 3 kg size, which takes a little less than about a year and a half, but opens the huge fillet market to the species. Often referred to by growers as being bulletproof, they have become the species of choice of the live fish distributors and consequently the darlings of the re-circulation sector.

Crystal-gazing future developments is always a risky task, but given the economies of scale achievable with sea cages, and with the market preference for barramundi grown in the sea, it would seem probable that a big growth in future production of barramundi will come from low production cost sea cages.

Barramundi cod

Production system	Sea cage Land-based mariculture
Broodstock/seedstock availability	Not available at any stage
Temperature/water preferences	Tropical: marine water
Current market status/potential	Established demand, particularly international, for live produce
Sector status	Conceptual

Barramundi cod (*Cromileptes altivelis*) is an attractive marine finfish, naturally found in clear tropical reef areas. In south-east Asia it is highly sought after in the live fish trade, where it is sometimes named 'hump-back grouper'.

The name used in Australia is a bit of a misnomer as it is not related to barramundi at all and is more closely related to the tropical snappers. It probably got the name from the fact that it has a solid shoulder and rear body, but the head is short, leading to the term 'hump-back' used in Asia.

The high demand and the fact that barramundi cod is sold in the live trade offers good prospects for the farming of this species. However, at this time, there is no reliable supply of juveniles to support a grow-out industry. Research is being undertaken in northern Australia with a view to developing hatchery technology to a 'cookbook recipe' stage. It would seem probable this will be achieved within several years. The situation is different in Indonesia, where juveniles are produced on a regular basis, and many are sold for grow-out. In the good tropical climate available there, it is reputed to take between 12 and 14 months before the fingerlings can be grown to a size of 500 g.

Given the predilection of wild barramundi cod for good quality marine waters, it would seem most likely that the best chances for farming success would lie with cage culture in marine waters, but at current values the cost of establishing an on-shore flow-through system is a feasible grow-out alternative.

Some areas may present difficulties for the culture of barramundi cod. At the Darwin Aquaculture Centre in the NT, adult barramundi cod get infestations of gut worms, which leave scarring in the intestine, limiting the fish's ability to assimilate food. Barramundi cod have a patchy distribution throughout the tropics, and it is possible that some areas may be infested by these worms, thus limiting the species habitat options.

Bay lobster

Bay lobster is the marketing name applied to decapod crustaceans otherwise known as 'bugs'. See section on 'Bugs'.

Beche-de-mer

See 'Trepang'.

Biomass

Production system	Unknown
Broodstock/seedstock availability	Unknown
Temperature/water preferences	Unknown
Current market status/potential	Unknown
Sector status	Conceptual

Biomass is a 1970s and 1980s sort of idea. When the oil crises were occurring in those decades, lots of alternative fuels were investigated. Methane was one. Methane could be reticulated and distributed like LP gas. It could be used for anything from running cars to heating houses. More importantly, methane could be obtained from rotting vegetation. The logic went that if enough cheap vegetation could be purposely rotted and the methane collected, the fuel shortage could be alleviated. This presented the problem of where to get the vegetation to rot. People familiar with the California coastline in the US knew that the giant kelp (*Macrocystis* spp.) grew faster than just about anything else in the world. It had also been harvested considerably over the previous century without too much ecological damage (though perhaps that could be debated). Schemes were put forward to farm the kelp and harvest it to be used as biomass. One idea was to create deep-water rope structures, and seed the ropes with spores from the kelp: it never really eventuated.

A similar idea involved producing alcohol by fermenting biomass. The alcohol would be used as a fuel, and is more immediately adaptable to engines built to run on petrol.

The biomass idea was appealing, but obviously not so appealing as to become a commercial reality. Still, times change and so do price structures. Farming kelp for biomass may become commercially viable some time in the future.

However, the concept has potential and any seaweed that has a use and can be been grown efficiently could be produced as a raw material source for industry, whether it is for pharmaceutical extracts, feeding abalone or as raw material for fertiliser.

Black bream

Production system	Sea cage Land-based mariculture
Broodstock/seedstock availability	Limited availability of larvae
Temperature/water preferences	Cold water; freshwater through to marine
Current market status/potential	Niche domestic demand
Sector status	Pilot

In Australian aquaculture, the name 'black bream' is given to two separate categories of finfish. The first category includes temperate estuarine/marine species of the genus *Acanthopagrus* (most likely of the species *butcheri*, but maybe also *berda*) that are related to pink snapper and tarwhine. See the section on 'Bream' for more information. The second species known by the same name is the sooty grunter (*Hephaestus fuliginosus*) a freshwater tropical finfish. For more information on sooty grunters, see section on 'Sooty grunter'.

Black bream, and related species have been subject to some degree of research and hatchery technology has been proven. Overseas, similar species are successfully farmed. The species would appear to be suited to sea cage farming. However, black bream appear to be relatively slow growing and do not have the market value of their cousins, the pink snapper. (See section on 'Pink snapper'.) If you are going to go to all the trouble of farming bream species, it may well be better to farm pink snapper instead.

Black mussels

See 'Blue mussels'.

Black tiger prawn

Production system	Land-based mariculture
Broodstock/seedstock availability	Larvae and post-larvae available
Temperature/water preferences	Tropical to subtropical marine/brackish water
Current market status/potential	Established domestic and international commodity demand
Sector status	Mature

The main prawn species farmed in Australia is *Penaeus monodon*. It goes by a variety of common names: the leader prawn, black tiger prawn and brown tiger prawn. The name 'tiger prawn' is more or less general and it means that the animal has a pattern of vertical bands.

Black tiger prawns naturally spawn at sea and spend the juvenile part of their lives in coastal swampy areas. They grow fastest in salinities less than that of sea water, so that in many locations, farmers need a plentiful source of freshwater to shandy the farm ponds, during this stage, especially where it coincides with the dry season.

At the time of writing, the life cycle of black tiger prawns has not been closed in captivity: not in commercial terms at least. Gravid brood prawns ('spawners' or 'mother prawns') have to be caught from the wild. This supply is not always reliable and causes some problems for the aquaculture industry.

Site access is also a problem for the industry. The industry developed along the eastern seaboard, but as these regions have become prime real estate prawning has had to compete with NIMBYs. Proximity to the Great Barrier Reef has fuelled the efforts of conservationists who have identified aquaculture as a soft target for their cause.

Prawns are highly regarded domestically and internationally, but the local market comes under pressure from imported produce and the cost of production is one factor impacting on industry growth.

Up until the end of the last century, almost all the black tiger mother prawns were caught in Queensland. However, new areas are being identified where brood prawns can be acquired: sources of supply are being identified in the Top End and the Kimberley. Given access to suitable sites, it's possible that the centre of the Australian prawn industry could shift to these less contentious regions.

Blacklip abalone

Production system	Land-based mariculture Ranching
Broodstock/seedstock availability	Technology available Stock availability growing
Temperature/water preferences	Cold oceanic water
Current market status/potential	Established international demand: niche domestic demand
Sector status	Developing

Blacklip abalone (*Haliotis rubra*) is found on the south-eastern parts of the Australian continent and Tasmania. It is the most common abalone species found in these areas and form the basis of the commercial abalone fishery. (See the section on 'Abalone' for general information on the aquaculture of these species.)

The surface of the shell, when not covered with weeds or sponge is reddish (hence the scientific species name '*rubra*'). Compared to some other species of abalone, the outer surface of the shell is roughish.

Blacklip abalone generally have a strongly pigmented skin (hence the name 'blacklip'). The black colour makes it a little more difficult to see the underlying gonads, and therefore makes it harder to determine the sex of a mature abalone. The colour may also be a minor disadvantage in the marketplace, although most methods of processing remove the outer layer leaving the white underlying flesh.

Because these abalone are comparatively common, it is relatively easy to obtain access to wild brood stock, although fisheries permits are usually required to do it legally.

Blacklip are one of the larger Australian abalone, and the total body size to marketable flesh ratio is good. They reach sexual maturity somewhere around 8 cm across the shell. Most of the aquaculture abalone are about this size when harvested, this makes them clearly distinguishable from wild fishery produce, which is usually subject to minimum legal sizes somewhere around the 10–13 cm mark. The shell colour of aquaculture abalone is clearly different too.

Blacklip abalone have a proven slot in the marketplace, minimising uncertainty in farming them. They have also been proven performers when it comes to rearing them in captivity.

Blacklip oysters

Production system	Inter-tidal mariculture
Broodstock/seedstock availability	Limited
Temperature/water preferences	Tropical
Current market status/potential	Niche domestic demand
Sector status	Pilot

Blacklip oysters (*Saccostrea echinata* and *S. tuberculata*), sometimes known as 'mangrove oysters' are a tropical species of cupped oyster. (See sections on 'Oysters' and 'Cupped oysters' for more general information on this group of bivalves.) Blacklip oysters get their common name from having a black perimeter around the open shell. They can grow to quite a large size, maybe 12 cm across the shell.

In the wild, blacklip oysters are found on the roots of mangroves, or on rocky outcrops in the lower range of the inter-tidal zone.

In the tropics, the annual weather pattern is wet season/dry season. Over the dry season, the oyster gonads mature. With the onset of the wet, spawning is stimulated. As is common in cupped oysters, fertilisation is external, that is the shed eggs and sperm meet and fuse in the open water. The larvae float for a while, then settle in a sheltered area with a suitable bottom where they take up the typical fixed oyster lifestyle.

Blacklip oysters are farmed in Queensland, and if problems with quality assurance can be satisfactorily addressed, it may be possible to farm them in other parts of tropical Australia. Areas without human habitation in the catchment may have an advantage when it comes to obtaining accreditation. It is possible to speculate that in remote communities, the technology used in the early days of the New South Wales Sydney rock oyster might be applied, that is, harvesting spat as it settles onto rock or some other readily available substratum.

Blue mussels

Production system	Marine long-line
Broodstock/seedstock availability	Good – growers catch their own larvae
Temperature/water preferences	Cold to cool temperate water
Current market status/potential	Established international and domestic demand
Sector status	Mature

In Australia, all the native marine mussels are blue in colour. Sometimes this blue is so dark they are referred to as 'black mussels'. Only one species, *Mytilus edulis*, is farmed. The other species tend to be smaller, and less suited to domestication generally.

See the section on 'Marine mussels' for more information on growing and marketing.

Blue swimmer crab

Production system	Unknown
Broodstock/seedstock availability	Not available
Temperature/water preferences	Cool water
Current market status/potential	Established domestic demand
Sector status	Experimental

Around Australia there are fisheries based on blue swimmer crabs (*Portunis* spp). Similar species are also sought for food elsewhere in the world. Because of the pre-existing market, people are interested in the aquaculture of blue swimmer crabs. Research into hatchery and nursery technology has been undertaken in Queensland. However, at the time of writing, these crabs fall into the 'potential' category.

If a supply of blue swimmer seedstock becomes available, the next question to resolve will be the best method of farming them. Farming them near sandy bottomed coastal areas would seem to create a conflict with recreational beach users. It might be speculated that they could be grown using the same technology as prawns, that is, in prawn farms. The first consideration of persons owning such ponds would be to determine if farming crabs was more profitable and no more risky than growing prawns, and then they would decide which crop to grow. At this stage, the answer is a matter for speculation.

Blue throat wrasse

See 'Temperate wrasses'.

Bluefin tuna

See 'Southern bluefin tuna'.

Bluff oyster

Production system	None
Broodstock/seedstock availability	None
Temperature/water preferences	Cold water
Current market status/potential	Established international and domestic demand
Sector status	Illegal in Australia

Bluff oysters are a flat oyster found in the seas off the southern part of New Zealand. (See sections on 'Oysters' and 'Flat oysters' for more general information on this group of bivalves.) They are not-too-distantly related to Australian native flat oysters. As with their Australian cousins, bluff oysters are subject to plagues of *Bonamiasis*, and periodically undergo population crashes. Bluff oyster production is primarily a wild fishery, and there is little farming of this species.

Bream

Bream is one of those nebulous names that apply to a variety of fishes: not all closely related. Perhaps the most common use is the one applied in the southern half of the country where the name 'bream' is applied to members of the family Sparidae (sometimes referred to as 'porgies' in the USA). This family also includes the much sought after southern pink snapper. In the north of the continent, people do things differently (sometimes as a matter of principle) and in the Kimberley and the Top End, the term 'black bream' is also applied to the freshwater sooty grunter. This is despite the fact that at least one member of the family Sparidae are also found in the estuaries there, and it is also often called 'black bream'. To further confuse the issue, the freshwater silver perch is also referred to as 'bream', or 'black bream'.

For more detailed information on each of these species, see the sections on 'Black bream', 'Silver bream', 'Pink snapper', 'Tarwhine' and 'Sooty grunters'.

Brine shrimp

Production system	Land-based mariculture
Broodstock/seedstock availability	Available
Temperature/water preferences	Cold to tropical
Current market status/potential	Established international and niche domestic demand
Sector status	Experimental

There are two common kinds of brine shrimp found in Australia. There is the exotic *Artemia* and the indigenous *Parartemia*.

As the name 'brine shrimp' suggests, both these species live in salt lakes and do well in the hyper-saline water. They are common in the evaporation ponds of saltworks. Few other animals can live in these waters, so the brine shrimp have the ponds to themselves to browse on all the natural products in the lakes. Large standing crops of brine shrimp monocultures can be obtained.

Artemia are well known to most aquaculturists. They form the basis for most feed fed to developing larvae in indoor hatcheries and nurseries and have wide use in the ornamental sector. At times the reproductive effort of this species is directed at producing eggs in protective cysts. These eggs float to the lee shore and are collected, vacuum packed for distribution around the world. The main suppliers draw their supplies from the Great Salt Lakes in Utah and they have a reputation for quality. However, adverse seasonal conditions can decimate the carefully managed harvest and local distributors carry large reserves to cover these eventualities. This could become a market opportunity for an Australian producer, but you would need to explore the markets and establish production methods thoroughly.

Parartemia are not as well known as they do not produce cysts in the same way and are nowhere as convenient to handle.

Very few humans would consider eating brine shrimp (except maybe for a bet after a few beers), but the nutrient value of the shrimps warrants them being explored as the possible raw materials for a processed meal in animal diets.

Brook trout

Production system	Flow-through freshwater
Broodstock/seedstock availability	Fingerlings sometimes available
Temperature/water preferences	Cold water
Current market status/potential	Non-existent
Sector status	No commercial industry

Brook trout were brought into Australia as part of the 'acclimatisation movement'. It was thought at the time they might make a beneficial addition to fish and wildlife found in this country. Attitudes have changed a lot since then. Nowadays people worry about non-indigenous species going feral.

The reason it was thought that brook trout might be beneficial was to improve recreational angling. Like the other species of trout, they like cool running water, and can only live in cool/temperate climates. Brook trout have an attractive enough pattern and can be bred in captivity. Some stocks of brook trout were held in Tasmania, and may still be found there.

Brown trout

Production system	Freshwater flow-through or aerated ponds
Broodstock/seedstock availability	Good
Temperature/water preferences	Cold water
Current market status/potential	Limited – boutique market
Sector status	Limited sales for stocking angling waters

Brown trout (*Salmo trutta*) was imported into Australia by the acclimatisation movement to provide angling. Stocks are maintained in some government and private hatcheries.

Brown trout do not appear to be as hardy as other trout species in Australia. Some anglers contend that the sporting characteristics of brown trout are superior to those of other salmonid species. There would seem to be a small spot in the marketplace to supply brown trout (either as adults or as fingerlings) for stocking of angling waters, but other than that, there's not much aquaculture potential for this species.

Brownlip abalone

Production system	Land-based mariculture Ranching
Broodstock/seedstock availability	Technology established Stock availability poor
Temperature/water preferences	Cold water
Current market status/potential	Established international demand
Sector status	Developing

Brownlip abalone (*H. conicopora*) naturally occur on the south-western coast of Australia, where they seem to occur in more or less the same niche as blacklip do on the eastern side of the continent. Brownlip look very similar to blacklip, and there is some speculation that they are really the same species, but varying a little as the population has strung out across the Great Australian Bight. Much of what has been written about blacklip abalone applies to brownlip, so see the sections on 'Blacklip abalone' and 'Abalone' for more information.

Bugs

Production system	Land-based mariculture Re-circulation systems
Broodstock/seedstock availability	Poor
Temperature/water preferences	Temperate
Current market status/potential	Established domestic demand
Sector status	Experimental

In the broader scheme of things, bugs are a decapod crustacean not-too-distantly related to lobsters. They are a species in the genus *Thenus*. Bugs look something like a lobster that has been flattened under a steamroller – minus the antennae.

Sometimes the location of the bugs' habitat is added to their names, hence the names 'Morton Bay bug' and 'Balmain bug'. In recent years, in what is probably an attempt to make their name more attractive to purchasers, this group has been referred to as 'bay lobster'.

The life cycle of bugs has a lot in common with the more conventional lobster.

Females spawn in summer and the resulting larvae (phyllosoma) float on the currents for about four weeks (much shorter than for rock lobsters). After a series of moults, their body form starts to resemble that of an adult, and they settle out, to take up residence on and in sandy and/or muddy areas of seabed. Their flattened shape allows them to bury themselves. Their maximum size is somewhere between 250 g and 750 g. They are reputed to grow to market size in about a year.

In years gone by, bugs were taken as by-catch from trawlers, which typically were seeking prawn or scallop. Their flesh was every bit as good as that of lobsters, but people weren't used to purchasing them. In those days, prices were low, especially compared to those for lobster. One of the authors remembers seeing boxes of bugs in an out of the way corner of the Melbourne Fish Market in the 1970s going for a song. However, since then, the seafood-purchasing public has grown increasingly sophisticated and the difference in prices has reduced. Bugs are not cheap any more.

There has been some research into the aquaculture of bugs, and some of the results are quite positive, but only time will tell if a full-blown farming industry based on bugs will appear.

Carp

Production system	Freshwater pond
Broodstock/seedstock availability	Noxious in some states
Temperature/water preferences	Wide range
Current market status/potential	Niche domestic demand at the lower end of the scale
Sector status	Check for legality in your state

Common carp (*Cyprinus carpio*) is a hardy fish that has been selectively bred for aquaculture and can do well in a wide variety of water conditions. The species appears to have originated in Europe and Asia. This hardiness has meant it has been adopted for aquaculture in Europe and Asia.

However, in Australia, carp is not widely accepted. There is considerable prejudice against the fish for the havoc it has caused to native fish habitat and for the particular flavour and smell it possesses. With growing migrant populations from inland Europe and eastern Asia, the carp has a growing following, but even in its homeland it is regarded as a cheap fish. It's widely used as crayfish bait and as raw material for fish-based fertilisers but it still only brings relatively low prices.

There are significant feral populations in the wild and supply seems to keep pace with demand, although the price has started to rise during the 1990s. It is cheap to grow, however, it is a noxious species in many states and farming may not be legally permitted.

Catfish

Production system	Freshwater pond
Broodstock/seedstock availability	Available
Temperature/water preferences	Warm water

Current market status/potential	Very small domestic interest at the lower end of the seafood market. Main interest as a recreational species for farm dam stocking
Sector status	Mature, but small

There are very many species of catfish. They comprise a diverse collection of fishes, many without scales and many characterised by having a second fleshy fin on their back. The overwhelming feature that draws the catfishes together is the presence of long feelers around the mouth, hence their common name.

Generally catfish are not considered to be high value species. Their flesh, by itself, can be white and sweet, and is generally acceptable to the widest cross-section of fish consumers, but the low fillet recovery makes it an unattractive commercial proposition but it has a small following from south-east Asian cuisine.

The flesh however is highly regarded by recreational anglers and the silver cobbler of WA (*Arius midgleyi*) has a strong following in that state, especially the species coming from Lake Argyle in the Kimberley.

Australia has many tens of species of catfish, most from freshwater but there are a few marine species as well. Over the years, most aquaculture interest has focused on *Tandanus tandanus*, a native of the Murray–Darling basin and the warm temperate to tropical reaches of the east coast. This is a scaleless catfish, coloured from yellowy to dark brown. Its tail fin is not forked, resulting in the common name of 'eel tail catfish'. Despite interest over the years, and several attempts, aquaculture for food has never really been developed, but a small market has evolved for stocking of farm dams to provide recreational fishing or subsistence food.

In the southern USA there is a very large inland aquaculture industry based on channel catfish (*Ictalurus punctatus*). Even the most cynical of observers would have to acknowledge its success. It has often been suggested that this success could be translated to Australia, since similar economic and climatic conditions can be found in this country. However, three key factors are not present in Australia: we do not have the same catfish species (and effectively cannot import it), the huge supplies of cheap water found in the Mississippi Delta are not found here, and there is no pre-existing domestic demand for catfish.

Cherubin

Production system	Freshwater pond
Broodstock/seedstock availability	Poor
Temperature/water preferences	Tropical
Current market status/potential	Established internationally as a seafood species but markets not developed in Australia
Sector status	No industry in Australia

Cherubin (*Macrobrachium* spp.) are freshwater prawns found in northern Australia. The live product looks good. They are large with a more or less transparent body. They have very long claws with sharp little pincers (which seem to be able to search out and crimp the soft skin beside the fingernail regardless of how they are held).

Cherubin have a complex social order potentially influencing the speed at which individuals will grow, with implications for the time or density that can be used to grow a commercial crop. Their life cycle is also complex and even though most of their lives they can live in freshwater, they need a degree of salinity to breed. Hatchery technology has been worked out and proven, but producing seed is not something that can be easily done on the average farm.

Macrobrachium species closely related to those found in Australia have been successfully farmed in the tropics of the Indo-Pacific region, although this has never been regarded as a highly lucrative form of aquaculture. Despite several high profile attempts, no real economic successes have been demonstrated in Australia.

Chinook salmon

Production system	Freshwater flow-through Land-based mariculture Marine finfish sea cage
Broodstock/seedstock availability	Available
Temperature/water preferences	Cold water
Current market status/potential	Niche demand
Sector status	No commercial industry

Chinook salmon (*Oncorhynchus* sp.) are a large silvery salmonid, initially brought into Australia for stocking of native waterways for angling. They never really managed to establish self-sustaining populations. It was speculated that when the time came for the fish to go to sea (as part of their natural life cycle), they did, but instead of hanging around the local coastline, their in-built response to the local currents stimulated them to go elsewhere (perhaps back to North America to see the relatives?). Anyway, stocks were maintained in government hatcheries, which stocked enclosed waters with this species.

In the last couple of decades of the last century, the successes of Atlantic salmon farming in Tasmania spurred research into the commercial potential of Chinook salmon, and considerable effort was directed to this end. In any event, commercialisation never occurred. Salmon farming is now such a competitive business, and profit margins are so fine, that it would seem even less likely that Chinook salmon could find a place in the contemporary industry. It would be difficult to distinguish Chinook salmon from Atlantic salmon in the marketplace.

Clams

Production system	Inter-tidal shellfish mariculture Subtidal shellfish mariculture
Broodstock/seedstock availability	Not available
Temperature/water preferences	Varied according to species
Current market status/potential	Established international and niche domestic demands
Sector status	Pilot

The name 'clams', like the term 'shrimp' has different meanings in different places. In America, clams are just about any bivalve shellfish that lives in sand or mud, and the name more or less corresponds to the terms 'cockles' and 'pipis' in Australia.

In Australian aquaculture, the name 'clams' is more commonly applied to the tropical 'giant clams' that grow to very large sizes. For more information on these species, see the section on 'Giant clams'.

Clown fish

Production system	Marine intensive re-circulating systems
Broodstock/seedstock availability	Broodstock may be purchased in retail aquaria
Temperature/water preferences	Tropical
Current market status/potential	Reasonable demand for quality cultivars
Sector status	Developmental

Clown fish, or anemone fish, are small marine finfish of the genera *Amphiprion* and *Premnas*. As the second common name suggests, they often take up abode in sea anemones, where they are immune to stings that normally kill other species of fish. This is a novelty feature and they are sought after as an aquarium fish. Clown fish are a small attractive fish, sometimes red and white, sometimes black and white.

The breeding of these fish involves the formation of male/female pairs, then the laying down of adhesive eggs on a clean substratum. An anemone is generally used in the wild but is not a necessary component of the process. When the young hatch, they float in the water but they are not as small as many marine species and can be fed on rotifers. In common with a lot of other aquarium species, it takes months, rather than years, before the clown fish are at a size sought in the marketplace.

Anemone fish are found in seas off many countries other than Australia. Competing in the export market with fish sourced from these places can be difficult unless a market edge is found. In some places in Australia, unique variations are found, for example, a local variant is black and white rather than red and white as is found elsewhere. In this case, the novelty accruing to the fish makes it more profitable to sell (till somebody overseas starts to breed them of course).

Cobia

Production system	Sea cage
Broodstock/seedstock availability	Not available
Temperature/water preferences	Tropical
Current market status/potential	Poorly established but possible international demand
Sector status	Experimental

Cobia, sometimes known as 'black kingfish' (*Rachycentron canadus*) is a species of marine finfish found in tropical waters in Australia and in other places around the world.

Cobia are farmed in Asia, where they have been shown to be amenable to domestication and to sell as a high value product. Interest has been shown in adopting this species in Australia, perhaps as an alternative crop to barramundi in tropical sea-cage culture.

Copepods

Production system	Re-circulations systems; open ponds
Broodstock/seedstock availability	Not commercially available
Temperature/water preferences	Varies according to species
Current market status/potential	Limited to aquaculture food
Sector status	Experimental/developmental

In aquaculture, many species require live feed. When the farmed species are at the larval stage, the live food has be well and truly small enough to fit in their mouths, or they don't eat. For a long time, fish larvae were fed on brine shrimp larvae or rotifers. This worked OK for some fish, but not for all, in particular the marine snappers and groupers. To successfully farm these species, a smaller source of food had to be found, so attention turned to copepods.

Research has shown that copepods can be successfully cultured and used as a live food, in particular species in the genus *Acartia*. It is a highly technical and labour intensive process with a limited market.

Coral and related invertebrates

Production system	Re-circulation systems Ranching
Broodstock/seedstock availability	Not available
Temperature/water preferences	Tropical
Current market status/potential	Good
Sector status	Experimental

The aquarium trade has a steady demand for corals and related animals such as corallimorphs and anemones. As in other kinds of wild fisheries, conservation interests are limiting supply by strictly controlling access to wild stocks. Demand is not gigantic but steadily increasing.

Techniques for breeding corals have been developed, albeit at an early stage. Some species grow fast whilst some are likely to grow too slowly to be economical to produce. Which of these is in the most demand in the marketplace has yet to be determined.

The volume of this trade is probably insufficient to justify the involvement of corporate aquaculture, but there may well be sufficient returns to make it worthwhile for a suitably placed owner-operator to become involved.

Coral lobsters

Production system	Land-based mariculture Flow-through systems
Broodstock/seedstock availability	Not available
Temperature/water preferences	Tropical
Current market status/potential	Well established domestic and international demand
Sector status	Experimental

In the tropics, some lobsters live in coral. It's only a small step for people to start calling them 'coral lobsters'. As a group, there is little to distinguish these lobsters from rock lobsters, except that they live in warmer reefs. See the section entitled 'Lobsters' for more information. The term 'coral lobster' is more or less interchangeable with the term 'painted lobster'.

Coral trout

Production system	Sea cage Land-based mariculture Re-circulation systems
Broodstock/seedstock availability	Not commercially available
Temperature/water preferences	Tropical
Current market status/potential	Established domestic and international demand
Sector status	Experimental

Coral trout are species of tropical marine finfish in the genus *Plectropomus*. They are much sought in the Asian live fish trade and the high demand has ensured that lots of businesses are looking for additional sources of stock. There is a very high awareness of the potential of coral trout for aquaculture production.

At this time, the limitation on aquaculture would appear to be supply of juveniles. In Asia, broodstock has been successfully conditioned, and fertilisation has occurred following spawning. However, raising the larvae has proved a problem and survival percentages are low. One of the problems is that they have long spines that become entangled. They are difficult fish to work but their market appeal has ensured that people keep trying to raise them. Once the methodology has been established and has become freely available it is likely that the species will lose its market position.

Several high profile businesses, seeking investors, have claimed to be able to successfully produce coral trout. At the time of writing, none of these has been successful and some have failed spectacularly. This is not to suggest that a supply of coral trout juveniles will never become available, but more to warn caution of persons claiming to hold the 'secret' of producing coral trout.

Crabs

Production system	Flow-through land-based mariculture/ marine re-circulation systems
Broodstock/seedstock availability	Not commercially available
Temperature/water preferences	Cool temperate to tropical
Current market status/potential	Established domestic and international demand
Sector status	Experimental

A variety of crab species are being farmed, or show farming potential. The two most commonly touted for this prospect are mud crabs and blue swimmer crabs. See the sections on 'Mud crabs' and 'Blue swimmer crabs'.

Crabs taken from wild fisheries are often kept live. There is a big market demand for live crabs. Keeping them alive may, to some extent, involve aquaculture water quality management technologies, although mud crabs can be successfully stored out of water for many days.

There is interest in developing technology for crab farming, and developing it in a way that is appropriate for Australian conditions and Australian land ownership practices. Crab farming could provide an option whereby prawn farmers might diversify, reducing risk from market collapse or prawn-specific disease.

Crab breeding or crab grow-out has yet to become an established industry in Australia. It is occurring overseas. In Vietnam areas of mangroves are fenced off and stocked with small crabs (of a type Australians would call mud crabs). The crabs are taken care of, and when they reach a suitable size, they are harvested. It seems to work quite well under cost structures and land ownership arrangement in that country.

One opportunity that is offered from keeping crabs in captivity is the option to develop a supply of 'soft shell' crabs. These are crabs that have just shed their shells. The new shell is still soft, so that the entire crab can be eaten. Not only does this avoid wastage, but soft shell crabs are considered a delicacy and can command a higher price.

Crayfish

Production system	Static water ponds; flow-through ponds
Broodstock/seedstock availability	Good to nil dependent on species
Temperature/water preferences	Cool to warm water – depending on species
Current market status/potential	Established domestic and international demand
Sector status	Experimental to mature

'Crayfish' is the name applied to the species of clawed decapods that inhabit freshwater. There are other somewhat similar animals and it helps to get the names straight. Strictly speaking 'lobsters' live in the sea. In the Atlantic Ocean of the Northern Hemisphere there are 'clawed lobsters'. The marine beastie commonly called 'crayfish' in Australia is one of several species of 'spiny lobsters'. Since most people are familiar with those that live in the south (around rocky reefs) these species are often referred to as 'rock lobster' (see the relevant sections for more information).

To make things a little clearer in Australia, most people refer to crayfish as 'freshwater crayfish'.

There are three species of freshwater crayfish that have proved themselves to be suited to aquaculture: marron, redclaw and yabbies. For more information on these species, see the appropriately named sections.

If you want to farm crayfish, and have to make a decision, pick one of the big three and pick the one that occurs in the local area. In this way you get a species pre-adapted to local conditions, you don't risk introducing a foreign pest into local waterways and you are far less likely to fall foul of the law.

Other species sometimes proposed for aquaculture, even though they are far less suited to domestic life, are the giant Tasmanian crayfish, Murray crayfish and spiny crayfish. See the relevant sections on these for more information.

Freshwater crayfish farming has been around in Australia for several decades. It has perhaps not lived up the potential initially envisaged but it is possible to make a dollar from crayfish if you make a serious attempt and put in serious dollars as investment.

Crocodiles

Production system	Pond culture
Broodstock/seedstock availability	Limited to licensed egg collectors
Temperature/water preferences	Tropical
Current market status/potential	Niche international demand for skin and meat
Sector status	Mature

Including crocodiles in aquaculture may be stretching the definition a bit, but there is no doubt that there are successful businesses based on crocodile production that have stood the test of time. That many of these businesses are associated with poultry farms does not diminish the success, but might tell us something about the economics of feeding crocodiles.

Generally baby crocodiles are grown from eggs taken by licensed collectors from the wild. They are on-grown in captivity. Many crocodile farms have a tourism component, and this may generate a significant component of income.

The skins are the primary products for sale. While good money can be obtained for a first-grade skin, marketing crocodile skins internationally takes skill and takes place in a very competitive environment.

Cupped oysters

Production system	Inter-tidal shellfish mariculture Subtidal shellfish mariculture
Broodstock/seedstock availability	Available
Temperature/water preferences	Temperate/cold water/tropical
Current market status/potential	Established domestic demand
Sector status	Mature (for most species)

Cupped oysters, as a group, have earned their name by having a lower shell that is more or less cupped. This makes for a neat oyster, with a not too extensive shell, but containing a reasonable portion of edible meat. This is well accepted in the marketplace.

Cupped oysters have external fertilisation, that is, they expel sperm and eggs into the water column, where fertilisation takes place. The larvae float on the currents, growing until after some weeks, they find it time to settle out onto a hard surface and take up the mode of living of an adult oyster. When they first settle, they are termed 'spat'.

A fundamental part of being a cupped oyster is that you are stuck to the rock or whatever you are living on. If a threat appears, such as a predator or dose of poor quality water, you have one defence: close your shell and hope the threat has gone away when you open it. In the early days of aquaculture, the immobility of oysters was a key part of the farming process. Oysters were encouraged to settle on rocks, or later, on wooden sticks. The wooden sticks were translocated to the farm area and simplified handling oysters in bulk.

For more information on species of cupped oysters sometimes considered for farming in Australia see the sections on 'Oysters' 'Blacklip oysters', 'Milky oysters', 'Pacific oysters', and 'Sydney rock oysters'. There is also a western rock oyster.

There is another category of oyster which also has prospects for farming, and that is the flat oyster. See the relevant section on 'Flat oysters' for more information.

Daphnia

Production system	Pond-based systems
Broodstock/seedstock availability	Not commercially available
Temperature/water preferences	Warm water
Current market status/potential	Niche domestic demand in the ornamental and hatchery trade
Sector status	Pilot

Daphnia are small crustaceans found in freshwater ponds. They are somewhere in size between a just-detectable tiny dot and about three millimetres. Instead of using a tail to propel them, they move by flipping their antennae, producing a characteristic jerking motion. Most kids with a fascination with things living in freshwater will have seen them.

Daphnia make fine tucker for some species of finfish, especially natural predators that rely on movement to stimulate them to feed. Rather than collect *Daphnia* and then feed them to small fish (although this is sometimes done in the aquarium sector) the most common practice is to manage a pond: a 'plankton' pond, to produce *Daphnia* and similar animals. A dry pond is fertilised and then filled. First, algae grow, and then the things that feed on it, then the things that feed on them, and so on. In each step, the things doing the eating get to be bigger and bigger. About a couple of weeks after filling, *Daphnia* and similar things appear in numbers. Hopefully, the target crop of finfish was conceived just long enough before to have a mouth large enough to fit in a *Daphnia* at the time.

If you get enough *Daphnia*, you can process them as a raw material, for example, as a constituent of formulated foods or as a frozen block of feed that can be distributed through aquarium shops. There have been some attempts at harvesting this resource from sewerage farms but the authors aren't aware of anyone who has been commercially successful. Modern sewerage treatment methods have removed the type of settlement ponds conducive to *Daphnia* production from sewerage plants.

Dolphinfish

See Mahi mahi.

Dunaliella

Production system	Inland saline/hypersaline pond
Broodstock/seedstock availability	Not readily commercially available
Temperature/water preferences	Warm water
Current market status/potential	Established international demand
Sector status	Mature but not apparently profitable

The authors remember visiting a series of ponds in Victoria used to treat seawater to make salt. They were extensive areas where the sun evaporated the water leaving a progressively stronger solution of salt until a dry layer of white crystals could be seen. In the ponds nearing the end of the process, the shallow water had a distinctly orange cast. The colour was brought on by a bloom of a micro-alga called Dunaliella (*Dunaliella salina*).

It is possible to build a very similar system to commercially produce this alga. It is a prime source of beta-carotene and can be used as a natural organic colourant. In some places in the world, such farming has been undertaken.

It has been suggested that Australia has a lot of areas that have too much saline groundwater and plenty of sun: the needed ingredients for Dunaliella. We also have plenty of space and land is inexpensive. The next step is to suggest that we should be turning the problem of saline water into a resource. Despite the virtues of the suggestion, Dunaliella farms have yet to prove commercially viable in Australia. Like other forms of micro-algae farming, Dunaliella is low profit margin/large volume in nature. It needs a very significant investment, and at the time of writing, this investment has yet to be made. Still, there are possibilities for the future.

Eastern cod

See 'Murray cod'.

Eels

Production system	Ranching in inland waters; open ponds and re-circulation systems
Broodstock/seedstock availability	Larvae available
Temperature/water preferences	Cold water/temperate
Current market status/potential	Established domestic and international demand
Sector status	Mature

For many years on the east coast of Australia there have been fisheries based on longfin and shortfin eels. Young eels are translocated to wetlands allocated to licensed harvesters where they are allowed to grow naturally. Reliability of production was low, but this was balanced by very low costs. Both of these species belong to the genus *Anguilla*. Produce was sold into European and Asian markets, where the demand for eels has been steady. During the 1990s over-fishing around the world led to a steady decline in the availability of glass eels and prices increased. This sparked a market driven interest in farming them in Australia.

Re-circulation technology had been used to grow eels in Europe and the boom in prices saw several large re-circulation systems built specifically for eel production. When the seedstock equilibrium returned to the wild harvest of glass eels, the great eel boom collapsed and markets came back to normal. This tended to take the energy out of the Australian operations but there is renewed interest based on the fattening of adult eels as well as the grow-out from glass eel stocks, particularly the longfin eel which has a market following in Eastern Asia.

Flatfish

Production system	Re-circulation seawater systems Flow-through seawater
Broodstock/seedstock availability	Poor
Temperature/water preferences	Cold water
Current market status/potential	Established domestic and international demand.
Sector status	Experimental

'Flatfish' are a diverse group of fishes. They are characterised by living on their sides, and being so committed to this life-style that the eye from the lower side migrates to the upper side. These fishes occur all around the world, and in common with other such widespread and diverse groups, they go by a variety of names, including 'halibut', 'flounder' and 'soles'. In Australia we have 'left-eye flounders', 'right-eye flounders', 'large-tooth flounders', and 'soles'.

Tasmanian Fisheries scientists have established the guidelines to breed greenback flounder (*Rhombosolea tapirina*) but commercial development of the species seems to have stalled. To date they have been grown in costly on-shore facilities and it would appear that the ready availability of keenly priced fish taken from the wild fishery, as well as frozen imports, have made the production of flounder uneconomical.

Flat oysters

Production system	Subtidal mariculture
Broodstock/seedstock availability	Not commercially available
Temperature/water preferences	Cold water
Current market status/potential	Established domestic and international demands
Sector status	Experimental

As well as cupped oysters, Australia and New Zealand also have flat oysters. In the southern parts of Australia, the scientific name of the flat oyster is *Ostrea angasi*. These have considerable commercial potential. The flat oyster is known in France as the Belon oyster, in the UK as the Colchester oyster.

From time to time and in place to place, large densities of flat oysters have been found. In years gone by, flat oysters have formed the basis of significant dredge fisheries.

It is still possible to find them in large quantities. One of the authors recollects diving in a southern New South Wales estuary finding piles of flat oysters tens of centimetres deep. In other parts of southern Australia, there are many places termed 'Oyster Bay' or similar names, suggesting that at the time of naming, oysters (most likely flat oysters) were common. In other places and even if live oysters are no longer common, the seabed can be littered with shells, suggesting that once there were lots of flat oysters there (the San Remo Channel in Victoria is a good example). There must be a reason for the boom and bust populations.

In the latter decades of the last century, the Victorian government undertook considerable research into developing hatchery and fattening technology for flat oysters. Hatchery technology was successfully developed. Grow-out trials with oysters in cages and suspended from ropes were very encouraging, with very good growth rates being observed. The Government started to crank up a full-blown industry development program. Then some of the oysters started to die.

When the oyster sickness was diagnosed, it was found to be caused by a haplosporidian called *Bonamia*. It may be that the disease is a natural co-inhabitant with flat oysters, but it only expresses itself once populations reach a high enough density. This would explain the boom and bust nature of wild populations. This bug, or something very closely related, was responsible for the demise of the French Belon oyster industry and for wiping out whole areas of oyster farming in the USA.

Bonamia has a very high shock value: just mentioning the name can effectively traumatise an oyster farmer, and send them into shock. While it is possible to farm around this disease, the discovery provided an instant stigma, effectively dissuading any investment or further development of a flat oyster farming industry in Victoria. There is a lesson to be learned from this story: it is wise to investigate the disease status of a particular species before attempting to commercialise it.

Flounder

See 'Flatfish'.

Freshwater crayfish

See 'Crayfish'.

Freshwater mussels

Production system	Ranching in freshwater
Broodstock/seedstock availability	Not commercially available
Temperature/water preferences	Temperate to tropical
Current market status/potential	Nil demand for meat, Niche demand for pearls
Sector status	Experimental/developing

In the inland waters of Australia, there are various species of freshwater mussels. Cooked, the flesh of these mussels tastes like mud-flavoured rubber and it is bloody chewy, so there is little chance of a market as food.

However, the shells of freshwater mussels have a nacre on the inside and can be used for freshwater pearl production. This kind of aquaculture is an enormous industry in China, but there are only one or two freshwater mussel pearl farms in Australia, suggesting that this might not be a very profitable business. Certainly, freshwater pearls are considered to be inferior to marine pearls.

See the sections 'Marine mussels' and 'Pearl oysters' for more information on mussels and pearl production.

Giant clams

Production system	Subtidal shellfish mariculture
Broodstock/seedstock availability	Limited
Temperature/water preferences	Tropical
Current market status/potential	Established international demand
Sector status	Pilot

Giant clams (*Tridacna* spp.) are found in tropical marine areas. They grow to a large size and have the lurid reputation of trapping divers' feet and thus leading to drowning. Fortunately the reputation is less than completely true.

In some other places in the world, the term 'clam' has a more general meaning for shellfish. For more information, see the section on 'Clams'.

Hatchery technology for giant clams is not all that different from other species of bivalves such as oysters, and despite the need for fork-lifts to move around the brood stock, is more or less a cook-book recipe affair. The technology has been around for several decades.

At one time a brilliant future was predicted for giant clam farming. The market slot would appear to be there, as there was once a substantial commercial fishery for large clams, with the adductor muscles being the part kept, so there was apparently a demand for meats in Asia. The juveniles are attractive and can demand a high price in the aquarium trade. Giant clams grow fast. Unlike many species of bivalves, they are not dependent on floating algae for food, but contain natural algae (zooxanthellae) within the tissues around their lips. All you really have to do is put them out in the sun and protect them from predators and thieves. Despite this, farming did not take off.

It was found to be difficult to find a good site – the best were inside the Great Barrier Reef Marine Park Authority's boundaries, and while the managing body allows aquaculture, it does not look favourably on it. A few farms have dribbled along, but there has been no explosive growth in production.

Giant Tasmanian crayfish

Production system	Freshwater flow-through
Broodstock/seedstock availability	Not available
Temperature/water preferences	Cold water
Current market status/potential	Not established
Sector status	Forget this species

The giant Tasmanian crayfish (*Astacopsis gouldi*) is, as its name suggests, found in inland areas of Tasmania. It also grows to very large sizes, but grows very slowly, taking maybe a decade to get to a size that can be sold. Not a commercial species.

See the section on 'Crayfish' for more information on related species.

Goldband snapper

Production system	Marine finfish cage culture
Broodstock/seedstock availability	Not commercially available
Temperature/water preferences	Tropical
Current market status/potential	Established domestic and international demand
Sector status	Species with a possible future

Goldband snapper (*Pristipomoides* spp.) is a tropical reef fish. Around the Pacific Ocean, related species are found and they generally go by the same name.

All the goldband snapper species are regarded as a premium eating fish. One of the authors remembers paying a very high price in the Sydney Fish Market, but also deciding, when he got to eat the fish, that it was worth it! It had a light white flesh, that was very nicely complemented by breadcrumbing.

In Hawaii, the aquaculture of the local goldband snapper species is being investigated. Technology similar to that used for tropical snappers is being applied. If this is successful, one would imagine it would not be long before people in Australia became interested in this species.

Since goldband snapper are an offshore reef-inhabiting species, one would imagine that very good water quality would be most appropriate, leading to the probability of them being grown in sea cages rather than ponds.

Golden perch

Production system	Static freshwater ponds
Broodstock/seedstock availability	Available at all stages
Temperature/water preferences	Warm water
Current market status/potential	Niche domestic demand
Sector status	Mature

Golden perch (*Macquaria ambigua*) is a handsome freshwater finfish, originating in the Murray–Darling basin. When grown in clear water, they are a spectacular green and gold: Australia's Olympic colours.

At the end of the last century, there was a lot of interest in the culture of this species. It was one of the first to which hormone inducement has been successfully applied, resulting in a reliable supply of juveniles for on-growing.

The fish has a traditional following amongst the Jewish community, particularly at Passover. They also have a strong following in eastern Asian cuisine.

However, golden perch can be difficult to feed, having a strong preference for live food. It is quite possible to run a farming system producing live food for the primary crop, but it takes extra time and extra money. Larger pond areas are likely to be needed. These all translate into lower profit margins.

Golden perch are now mainly used for stocking farm dams to provide recreational fishing for the owners.

Golden snapper

Production system	Marine finfish cage culture Land-based mariculture
Broodstock/seedstock availability	Limited availability
Temperature/water preferences	Tropical
Current market status/potential	Niche domestic and international demand
Sector status	Species with a possible future

Golden snapper (*Lutjanus johnii*) is a true tropical snapper, related to, and similar in appearance to mangrove jacks. (See the section on 'Snapper' for more information on the group) Golden snapper are found in seawater of more or less oceanic salinities, but can successfully handle lower salinities.

Research has been undertaken into farming this species, and the life cycle has been successfully closed in captivity. They take artificial foods. So far, there has been insufficient interest for this to be translated to commercial activity.

In places in Australia where golden snapper occur naturally, they are generally sought after as a premium eating fish. The name 'golden' is also likely to enhance their value in the Asian food market. However, they are not well known in temperate Australia and are unlikely to bring a very high price.

Golden snapper show potential to grow in sea cages and in ponds filled with seawater.

Goldfish

Production system	Static freshwater pond system
Broodstock/seedstock availability	Available at all stages
Temperature/water preferences	Temperate
Current market status/potential	Established domestic demand
Sector status	Mature

Goldfish (*Carrassius auratus*) is an exotic species of freshwater finfish grown and sold for the aquarium trade and for stocking into garden ponds. They are related to, but distinct from, common carp or koi carp.

There are several medium-sized inland fish farms devoted to the production of goldfish. These supply a significant proportion of the domestic demand, with fancy breeds being imported to fill the gap. Some of these farms appear to be quite effective money-spinners for their owner-operators.

Spawning technology is not complex. In spring, when the water temperature raises above the mid-teens, a young goldfish's fancy turns to love. Their preference for laying eggs on leafy areas is capitalised upon by farmers placing egg-mops by the pond's edge, then removing them to nursery ponds once they are covered with adhesive eggs.

When producing aquarium fish, some of the normal rules governing fish farming for food species do not apply. Fast growth is not necessarily desirable, especially when you have an annual breeding cycle, but need to have a range of size fish over the whole year. Goldfish are often stocked densely to reduce growth rates. Feeding is not important. Addition of food is mainly undertaken to attract fish to harvest nets or to administer oral therapeutics.

Goldfish have a disease called 'goldfish ulcer disease', which may well be transmissible to native species. Government regulation of goldfish farming appears to be directed at minimising the expression of this disease. In most states farms have to be quarantinable, and reasonable precautions must be taken to prevent introduction of goldfish ulcer disease. Being able to ensure specific pathogen-free status for this disease is a big plus for goldfish farming.

Green mussels

Production system	Subtidal shellfish mariculture
Broodstock/seedstock availability	Not allowed in Australia/OK in New Zealand
Temperature/water preferences	Cold to temperate
Current market status/potential	Established
Sector status	Not appropriate for Australia/Mature in New Zealand

In Australian seafood shops, it is quite common to see green mussels (*Perna canaliculus*). These are a very handsome mussel, with large green shells. They make quite an attractive display. In some places, greenlip mussels are considered to be a premium product.

See the section on 'Marine mussels' for general information on the culture of mussels.

Green mussels originate in New Zealand. The species is not found in Australia, and it would be unlikely for live greenlip mussels to be allowed into the country.

As well as the eating qualities of the meats, green mussels are also ascribed, by some, to have an analgesic or painkilling property. Extract of green mussel can be found in the health food section of supermarkets. The authors have known at least one person who swore that greenlip mussel extract assisted her to control the pain of arthritis. How effective it might be is a matter for the medical profession to determine, but there is a definite demand for the extract in the marketplace.

The New Zealand species is not the only species of green mussels. There are also reputedly other species of green mussels found in the tropics: not in Australia, but not too far to the north. A very limited number of yachts entering Australia after visiting these countries have been found to have tropical green mussels growing on their hulls. The mussels have been regarded as potential pests, and the matter has been treated seriously, with hulls being cleaned and stripped of any living attachments.

Greenlip abalone

Production system	Land-based mariculture Ranching Feedlotting
Broodstock/seedstock availability	Rearing technology established but limited stock available commercially
Temperature/water preferences	Cold to temperate
Current market status/potential	Established international demand
Sector status	Developing

Greenlip abalone (*Haliotis laevigata*) are found in the southern seas of Australia. They are arguably the best looking of the commercial Australian abalone. As the name indicates, the skin on the foot has a gentle green colour. The shell is smoother and flatter than that of most other species of abalone. Greenlip tend to prefer to be out on rock flats in areas subject to heavy surge. The smooth, flat shell may assist them to adapt to that habitat.

From time to time wild populations of greenlip have been subject to plagues of *Perkensosis*, and this has reduced numbers. It may be that greenlip are naturally prone to this disease, and this may be an issue in farming them. It may also be that *Perkensosis* was a one-off event, or brought on by some human-induced environmental stress. In any event, it is something to be aware of.

Grouper

Production system	Finfish cage culture
Broodstock/seedstock availability	Hatchery technology available No commercial supply
Temperature/water preferences	Tropical
Current market status/potential	Established international demand
Sector status	Species with possible future

Grouper are a group of generally large carnivorous fishes, generally from the genus *Epinephelus*, or related groups.

Sometimes the name grouper can be applied to other fishes, particularly in Asian usage. A good example is the fish known as the Barramundi cod in Australia, but which goes by the common name of 'hump-back grouper' in the countries to our north.

In Asia, groupers have been grown in sea cages and sold into the live fish trade. One of the authors vividly remembers peering in through the walls of a sea cage (he was diving) in Singapore harbour and seeing red coloured grouper sitting on the bottom.

In Australia there are quite a variety of grouper species, from the giant Queensland grouper found in the tropics, estuary cod and black cod found in temperate areas, to hapauka found in cooler waters. The authors haven't done a check, but it seems likely the Patagonian tooth fish, subject to so much publicity about poaching, is also a grouper and it is found in frigid waters.

At least one of the authors regularly dines on grouper (taken from the wild) and will attest to its eating qualities.

In New South Wales there is species called 'blue groper' but this is not a true grouper, but is more correctly grouped with the wrasses. (See the section on wrasses for more information.)

Despite the presence of a large variety of species here, little attention has been paid to the aquaculture of grouper in Australia. Possibly the prices received in the marketplace have not been sufficient.

Grunters

Production system	Freshwater/brackish static pond
Broodstock/seedstock availability	Limited
Temperature/water preferences	Mostly tropical
Current market status/potential	Undeveloped generally; farmed species have a niche market due to growers' efforts
Sector status	Species with possible future

The grunters are a group of hardy Australian inland finfish. 'Jade perch', 'silver perch' and 'sooty grunters' are all grunters.

Grunters have many features suiting them to farming. They are robust, aggressive fish, generally with a good tolerance of less-than-perfect water quality. They can be stocked in very high densities. They are omnivores and supplement added feed by scavenging on the bottom of a pond. They are readily bred using contemporary technology.

In many ways the grunters are akin to species from overseas such as African and Asian tilapia and American sunfish, but grunters have one great advantage: they are native to Australia and therefore present less chance of becoming pests.

Few grunters grow to a large size, but some grow to a size that is acceptable as 'plate-size'.

A big marketing disadvantage of grunters is their name, hence the use of names such as 'silver perch' and 'jade perch'. Sooty grunters are often termed 'black bream'.

Hump-back grouper

See 'Barramundi cod'.

Jade perch

Production system	Static pond Freshwater re-circulation systems
Broodstock/seedstock availability	Available
Temperature/water preferences	Warm water/tropical
Current market status/potential	Niche international demands for seedstock; niche domestic demand for seafood
Sector status	Established

'Jade perch' is the marketing name for Barcoo grunter (*Scortum barcoo*). (See section on 'Grunters' for more information on relatives of this species.)

Jade perch came into the fish farming scene at the end of the last century. They have proved to be a hardy fish that adapts well to domestication. Where appropriate, they have been farmed with enthusiasm.

Often, jade perch have been farmed in re-circulation facilities. The economics of intensive production generally means high break-evens. For the factories to be viable, the fish produced have to attract high prices: everyday common fish are not good enough. One way to get the high prices is novelty, that is, new species have be introduced and grown on an ongoing basis.

There has been interest in the species in mainland East Asia and fry are being exported to China.

Jade perch are also grown in ponds in subtropical Queensland. The 'silver perch' growers around Childers have been giving them a fair dinkum go. They have their following but generally bring a few dollars a kilogram below silver perch.

Jewfish

Production system	Marine finfish cage culture
Broodstock/seedstock availability	Hatchery technology available Commercial availability limited
Temperature/water preferences	Temperate to tropical, depending on species
Current market status/potential	Niche domestic demand
Sector status	Developing

Jewfish belong to the family Sciaenidae. In the USA, they are known as 'croakers' or 'drums'. This has something to do with the fact they somehow make a noise with their air bladders when removed from the water.

On the south-eastern coast of the USA, members of the family have been regularly bred in captivity to produce juveniles for release to stock recreational fisheries. The red drum is a particularly attractive species. The same technology should be more or less applicable to Australian species.

Australia has quite a few species of jewfish of its own. Some are larger than others. Perhaps the most famous is the east coast mulloway, which has been used for aquaculture. See the section on 'Mulloway' for information on this species.

Kingfish

Production system	Marine finfish cage culture
Broodstock/seedstock availability	Available
Temperature/water preferences	Temperate
Current market status/potential	Niche domestic demand, possible sashimi market
Sector status	Developing

Kingfish (*Seriola lalandi*) is a large, fast-moving pelagic finfish, occurring naturally on temperate coasts of Australia. Very similar fish are farmed in sea cages in Japan. Interest is increasing in growing them in Australia, and proposals have been put forward for places as widespread as the South Australian gulfs and Morton Bay in Queensland.

It has been suggested that these fish could be harvested from the wild, then feedlotted in sea cages, in a manner similar to the tuna farms in South Australia. In years gone by, kingfish have been harvested in floating traps in New South Wales. A big disadvantage of these traps was that the skins of the fish were often grazed and bruised, lowering their value as a sashimi species. Feedlotting them in sea cages, and allowing them to come back to peak condition, may well have been an ideal adjunct to trapping them. However, a great deal of public concern arose about the trapping, and it was banned. With the advent of farming, that particular opportunity has now evaporated.

Koi

Production system	Freshwater static pond
Broodstock/seedstock availability	All life stages commercially available
Temperature/water preferences	Temperate
Current market status/potential	Niche demand
Sector status	Mature – but illegal in some States

Koi are the decorative variety of common carp (*Cyprinus carpio*). The species that was used for food farming and fishing in Europe, and has become a pest in Australia and the USA, was taken by the Japanese and bred till it has been coloured with the most gorgeous of patterns. Looking down on a pond of koi is a delight.

In Japan, prize-winning koi become very valuable. They are used to breed from and will hopefully generate genetic lines that will in turn provide a good income to the breeder.

In Australia, koi are regarded differently. They are seen as a genetic reservoir that could add vigour to the already over-vigorous feral carp. Accordingly, they are prohibited in most states, except perhaps New South Wales, with possession sometimes carrying very high penalties.

Kuruma prawn

Production system	Land-based mariculture
Broodstock/seedstock availability	Post-larvae available
Temperature/water preferences	Temperate to tropical
Current market status/potential	Niche international demand in Japan
Sector status	Mature but limited in scale

Kuruma prawns (*Penaeus japonicus*) are another variety of prawn grown in Australia.

While generally not considered to be as desirable for growing as monodon prawns, kuruma prawns have some desirable features that ensure them a place in Australian aquaculture. They can grow in water with salinities around that of seawater, so a farm by the ocean doesn’t need to have a source of freshwater to shandy the water it gets in from the sea.

It has also been suggested that kuruma prawns have a better tolerance of cooler temperatures than monodon prawns, making them more attractive to growers operating at the cooler end of the prawn range.

Kuruma prawns can be sold live, gaining an additional premium in the marketplace, but the scuttlebutt is they are very sensitive to temperature variation. The temperature of the water they are kept in must be held within a 5 degree range during transport.

There was some fuss about the potential of kuruma prawns in the last decade of the last century, but they have remained a very minor component of Australian prawn production. It might be that extra premium does not justify the costs, or that there is only a limited sector of the market seeking this species.

Leader prawn

See 'Black tiger prawns'.

Live rock

Production system	Ranching
Broodstock/seedstock availability	Not applicable
Temperature/water preferences	Not applicable
Current market status/potential	Niche domestic demand
Sector status	Developmental

Your first impression, on hearing the name 'live rock', would be that it was something to do with music. A better description might be 'living rock'. The name sounds a contradiction in terms, but it is commonly applied in the marine aquarium world. There is a belief that water quality is best maintained by having a full complement of natural bacteria and related organisms present in a tank. These organisms require the appropriate habitat, which is in turn created on pieces of rock which have resided in the ocean for some time. Sponges, invertebrates, bacteria all live on the outside and cracks in the rock. This growth can be duplicated in the aquarium, but it takes time for it to achieve full maturity. Introducing 'live rock' into an aquarium will establish the appropriate equilibrium faster.

Live rock can be mined, that is, collected from the wild. However, government departments in most states are not happy to see this happen, and want to limit extractive activities in coastal areas. Aquaculture of a sort provides an alternative. Dry rocks can be placed in an appropriate marine area, and left for sufficient time to develop a full complement of life on them. They may then be removed and sold into the aquarium trade.

Lobsters

Production system	Land-based mariculture
Broodstock/seedstock availability	No stages commercially available
Temperature/water preferences	Temperate to tropical, depending on species
Current market status/potential	Established domestic and international demand
Sector status	Experimental

Lobsters are the decapod crustaceans that live in the sea. ('Crayfish' live on the land or in freshwater.)

In Australia, there are three lobster species that are exploited to any large extent: the southern rock lobster (*Jasus edwardsii*), the eastern rock lobster (*Jasus verreauxi*), and the western rock lobster (*Panulirus cygnus*). The fishery based on the latter species is one of the largest in the world. Lobsters similar, or identical, to eastern and southern rock lobster are also found in New Zealand. There are quite a few more species of lobsters found in Australia, particularly in the tropics, but they do not have the same high profile in the marketplace.

Lobsters are traditionally high value seafood around the world. The wild fisheries are strictly regulated. Those that aren't have long passed into obscurity because of overexploitation. Many people have seen the gap between demand and supply and have turned their attention to farming lobsters. In Australia, the major aquaculture research funding body, the Fisheries Research Development Corporation (FRDC) has devoted a special sub-program to coordinating research into propagating rock lobster species. In New Zealand research is being undertaken by the National Institute of Water and Atmospheric Research (NIWAR).

The trouble is, the first ingredient of a successful aquaculture industry is missing: a reliable supply of quality seedstock. Like many marine crustaceans, lobsters have a complicated series of stages in their development. It can take a one to two months for the eggs to hatch. Once hatched, the first stage of the larvae, the phyllosoma, float on the currents for over a year. Like all crustaceans, they moult their shells, and after each moult they are slightly different. There may be something like 9 to 17 moult stages. The next stage in the larval cycle is termed a 'puerulus'. These look very much the same shape as an adult, but they are smaller of course and tend to be more transparent. Puerulus also float on the currents, but they can swim and move from place to place under their own power. At the end of the larval stages, the puerulus settle out of the mid-water, and take up life on the seabed. At the next moult you have a proper lobster, albeit small, but clearly recognisable.

The big problem for aquaculture is that these larval and on-growing stages take time. According to FRDC reports, in some tropical species, the larval stage may take something less than 200 days. However, in some of the species that live in cooler waters, the process make take as much as two and a half years, or more, to complete. Larvae are difficult (read that as 'costly') to maintain, and keeping them alive for several years will require a very understanding bank manager. Research has been directed at shortening the larval stages by inducing early moulting, but at the time of writing, it is still too early to gauge how successful this approach will be.

Having reared the larvae, the next trick is to grow them to an acceptable market size. CSIRO information suggests it takes something like between three and six years to get adults conditioned to breed. However, this is not as bad as it seems as farmed lobsters can be sold well before they reach sexual maturity. In fact, this may allow a competitive advantage against the wild fishery. Most fishery management regimes in Australia attempt to allow wild fish to breed before harvest and set minimum allowable sizes to match. Usually this results in a lobster that is quite large. Most restauranteurs don't like a lobster that is too large. They prefer lobsters around 200 g. In most species, this is well below minimum legal size. If aquaculturists can supply these smaller lobsters, they have an advantage in the marketplace.

Scientific research is being put into lobster aquaculture, in some cases with relatively high budgets and lavish facilities. However, a quiet talk with research staff usually reveals that they think it will be a while before closed life cycle rock lobster aquaculture becomes an economic reality.

It has been suggested that puerulus might be harvested then on-grown. Commercial fishers of wild lobsters are likely to resist the adoption of this approach, arguing that these larvae could well be the primary stock that will grow on to be the lobsters the fishers have traditionally caught. Trade-offs have been suggested, with aquaculturists harvesting puerulus having to purchase catch quota before they take anything from the wild. Another approach suggested is that aquaculturists harvest larvae, and rear them, dramatically reducing mortality (they hope). Later on, a given proportion of the young lobsters are released back into the wild to be recruited to the wild fishery. Politics finds its way into debates of this kind.

Aquaculture might also start with adult lobsters and work in conjunction with a fishery. Commercial fishers have long known that live lobsters bring a much better price than dead. Healthy live lobsters withstand the vicissitudes of transport to markets much better than those that have been stressed. Once taken from the wild, aquaculture technologies are needed to keep them living. A look around in a live rock lobster-holding facility will show an enterprise hard to distinguish from an aquaculture venture.

Lucky fish

See 'Arrowana' and 'Saratoga'.

Macrobrachium

See 'Cherubin'.

Mahi mahi

Production system	Marine finfish cage culture
Broodstock/seedstock availability	Hatchery technology available Stock not commercially available
Temperature/water preferences	Warm water to tropical
Current market status/potential	Niche domestic and international demand
Sector status	Experimental

Mahi mahi, or dolphinfish (*Coryphaena hippurus*), are a very handsome finfish of a bright sea-green colour with a golden sheen. They also have fine blue spots on the side. In the wild, they are pelagic and live offshore. Recreational fishers often find them underneath floating debris.

Mahi mahi grow very fast to quite large sizes. Operators say they grow so fast that if you take a weekend off, when you come back, the fish have grown noticeably. It has been suggested that, under the right conditions, a 3 kg fish can be grown in little more than six months. The total natural life span might be something like five years.

These fish are reputed to become sexually mature at around one year of age. The males are sometimes called 'bulls' and the females 'cows'. The bulls live up to their name and behave in a truculent manner. They also say that once the males become sexually mature they become aggressive and skittish, charging off at the slightest provocation: sometimes hitting/butting the walls or net at close to fatal speeds.

The growth potential, on the face of it, makes this species very attractive. Mahi mahi farming has been investigated in several places in the world, including Japan and Australia. There was a lot of interest in WA in the 1980s, but nothing much came of it. The market may not have been encouraging. In recent years there has been a resurgence of interest, and time will tell what happens.

Mangrove jack

Production system	Marine finfish cage culture Land-based mariculture
Broodstock/seedstock availability	Limited
Temperature/water preferences	Tropical
Current market status/potential	Poorly known in market place
Sector status	Species with a possible future

Mangrove jacks (*Lutjanus argentimaculatus*) are snappers found in tropical Australian waters. The authors have seen them as far south as Nambucca Heads, but that is about the southern limit of their range.

Mangrove jacks are much sought after in this country, particularly as an angling species. They have sweet white flesh (at smaller commercial sizes anyway – bigger jacks can get a little oily). In Queensland the interest has been translated into hatchery technology research for this species, and theoretically at least, there is a potential supply of juveniles.

Jacks could be on-grown in sea cages and in inland seawater ponds once basic husbandry methods and commercial diets are established, neither of which should present too much of a challenge.

Maori wrasse

See 'Napoleon wrasse'.

Marine mussels

Production system	Long-line culture
Broodstock/seedstock availability	Usually collected from the wild; can be produced under hatchery conditions
Temperature/water preferences	Temperate species
Current market status/potential	Established international and domestic demands
Sector status	Mature

In seawater areas of Australia and New Zealand, green and blue mussels are grown in aquaculture. (See sections on 'Green mussels' and 'Blue mussels' for more information.)

They are sold as a fresh live product or as a processed and value-added seafood product.

In the tropical north, there is a largish white-shelled bivalve sometimes known as the 'mangrove mussel' but this is rarely seen in the marketplace, and when it is, it is sold as 'bush tucker'. Neither of the authors has heard of any interest in farming mangrove mussels.

Marine mussels are grown attached to dropper ropes hanging from a long-line suspended between anchored floats.

To obtain juvenile mussels, the ropes are hung in areas where there is a natural spat-fall of mussels. As the mussels grow they require more buoyancy. Tying floats to the long-lines is an ongoing task in mussel farming. Grow-out time will vary from district to district but in round figures it takes about a year.

Mussels feed on natural algae in the water, and this causes the conflict that forms the largest problem for mussel farming. Some planktonic algae contain toxins, for example those that cause paralytic shellfish poisoning, or amnesiac shellfish poisoning. Undesirable algae may not be toxic: in Victoria's Port Phillip Bay a common problem is 'bitter taste' caused by an exotic algae that occasionally blooms during the winter months in association with substrata disturbance. Fortunately the taste is purged from the mussels' flesh during the spring in time for the summer harvest.

Being filter feeders, mussels are also vulnerable to human-generated pollution so they are grown under strict water quality supervision and it's not unknown that mussel harvesting is suspended for the duration of the event. As these scares are usually site specific, smart operators have farms in more than one zone.

Cultured mussels are a premium product. In fact, dredging of mussels has been stopped except for bait, as the cost of water quality assurance drove the wild harvest out of business.

In common with most forms of mariculture, getting space in the sea is the main barrier to getting into mussel farming. In many cases, the best way of getting into the industry is to buy an existing mussel farm.

Marine worms

Production system	Land-based mariculture
Broodstock/seedstock availability	Poor
Temperature/water preferences	Variable
Current market status/potential	Unknown
Sector status	Pilot

Farming marine worms is not an established aquaculture industry, but there have been a few proposals, which, on the face of it, might generate a profit.

There are various species of marine worms – possibly thousands, each with its own particular characteristics. There is scant literature on their biology.

It has been suggested that a good marine worm farm arrangement would be a flat 'soil' substratum containing a high nutrient load. The worms would live and feed in this area. The oxygen requirements of worms are little known, and some species may be able to tolerate low levels of dissolved oxygen, but having too much oxygen is rarely a problem. To keep oxygen levels high, the 'soil' substratum would have a shallow layer of well-aerated water moving over it.

The produce of the farming, that is, the worms, could be sold as fishing bait, or as aquarium fish food (as long as translocation and disease issues were satisfactorily addressed) but if the volume of the farm was large enough, worms could be used for the production of raw protein and they may be rich in some highly sought after food components such as omega 6 oils.

Speculation aside, farming for marine worms is far from being a proven industry and involves a great deal of uncertainty.

Marron

Production system	Freshwater static ponds Freshwater flow-through
Broodstock/seedstock availability	Niche to good
Temperature/water preferences	Mediterranean to cool temperate
Current market status/potential	Niche international and domestic demand
Sector status	Developing/mature

Marron (*Cherax tenuimanus*) are a freshwater crayfish indigenous to the well-watered south-west corner of Western Australia. While they do not appear to grow faster than alternative species of freshwater crayfish, marron do eventually grow to over 1 kg. They also attract a healthy premium over the price paid for the two competing species, redclaw and yabbies, making the wait and effort worthwhile.

During the 1980s, marron were highly promoted as being the answer to a fish farmer's prayer. There was a flood of attempts at farming marron in Queensland. However, a hot summer took them outside their comfort zone and the attention turned to the tropical redclaw, which proved more suited to the aspirations of Queensland crayfish farmers.

At the same time marron were introduced to Queensland attempts were made to farm them commercially in South Australia. Marron farming failed on the mainland but the stable maritime climate of Kangaroo Island matched that of their native Margaret River and the species has thrived in this region to become one of the major industries on the island, after tourism and fishing.

Marron are a temperate climate species and breed annually. Dedicated hatcheries have been used to produce seedstock.

There is a place for marron farming, and it is in the south-west of Western Australia. The total production of marron in 2002–03 was 52 tonnes from WA and 8 tonnes from SA, which indicates a low yielding product. The most successful farms seem to be found in tourist areas so it would appear that sales should be aimed at the high value areas to compensate for relatively low yields.

See the section on 'Crayfish' for more information on related species.

Micro-algae

Production system	Re-circulation systems
Broodstock/seedstock availability	Available
Temperature/water preferences	Temperate to tropical
Current market status/potential	Trade yet to be established
Sector status	Mature, but mainly within some vertically integrated productions systems

Micro-algae has many uses in a hatchery; it is primarily used to feed fish or crustacean larvae or feed the living animal food for the larvae, but can also condition water, increasing survival. Some commonly used algae are in the genera *Chaetocerus*, *Isochrysis*, *Rhodomonas*, *Skeletonema*, *Tetraselmis* and *Pavlova* spp.

In most hatcheries, micro-algae is bred on site: small cultures that are 'axenic' (bacteria-free) are seeded into jars containing plant nutrient (fertiliser), and through which carbon dioxide is bubbled to increase production. The jars are kept in the bright light – usually in a room lit with large numbers of fluorescent lights. From this base the algae is harvested and fed to the target species, usually larvae but it can also be used to grow zooplankton, which in turn is fed to the larvae of the target species.

When showing visitors around a hatchery, one of the authors used to suggest that the algae growing area looked like 'real science' because it had containers of coloured water with bubbles flowing through them!

Maintaining an algae laboratory is costly so there have been a variety of attempts to automate the process. One way has been to draw on water analysis technology and have a very long, continuous, clear pipe held under bright light. A small amount of algae, with a lot of nutrient is fed in at one end, and out of the other end comes a liquid containing a high density of algae. Also available are freshly harvested algae in paste form. The general consensus is that the pastes are comparable with fresh algae for most applications, and that even though they cost, they save a lot of time and trouble.

For other information on commercial growing of micro-algae, see 'Dunaliella' and 'Spirulina'.

Milkfish

Production system	Land-based mariculture Marine finfish sea cage
Broodstock/seedstock availability	Poor
Temperature/water preferences	Tropical
Current market status/potential	International sales possible, but regarded as a low value product
Sector status	Pilot

Milkfish (*Chanos chanos*) is farmed in Asia. The same species also occurs in Australia. Milkfish are by nature algal-grazers, and are complete vegetarians. To the casual observer, this often comes as a surprise as they resemble fast swimming pelagic predators such as kingfish.

There is no milkfish farming in Australia.

Neither of the authors have eaten milkfish, but it is reputed to be bony and not all that flavoursome to the Australian palate. There is no doubt that there is demand for milkfish in the Asian food market, but it appears likely that the price received is not attractive.

An alternative use has been suggested for milkfish. Some approaches to prawn farming rely on the development of an appropriate bloom of algae in the ponds. It has been suggested that milkfish, with their bottom-grazing habits, remove nutrients from the bed of the ponds, and, after some digestion, expel the excess into the mid-water, assisting to keep plant productivity up in the water column, rather than on the bed or the walls of the pond. In other words, throwing a couple of milkfish into a prawn pond may boost production. If this idea becomes well accepted, and there is a supply of them available, there may be a demand for milkfish to undertake this function.

Milky oyster

Production system	Inter-tidal shellfish culture
Broodstock/seedstock availability	Limited hatchery/nursery produce
Temperature/water preferences	Tropical
Current market status/potential	Niche domestic demand
Sector status	Pilot

Milky oysters (*Saccostrea amasa*) are a tropical species of cupped oyster.

In the wild, massed clumps of milky oysters are found on rocks, usually well up in the tidal range (given that tides can rise and fall by as much as 8 m in some parts of tropical Australia, this can be a significant distinction). They can grow very thick, so that they are a real source of annoyance to anglers, who snag their lines in them, and to shore-based divers and swimmers who have to enter the water over the oysters. Walking over a patch of milky oysters is not something you do in bare feet. (One of the authors has scars to attest to this.)

Aficionados claim that the milky oyster is the best tasting of the tropical oysters, being smaller and sweeter than the other common tropical species, the blacklip oyster.

In the tropics, the annual weather pattern is wet season/dry season. Over the dry season, the oyster gonads mature. With the onset of the wet, spawning is stimulated. Fertilisation is external, that is, the shed eggs and sperm meet and fuse in the open water. The newly conceived larvae become free swimming and are initially very much at the mercy of the wind and currents. They flourish among the lower salinities and dense algae populations generated by the extra rainfall. The larvae float for a while, then settle in a sheltered area with a suitable bottom where they take up the typical oyster life style. Milky oysters are normally ready to breed after a year.

While there are massive potentially suitable areas for oyster cultivation across the top of Australia, there is little cultivation of tropical cupped oysters, and that is limited to

Queensland. The economies of scale needed for a proper quality assurance regime provide a formidable barrier to establishing a new oyster industry. One way of reducing the limitations imposed by health rulings is to establish a farm in an estuary, the catchment of which has no human habitation. These areas are few and far between, but are available in some parts of the Top End, the Kimberley and maybe even in parts of western Queensland.

For more information on this group of bivalves, see 'Oysters' and 'Cupped oysters'.

Monodon prawn

See 'Black tiger prawns'.

Moreton Bay bug

See 'Bugs'.

Moses perch

Like many common names, 'Moses perch' can be used to refer to more than one species. In Queensland, it refers to a tropical snapper, very closely related to golden snapper. For more information, see the section on 'Golden snapper'.

The name can also be applied to a fish found in the Middle East. The name 'Moses perch' invokes biblical imagery. However, the age of miracles has passed, and we do not reside in the Middle East: that kind of Moses perch is not for Australia as they are a variety of tilapia. See the section on 'Tilapia' for more information.

Mud crab

Production system	Inter-tidal (mangrove) culture Land-based mariculture
Broodstock/seedstock availability	Technology developed
Temperature/water preferences	Tropical
Current market status/potential	Established domestic and international demand
Sector status	Developing

Mud crabs are large, robust crabs of the genus *Scylla* and they are found in mangrove areas across the top of tropical Australia.

There is a strong market for mud crab in Australia, and also one in Asia.

In Asia, small mud crabs are harvested from the wild then placed in fenced areas in mangrove forests. They are allowed to forage till they grow to a size acceptable for the local market (probably smaller than acceptable in Australia) then re-harvested and sold.

In Australia, the presence of minimum sizes to protect wild fisheries means that this source of crablets is unlikely to be available. Research has been undertaken in Queensland and the NT on the hatchery production of crablets and this has shown sufficient success to indicate there could be a supply of seedstock for future crab farming.

The method used for grow-out is yet to be determined. At the time of writing, mud crab farms were being established in Queensland. It may be possible to fence off areas of mangrove, but participants in the wild fishery may see this as a loss of area essential for production of crabs for the fishery, and may resist the idea. It may be possible to grow mud crabs using the same technology as prawns, but the profits would have to similar to prawns to displace them from potential areas of ponds.

Mud oysters

The name 'mud oysters' is sometimes applied to native flat oysters (see 'Flat oysters'). It is not a good trading name, as it implies this species tastes muddy, which is not the case.

See 'Oysters' and 'Flat oysters' for more general information on this group of bivalves.

Mud-eyes

Production system	Freshwater static pond
Broodstock/seedstock availability	Not commercially available
Temperature/water preferences	Temperate
Current market status/potential	Keen but untested demand from recreational anglers
Sector status	Pilot

Mud-eyes are the larvae of dragonflies. They live in shallow water, among the cover of grass or branches, at the margins of rivers and dams.

A key feature of mud-eyes is that they are considered prime bait by trout anglers. Astoundingly high prices are received for them in areas where trout are fished. The supply of mud-eyes is often undertaken by youngsters, keen on the outdoors and seeking a source of income.

It is theoretically possible to establish a habitat desirable for dragonflies and mud-eyes, and then to harvest it at an appropriate time. The volume of sales would be small, but the margins very good. As with most bait supply, distribution costs may well be disproportionate.

The authors are only aware of one attempt at mud-eye farming, and it did not last all that long. But the idea is there.

Mullet

Production system	Land-based mariculture
Broodstock/seedstock availability	Poor
Temperature/water preferences	Temperate and tropical
Current market status/potential	Niche domestic demand
Sector status	Experimental

Mullet are marine and estuarine finfish. There are several species and between them, they can handle salinities from that of seawater to fresh.

Mullet are a low value fish, although the roe does have its position in the market-place. They have been farmed in conjunction with prawns, the bottom foraging habits of mullet assisting to maintain a floating algal bloom in the water.

Nobody seems to have found mullet to be a serious enough prospect to make it worth farming them.

Mulloway

Production system	Marine finfish sea cage
Broodstock/seedstock availability	Limited availability
Temperature/water preferences	Temperate
Current market status/potential	Niche domestic demand
Sector status	Developing

Mulloway (*Argyrosomus hololepidotus*) are a species of jewfish found on the east coast of Australia. (See the section on 'Jewfish' for more general information.) This species has been farmed.

One of the authors remembers strolling through the Melbourne Fish Market in the brisk early hours of the morning. Sometimes the fish lying around is less than perfect in the way it is displayed. In one place, fish on a table stood out: they were all in perfect condition and all were the same size. They were clearly aquaculture produce. They were, of course, mulloway.

A low to medium priced fish at the Sydney Fish Market, mulloway have more of a following for their angling properties than their farming capability, however, breeding techniques are established and several trials have hinted that the species may have commercial potential. They have been tried in floating marine cages and re-circulation systems and while the results have been encouraging they haven't set any records. Research on the species is continuing.

It has also been suggested that mulloway offer a chance of diversification for sea cage farmers of species such as pink snapper. They might not be as high value, but having a second species splits risk, and can assist in marketing.

Murray cod

Production system	Land-based mariculture Freshwater re-circulation systems
Broodstock/seedstock availability	Good
Temperature/water preferences	Temperate warm water
Current market status/potential	Niche domestic demand, possible export potential
Sector status	Developing

Murray cod (*Maccullochella peelii peelii)* is a robust ambush predator found in the Murray–Darling complex of rivers. There are closely related fishes: trout cod, eastern cod and Mary River cod and there is conjecture in scientific circles as to whether they are separate species or subspecies.

Breeding techniques were developed at NSW Fisheries' John Lake Centre at Narrandera in the late-1970s and fertilised eggs can be either collected from nesting boxes or hormone induced in hatcheries.

A decade ago, Murray cod were a fish 'showing potential'. The hatchery technology was well established, as was juvenile rearing technique. However, there was a perceived problem getting Murray cod to take a supplementary ration. Once weaning techniques were established, the mighty Murray cod became an aquaculture candidate. Cod are now grown in ponds and re-circulation systems.

Although national output, at around 100 tonnes in 2002, is low, farmed fish are available in most eastern capitals and some regional centres. They have a strong following in mainland East and South East Asian cuisine and Murray cod fry are being exported to China so the development of an export market may be shortlived.

The depth of the local market hasn't been fully tested but one plus in this direction has been the closure of the NSW inland commercial fishery. With this traditional supplier out of competition, it is expected that the farmed product will take its place but anyone considering growing the species should do their own market research as circumstances for new species can change very quickly as consumers evaluate the product and the true depth of the market is tested.

Also see the section on 'Trout cod' for information on this closely related species.

Murray crayfish

See 'Spiny crayfish'.

Mussels

The term 'mussel' can be, like many seafood names, less than specific, and not a little bit confusing. In Australia, there are two general groups of bivalve shellfish termed 'mussels'. In coastal areas on the south of the continent, there are marine mussels – see the section on 'Marine mussels' for more information. Inland in freshwaters, there are 'freshwater mussels' – see the section on 'Freshwater mussels' for more information.

Napoleon wrasse

Production system	Marine finfish sea cage
Broodstock/seedstock availability	Technology developed Stock not available
Temperature/water preferences	Tropical
Current market status/potential	Established international demand
Sector status	Species with a possible future

Napoleon wrasse (*Cheilinus undulatus*) is a tropical, reef-dwelling finfish. This fish is one of a group that are collectively known as Maori wrasses. It can grow to a very large size.

Napoleon wrasse are keenly sought for the Asian live fish trade and attract a high value. They fall into the same category as coral trout and barramundi cod. The potential for profit is the factor that brings them to the interest of fish farmers.

While demand is strong, supply is weak. In Australia, there is no commercial supply of juvenile Napoleon wrasse. In Bali, the aquaculture research institute at Gondol produces many thousands of larvae of this species. They are supplied to the multitude of small-scale fish pond farmers who grow them out. The proportion of successes is unknown, but there is a significant production from this source. In Australia, if Napoleon wrasse were to be grown-out, one would imagine this would be most appropriate in a sea cage.

Native trout

Production system	Freshwater static pond
Broodstock/seedstock availability	Not available
Temperature/water preferences	Cold/temperate
Current market status/potential	Unknown – most likely poor
Sector status	Conceptual

Some of the Australian galaxiid species have sometimes been called 'native trout'. Just having the word 'trout' included in their name sparks interest in some quarters. The native species are not related to salmonids, but do grow to a size that makes them of interest as a food production species. They have limited novelty to collectors of aquarium fish, but not being particularly highly coloured, are not of general interest.

Many species in this group are declared endangered, and this more or less rules them out for commercial culture

Another southern native species, grayling, is distantly related to the salmonid group, but, although a fine eating fish, has little to offer in the way of aquaculture potential. It is also on the endangered species list and even if it showed marketable and farming potential it is unlikely that a permit would be issued for its commercial cultivation.

Oysters

Production system	Tidal and subtidal mariculture
Broodstock/seedstock availability	Wild caught or available from hatcheries dependent on species
Temperature/water preferences	Temperate to tropical
Current market status/potential	Established international and domestic demands
Sector status	Mature

Production of edible oysters is one of the oldest forms of aquaculture in Australia.

In the marketplace oysters are usually described by the location in which they were grown, like wine, rather than the species. However, a lot of the growing characteristics are influenced by the species involved, and it is easier to deal with them on a species by species basis in this book.

Probably all species of oysters, or oyster-like bivalves are edible, but the main sources of oyster meat are cupped oysters, flat oysters and pearl oysters. The techniques of culture vary to a lesser or greater extent for each group. For information on cupped oysters see 'Cupped oysters', 'Blacklip oysters', 'Bluff oysters', 'Milky oysters', 'Pacific oysters', and 'Sydney rock oysters' elsewhere in this chapter. For information on flat oysters, see 'Flat oysters'. For information on pearl oyster meat see 'Pearl oysters'.

There may well be other species that are ultimately suitable for culture. One of the authors remembers scuba diving in the Montague Island shark gutter off the southern coast of New South Wales. In 20 m deep water, far too deep for the usual commercial species, he saw large numbers of cupped oysters, of a significant size. These unidentified species had possible farming potential.

People talk a lot of garbage about oysters, with gourmets propounding the eating virtues of one species against another. For example, in some parts of the country it is popular opinion that Sydney rock oysters are the best 'natural' (raw) oyster. (Not too surprisingly this is most commonly stated by people in New South Wales, especially those with an interest in oyster sales.) The truth is that most purchasers of oysters cannot tell one from another. At one time, one of the authors worked in a building where oysters were sold. Customers were given oysters free, and asked to compare the virtues of Sydney rock oysters vs. Pacific oysters vs. native flat oysters. Without exception, and without seeing the shells, the customers could not tell them apart.

Oysters are filter feeders. They sit still on the seabed and suck in water, which is filtered to remove algae before it is expelled. Clearly this is a mode of living that has worked for the oyster, but it carries with it risks for oyster connoisseurs. If the water contains undesirable living matter such as certain varieties of *Vibrio* bacteria, hepatitis or one of several toxic algae, this can be accumulated by the oyster. It is possible to eat a 'bad' oyster and become sick, even die. Needless to say, publicity of death following oyster consumption is bad for sales (and even worse for the person who ate the oyster). A variety of laws and standards have been introduced to prevent the unwanted occurrence. While these are generally beneficial for the industry (and society as a whole), they do add costs. And testing areas, if the tests are of any value, will mean that some areas will be closed to harvest and sales, also adding to the cost of running an oyster farm. This has proved quite a disincentive in some areas. The prize oyster growing estuaries are becoming prized estuarine real estate and production is moving from the NSW coast to more remote and pristine areas in Tasmania and South Australia.

Pacific oyster

Production system	Subtidal and inter-tidal shellfish culture
Broodstock/seedstock availability	Good
Temperature/water preferences	Temperate
Current market status/potential	Established international and domestic demand
Sector status	Mature

When the Sydney rock oyster industry underwent a decline in the latter decades of the last century, it did not spell the end of the oyster farming production in this country. In Tasmania and South Australia, newer oyster farming areas were developed, where to a large degree, they filled the gap left by the fall in production of Sydney rock oysters. In Tasmania and South Australia the industry is based on the Pacific oyster (*Crassostrea gigas*).

Pacific oysters are exotic, and not native to Australia. They originally came from Japan.

In some places in Australia, Pacific oysters will reproduce naturally. This is particularly true in New South Wales, where feral Pacific oysters are looked upon as a pest that poses a threat to the Sydney rock oyster industry (large quantities of Pacific oyster spat can settle over the Sydney rock oysters, either out-competing them, or making the final harvested product a mixture of two kinds of oysters). In other states, feral populations of Pacific oysters have become established, but there they breed in a less prolific manner. There are estuaries in Victoria that have populations of Pacific oysters, for example at Mallacoota and Anderson's Inlet. A walk on the rocks at low tide will show an oyster here, and an oyster there, with maybe 20 or 30 m between them. Some of them grow to be quite large.

Feral populations of Pacific oysters in some Tasmanian estuaries have grown to 150 mm to 200 mm. Growers harvest these wild crops and have found a lucrative market for them in the Chinatown markets of the mainland capitals. Interestingly the price rose dramatically as the supply dried up.

It has been stated that something like 80% of all oysters grown in the world are Pacific oysters. There has to be a reason for this. Pacific oysters are hardy (in the world of aquaculture, we never use the word 'tough' as people may confuse viability and resilience with eating qualities!). Pacific oysters are resistant to disease, and have replaced the Belon oyster which was once abundant on the Atlantic coast of France before the latter species was killed off by disease.

See 'Oysters' for more general information on this group of bivalves.

Painted crayfish

See 'Painted lobsters'.

Painted lobsters

Production system	Land-based mariculture
Broodstock/seedstock availability	Not available
Temperature/water preferences	Tropical
Current market status/potential	Established domestic and international demand
Sector status	Possible future potential

Some tropical species of lobsters have very bright colour patterns when they are alive, hence the name 'painted crayfish'. Once they are cooked, they go red of course.

See the section on 'Lobsters' for more discussion on aquaculture potential.

Paua

Production system	Land-based mariculture Ocean ranching
Broodstock/seedstock availability	Limited
Temperature/water preferences	Cold water
Current market status/potential	Niche international and domestic (NZ) markets
Sector status	Not indigenous to Australia Potential in New Zealand

Paua (*Haliotis iris*) is a large abalone naturally occurring in New Zealand. In that country, the commercial fishers for paua are generally not considered to be as wealthy as rock lobster fishers, and this may reflect the economic consequences of a different management regime. It may also reflect the fact that paua have a darker flesh which is not so acceptable in the international marketplace. The flesh can be bleached, but may lose a little attractiveness in the process.

Paua excels in the loveliness of its shell. The inside of all abalone shells have a nacreous (pearly) glow, and in paua this is a lovely reticulated green and silver colour. The shell can be used as it is for inlays, and traditional Maori carving made good use of it. Shell can be ground up and imbedded in resins or paints. At some stages in the development of the paua fishery, the shell has been worth more than the flesh.

Paua appear to be as suited to domestication as other species of abalone, and the aquaculture industry is developing along lines similar to those in Australia.

There has been some discussion of growing flat pearls in paua, and in fact some paua pearls have appeared in the marketplace.

Quarantine and environmental concerns make it unlikely that live paua could be imported into Australia, or that this species could be farmed here.

Pearl oysters

Production system	Marine long-line
Broodstock/seedstock availability	Some hatcheries/nurseries operating
Temperature/water preferences	Tropical
Current market status/potential	Established international demand
Sector status	Mature

The highest value pearls are grown inside the shells of bivalve molluscs of the genus *Pinctada*. In Australia, most are produced in gold lip pearl oyster (*Pinctada maxima*) but there are increasing efforts using the species black pearl oyster (*Pinctada margaratifera*) and penguin oyster (*Pteria penguin*).

Pearl shells are either fished from the ocean, or spawned and reared in hatcheries. To seed pearls, an artificial shape is inserted into the flesh of the pearl, along with a piece of mantle, which secretes the nacre over the shape. The shell are then sewn into ‘panels’ which are suspended from long lines, supported by anchored buoys. The pearl shell is left to develop hanging in the panels in much the same way mussels are grown.

In terms of dollar production, pearl oyster farming is one of Australia’s largest aquaculture industries, vying for the title of Number One with the southern bluefin tuna feedlotting sector of South Australia.

Getting into the industry is not easy. Access to suitable sites is difficult and existing licences are tightly held. Pearls are usually grown at remote locations and considerable costly support infrastructure is needed. The amount of investment needed is generally more than can be obtained from a single owner/operator.

Pearl production is increasing around the world, particularly in Oceania and in Indonesia. Increase in supply may well reduce the value achievable for pearls. In addition other kinds of pearls are coming on the market in ever increasing volumes, including freshwater pearls and abalone pearls. These may not be exactly the same premium product but they are sources of competition not previously found in the marketplace.

Pink snapper

Production system	Marine finfish cage culture
Broodstock/seedstock availability	Hatcheries operating
Temperature/water preferences	Temperate
Current market status/potential	Established domestic and international demand
Sector status	Developing

Pink snapper (*Pagrus auratus*) are temperate finfish, unrelated to the tropical snappers of the *Lutjanus* genus, but more closely related to bream and tarwhine. See sections on 'Bream', 'Silver bream', 'Black bream', 'Snapper' and 'Tarwhine' for more information.

Pink snapper are a high value species. They are an attractive fish sporting a beautiful pink colour with blue spots. There is good demand in the marketplace, particularly on the east coast of Australia. A very similar fish is also sought after in Japan. Other markets, particularly in Europe, have yet to be developed.

There are significant commercial and recreational fisheries based on pink snapper. In New South Wales there is evidence that the species is over-fished and that natural production has suffered as a consequence.

The good demand in the marketplace, and the perceived shortfall in supply has in turn stimulated interest in aquaculture. Hatchery technology is well proven. There have been commercial ventures growing pink snapper in sea cages, and these have produced hundreds of tonnes. A feature of snapper grown in cages in shallow, clear water is that, like people, they colour-up when they get a lot of sun – the snapper were brown rather than pink, and this presented a minus when it came to the marketplace. A variety of measures have been employed to change their colour: one is to keep them out of the sun, and another is to keep them in an environment that is light in colour, so they change to match.

Related species are farmed in sea cages in the Mediterranean and Japan.

Prawns

Production system	Land-based mariculture
Broodstock/seedstock availability	Commercially available depending on species
Temperature/water preferences	Subtropical to tropical
Current market status/potential	Established domestic and international demands
Sector status	Mature

The term 'prawns' in Australia generally refers to species of the genus *Penaeus*. In other parts of the world, notably the USA, the same animals are referred to as 'shrimp'.

A variety of species have been used, or considered, for prawn farming. See the sections on 'Black tiger prawns', 'Banana prawns', 'Kuruma prawns' and 'White shrimp' for more detailed information.

Depending on the species, broodstock (mother prawns) can be collected from the wild, or selected from existing farm stock (closed life cycle). The larvae are grown in purpose-built nurseries to post-larval stage before being stocked in the grow-out system.

The traditional approach to prawn farming is to duplicate normal growing conditions by creating shallow ponds, liberating post-larvae in them, maintaining the salinity of the water somewhere below that of seawater and supplying them with a mixed diet of natural food produced in the pond and a supplementary balanced ration. Water quality is maintained by a steady throughput of pumped water.

In some places the high density and significant size of prawn farming has led to a perceived problem with effluent. Joint efforts by industry and researchers are discovering ways to convert this so-called pollution to a resource by growing plankton-feeding fish, such as milkfish or mullet, on the algae produced by the nutrients in the exchanged water.

In any event, new technologies are developing, and these involve less water exchange.

The so-called 'Madagascar style' of prawn farming uses an extensive approach. Stocking densities are low – stocking densities reduced to two or three prawns per square metre. Feed input is low with prawns getting a lot of their food from the natural productivity of the ponds. Water exchange is low and water quality is maintained in the ponds by the natural bio-degradation processes. With everything in balance, aeration can be dispensed with.

Prawns can be grown in raceway ponds, with water movement being initiated by automatic oxygen sensors. A continual plankton bloom is promoted. Accumulations of pond bottom debris are addressed by the addition of pro-biotic bacteria cultures that literally eat the prawn faeces and uneaten food. Only minor water addition is used during the growing cycle to balance salinity. Stocking densities can be quite high using this system. Aeration is essential.

The most developed of the new prawn re-circulation technologies is the so-called 'Belize model'. In this system a continual bloom of benign bacteria is promoted. This is assisted by the addition of carbon, often in the form of sugar or molasses. The bacteria feed on the nutrients in the water and flock together. The small lumps of bacteria flock are readily eaten by the prawns. This ensures that almost all the nutrients in the pond water become available to aid the harvestable level of stock. Reputedly, Belize-style ponds can be operated for several years without water changes.

There is little trouble in selling prawns. Internationally there is a strong commodity demand. Domestic prices match the international commodity prices, but Australia also shows an additional profit spike over Christmas when prices take a significant jump.

Generally, prawns provide one of the most economically viable aquaculture options for tropical coastal Australia, provided a site suitable for farming can be obtained.

Rainbow trout

Production system	Freshwater flow-through
Broodstock/seedstock availability	Readily available
Temperature/water preferences	Cold water
Current market status/potential	Established domestic and international demand
Sector status	Mature

Rainbow trout (*Oncorhynchus mykiss*) is a salmonid fish from the Northern Hemisphere. (See section 'Salmonids' for more information on this group.) They are a very handsome fish. An adult in good condition has a red swathe running the length of its silver body and presents well on the display counter.

They were initially brought into Australia to provide recreational fishing in some of our cooler waters, but were coincidently also suited to farming. Rainbow trout are perhaps the hardiest of the salmonids in Australia. They can withstand high water temperatures (high for salmonids that is) and can live equally well in fresh or seawater. It is one of the most widely farmed species around the world and some people have unkindly dubbed it 'edible carp'.

Most rainbow trout are farmed in Victoria and southern New South Wales in freshwater using traditional flow-through raceways. Profit margins for this aquaculture sector are low, but farming methods and costs are established and the product is well accepted in the market as a flesh or smoked product. El Niño events can place some stress on the industry from time to time but the impact is absorbed, as unwelcome as it is, in the same way as in any farming sector. The total volume of fish produced is limited by access to suitable sites. Production has been increasing from the existing sites as growers have improved their methods and food companies have supplied more efficient diets.

The hardiness and activity levels of the species has made them popular with fishout ('catch-your-own') tourist operators and several family-run operations make a living from the rainbow trout where the water conditions are suitable.

Like all salmonids, rainbow trout can live in saltwater. When the boom in sea cage Atlantic salmon production was flying high, rainbow trout were tried too, and were marketed under the trade name of 'ocean trout'. Taste tests indicated that the average consumer could not tell the difference between sea grown rainbow trout and Atlantic salmon, yet in the marketplace goods sold under the name 'salmon' could command a better price than those labelled 'trout'. Cost for growing salmon and trout are much the same. The economic case was strong and growers focused on salmon.

Redclaw

Production system	Freshwater static pond
Broodstock/seedstock availability	Good
Temperature/water preferences	Tropical to subtropical
Current market status/potential	Niche domestic demand, possible export opportunities
Sector status	Mature

Redclaw (*Cherax quadricarinatus*) is one of the 'big three' freshwater crayfish that show the best potential for aquaculture in Australia. They are naturally found in the Gulf country and across the Top End but peter out before you get to the Kimberley. A very similar crayfish also occurs in New Guinea. See the section on 'Crayfish', 'Marron' and 'Yabbies' for more information on related species.

Of these three most commonly farmed freshwater crayfish, redclaw are best suited to tropical or subtropical environments, but prolonged low winter temperatures can minimise production and even cause mortalities. Economical farming is in earthen dams. They are more akin in habits and biology to yabbies than marron and grow fast in relatively high densities. By the time you get to northern NSW the growing time required makes them sub-economic.

Special hatchery technology is not needed as redclaw will breed in ponds provided they aren't experiencing what is, to them, an unnecessarily harsh winter. In fact, breeding can be a nuisance as it takes energy away from growing and increases stocking density, further limiting the size individuals in the ponds may achieve.

Red emperor

Production system	Marine finfish sea cage
Broodstock/seedstock availability	Poor to nil
Temperature/water preferences	Tropical
Current market status/potential	Established domestic and international demand
Sector status	The species has a possible future

Red emperor (*Lutjanus sebae*) is a tropical snapper much sought after in the market-place. (See the section on 'Tropical snappers' for more information on the group and possible farming technologies.)

There has been some interest in the aquaculture of red emperor, but to the best of the authors' knowledge, no serious commercial attempts have been made to farm them.

One of the authors has had some familiarity with red emperor. The fish have been found to tame very quickly, taking food almost immediately after capture.

Red snapper

Production system	Marine finfish sea cage
Broodstock/seedstock availability	Poor to nil
Temperature/water preferences	Tropical
Current market status/potential	Niche domestic and international demand
Sector status	The species has a possible future

There are two species known as red snapper: *Lutjanus erythropterus* and *L. malabaricus*. They both look pretty much the same but *L. malabaricus* is a little more heavily built. Both favour offshore areas, and are not as commonly found in estuaries as are some other tropical snappers such as mangrove jacks and golden snapper. This may or may not influence their preferred water conditions when farmed.

Tropical red snappers are not to be confused with the southern pink snapper. For more information on that species, see the section on 'Pink snapper'.

In common with the other tropical snapper species, red snappers are good eating. One of the authors remembers being at a barbecue where both fish were being served. He was told one species was better than the other, but when he applied the bite and chew test, both seemed equally good.

For more information on the farming of tropical snappers, see the section on 'Tropical snappers.'

Redfin

Production system	Static pond
Broodstock/seedstock availability	Poor to nil
Temperature/water preferences	Cold to temperate
Current market status/potential	Niche domestic demand
Sector status	Not developed

Redfin (*Perca fluviatilus*), sometimes called 'English perch', are a European species introduced into Australia.

Redfin have a sweet white flesh and are generally considered to be quite palatable to most Australians. They have only been available from the inland fishery. Subject to a disease named in their honour – redfin virus, EHN (Epizootic Haematopoietic Necrosis) – and the impact of ever-increasing dry spells, they have been offered in diminishing quantities. They receive good support when they do make an appearance on the market but farming them presents a few problems. That they aren't farmed in their native Europe where aquaculture is a well-established primary industry should tell us something.

In the USA, a closely related species, the yellow perch, is favoured for some kinds of subsistence aquaculture, but again does not form the basis of money-spinning sales success.

Redfin will breed readily, with little incentive needed. It is quite easy to throw a few into a farm dam, allow nature to take its course, and it won't be long before the pond is stocked with redfin. Trouble is, it will be too heavily stocked and the fish's natural response is stunted growth. It is common for people who have stocked redfin to comment that for the first year, all went well, but after that, the fish were too small. A common misconceived strategy is to leave them alone and let them grow, but all that does is allow them to breed more and stunt more. A far better strategy is to harvest ruthlessly. The survivors will have plenty of room in which to grow and reduced competition for tucker.

EHN is a locally grown disease of redfin that doesn't occur in its heartland, Europe. However, it is fatal to some native species, notably silver perch and Macquarie perch, and Murray cod and golden perch have been found to be carriers of the virus. While not on the noxious species list, the authors feel it should be, or at least clear warning given to the wider community about the disease and habitat-threatening status of this exotic species.

Rock lobster

Rock lobster is the term applied to spiny lobsters found in rocky areas. Well-known examples are southern rock lobster, eastern rock lobster and western rock lobster.

See the section on 'Lobsters' for more discussion on aquaculture potential.

Roe's abalone

Production system	Land-based mariculture Re-circulation systems
Broodstock/seedstock availability	Poor
Temperature/water preferences	Temperate
Current market status/potential	Established international and niche domestic demands
Sector status	Experimental

Roe's abalone (*Haliotis roei*) naturally occur in seas adjacent to the south-west corner of Western Australia. The population has the bad luck to be near Perth, and hence is subject to heavy harvest pressure and, as a consequence, strict regulation.

This species does not grow to a very large size. An individual with a shell 8 cm across would be considered large. They have, however, a following in the international market as well as attracting local domestic interest. They may not prove to be competitive with the larger species in an aquaculture situation and without a firm market advantage may not progress beyond the novelty stage as a farmed species.

Roe's abalone are found in rock headlands right in the surf zone. In their normal habitat they would have highly oxygenated water, and this might or might not reflect an advantage in aquaculture.

See the section on 'Abalone' for more general information on aquaculture of this species.

Rotifers

Production system	Re-circulation systems
Broodstock/seedstock availability	Available
Temperature/water preferences	Variable, but do better in warmer conditions
Current market status/potential	Aquaculture food trade yet to develop
Sector status	Technology developed, but little trade out of house.

Rotifers are an important component of the feed of finfish and crayfish larvae. Most larvae are stimulated to feed by moving food, and living rotifers do the job. The other important matter is size: the fishes' food should be between one-third and two-thirds of the gape of the fish's mouth. As the fish grow, the size of the food offered to them should change accordingly.

Growing rotifers is a farming operation in its own right. The rotifers are fed on micro-algae (requiring yet another farming operation). The art is to keep the algal food supply in equilibrium with the demands of the rotifers, while at the same time optimising the output from the system. Like most operations of this nature, rotifer cultures frequently collapse and have to be started again. Rotifers are usually produced in batches, the timing of which is synchronised with the requirements of developing finfish larvae.

Most fish nurseries produce their own rotifers as part of their procedures, so there is no real market for them.

Salmon

In Australia, two imported species of salmonids go by the name 'salmon'. They are chinook salmon and Atlantic salmon. See the sections dedicated to each for more information.

Both species were initially imported by the acclimatisation movement for stocking into native waterways to enhance recreational fishing. Attempts were made to commercialise production of both but only Atlantic salmon are farmed.

There is a native species called 'Australian salmon' which is not at all related to imported salmonid species. For more information on this species, see the section on 'Australian salmon'.

Salmonids

Production system	Marine finfish sea cages/Flow-through
Broodstock/seedstock availability	Good
Temperature/water preferences	Cold water
Current market status/potential	Established domestic and international demand
Sector status	Mature

Salmonids are a group of fish that occur naturally in the cool temperate/cold regions of the Northern Hemisphere. The group is quite large containing many species, most of which go under the names of trout, salmon or char. See the sections on 'Trout' and 'Salmon' for more information.

In Australia, the only native species with any relationship to salmonids at all are grayling, a fish of the south-eastern corner of the continent, which do not grow to a size to make them at all interesting to aquaculturists, and only marginally of interest to anglers.

During the early days of European settlement in Australia, many of the settlers yearned for all the 'good' flora and fauna they had left behind and the 'acclimatisation movement' was born. With the wisdom of hindsight, we now know that the introduction of species that might be considered benign in some other country may result in unwanted feral species here, but the acclimatisation movement had yet to learn that lesson.

In the days of sail, and later on when the main form of international transport was still by sea, it took a long time to get to Australia. Transporting fish was not all that easy, and it is a testament to the energy and persistence of the settlers that they managed to bring any salmonids to Australia at all. However, the range of species was not all that wide. The species that are here now are Atlantic salmon, chinook salmon, rainbow trout, brown trout and brook trout. See the relevant sections on each to obtain more information.

Saratoga

Production system	Static pond
Broodstock/seedstock availability	Available
Temperature/water preferences	Tropical
Current market status/potential	Niche market
Sector status	Established but limited in size

Saratoga (*Scleropages* spp.) are the Australian representatives of a group sometimes termed the arrowanas. They occur in tropical Australia and can grow to over 1 m, with the large ones having a formidable array of dental equipment. Anglers seek them for their fly-fishing qualities but saratoga flesh is not considered to be a delicacy. They will breed if left to themselves in a farm dam of suitable size. They are mouth brooders, with the adults holding eggs and newly hatched young safe behind those dreadful teeth.

Where saratoga have value is as an aquarium fish on the export market. It is reputed that in Chinese culture, this group of fish, especially the golden-coloured variety, are very lucky, and this makes it worth paying good money for the one you feel will bring you good fortune. However, don't think that you could sell one saratoga, then pay off your house, set up a fund to educate the kids and buy a new four-wheel drive, with a little left over to put towards your superannuation. They are potentially profitable, not too good to be true. Unfortunately local species do not appear to have an albino, lutino or golden strain. If you get hold of one, set up the stud farm!

Scallops

Production system	Long-line Ranching
Broodstock/seedstock availability	Technology developed
Temperature/water preferences	Cold to temperate
Current market status/potential	Established international and domestic demand
Sector status	Developing

Scallops are bivalves that live on the seabed, usually in sandy or gravelly areas. Most interest has been directed at the species that forms the basis of southern fisheries, *Pecten fumatus*, but interest has also been directed at other species such as queen scallops (*Amusium* spp.) and doughboy scallops (*Annachlamys flabellate*).

When disturbed, scallops squirt water from their shells making them move by reaction. They look rather like a feral flying pair of false teeth when they do this.

With many bivalves, only the adductor muscle (the one that holds the shells together) is eaten, but scallops have colourful reproductive organs, usually a bright orange to red, but sometimes a bluish colour. These are generally eaten with the adductor muscles.

In many places in the world there have been significant fisheries for scallops. In most, a cage is dragged over the seabed. Often the front of the cage has a rake with tines that dig down into the sand. When these come into contact with the scallops, the shellfish flip up into the water, and the cage moves forward to catch them. Scallop dredges take everything on the seabed, all that is left is ploughed-over ground. The resulting changes in the seabed are visible and are often (rightly or wrongly) blamed for declines in other fisheries, so an alternative to scallop fishing is seen as being socially desirable.

Aquaculture technologies have been applied to scallops in a variety of ways. Scallops can be bred in hatcheries. The resulting shellfish can be glued, or drilled and tied to dropper lines that hang from long-lines suspended from buoys. One popular method adopted from Japan is to hang them in lantern cages. There they can grow, free from some of their traditional enemies close to the seabed.

Scallop farming is labour intensive and this is reflected in the cost of production. Imported frozen product, grown or harvested in low labour cost areas, can be imported into Australia cheaply. The high cost local product may find that it is only competitive in the fresh chilled or live niche market.

Scallop spat can also be collected in the same way mussel or oyster spat can be collected. When the larvae are ready to settle, a suitable settling media is hung in the water column – usually onion bags. In this way, a good catch of young is ensured. These are taken to an area good for on-growing and later dredging. This methodology has been used in Japan and in the last few decades was the subject of foreign aid from Japan to Tasmania. It was a technical success, but unfortunately the scallops came ready to harvest at the same time as a worldwide glut in scallops, so it was an economic failure.

Scampi

Production system	Unknown
Broodstock/seedstock availability	Zero
Temperature/water preferences	Poorly understood
Current market status/potential	Niche international and domestic demand
Sector status	Non-existent

Scampi are lobster-like decapod crustaceans that live on the seabed in deeper waters. While there would no doubt be a market for aquaculture-produced scampi, the authors are not aware of any attempts to farm this species, and strongly suspect that details of its life cycle have yet to be identified.

Sea bass

This is the term used in Asia for barramundi – see section on 'Barramundi' for more information.

In Europe, the name is often applied to members of the family Sparidae. See the section entitled 'Bream' for more information.

Sea dragons

Production system	Marine re-circulation systems
Broodstock/seedstock availability	Availability limited
Temperature/water preferences	Cool to temperate
Current market status/potential	Niche international and domestic demands; demand untested – possible boutique in nature
Sector status	Established but very limited in extent

As with many common names, the term 'sea dragon' can mean different things to different people. The average Australian with some interest in aquatic life will take the term to describe two Sygnathid species: the common sea dragon (*Phyllopteryx taeniolatus*) and the leafy sea dragon (*Phycoduous eques*). Even these two get confused, and one author prefers to call them the common sea dragon and the uncommon sea dragon, as the latter species has a more restricted natural distribution, and it can be argued that it is the more striking species.

These sea dragons have a very exotic appearance and have acquired a 'notable' status among naturalists. As a consequence they are generally well protected by law and special permits are needed to harvest them.

Both of these sea dragon species are being farmed in Australia, but it is the authors' understanding that it takes a great deal of skill to take broodstock from the wild, keep them alive in captivity and rear the young. The life cycle is not closed in captivity. Around the end of the calendar year, males can be found carrying eggs on a pad under the tail. The males are harvested (they don't swim any faster than a diver, but need a lot of tender love and care if they are to survive the catching process) and are kept under conditions where the young will hatch. Very young sea dragons are about the length of a match and are able to take quite large (by normal aquaculture standards) live food. Only a very limited numbers of operators are successful.

Very good prices can be obtained for these species of sea dragons when they are sold into the ornamental sector, but they must arrive in first-rate condition. This is the most boutique of the boutique markets and if there is a significant increase in supply, prices may fall dramatically.

In the Chinese medicine trade, the name 'sea dragon' has a slightly different meaning. It refers to Sygnathids that have a similar body form to the just-mentioned species, but of a different species. The authors do not claim any special expertise in Chinese medicine, but they understand that it is quite specific in the varieties considered to be the most effective and potent, and that near-enough is not good-enough. There are many species of Sygnathids in Australia, and some may well be of a quality considered desirable. Thorough market research is essential.

It would seem probable, that in a general sense, the name sea dragon can be applied to any Sygnathid that has a body deeper than wide and a head that extends forward along the line of the body, that is, a deep-bodied pipefish, or a seahorse that has been straightened out. Sometimes the term 'pipe horse' is applied to the animal. If the fish have protrusions that look something like leaves, so much the better. One of the authors has seen some unusual and bizarre fish fitting the description taken from Darwin Harbour. There may well be markets for other species.

See the section on 'Sygnathids' for more information on sea dragons and related species.

Seahorses

Production system	Marine re-circulation systems
Broodstock/seedstock availability	Available
Temperature/water preferences	Cold to tropical dependant on species
Current market status/potential	Established international demand
Sector status	Developing

In recent times there has been some attention applied to developing farming technology based on seahorses and several businesses have been established. Seahorses are species of the Sygnathid family in the genus *Hippocampus*. They are related to other species such as pipefish and sea dragons. See the section on 'Sygnathids' for more information on seahorses and related species.

There are various species of seahorses found around Australia. In southern regions there is a charming little species called White's seahorse and the larger big-bellied seahorse. Both of these are attractive, but in common with many temperate marine species they have problems when water temperatures rise over about 20°C, which can happen if they are kept in fish tanks in summer.

In tropical Australia there are other species. These are likely to be better adapted to living in tropical fish tanks and some are quite colourful. Another consideration is that many of the tropical species will be the same, or very similar, to species found in Asia, and are likely to have a pre-existing slot in the marketplace.

Seahorses are reported to undertake quite complex and extended courtships. Once mated, the males store the eggs in a pouch. When the eggs hatch, the small, but fully formed, juvenile seahorses are expelled. They require live food.

One common husbandry problem with seahorses is they can get large bubbles under the skin. Not only do these look uncomfortable (and they can't be good for the animal's health) but they also fill with gas, and destroy the seahorse's balance in the water. One of the authors recollects seeing seahorses with weights tied to them to prevent them from floating to the surface. The cure for gas bubbles is not known (or at least kept a secret by producers) but attention to water quality parameters and the stability of the system would have to be a start.

There are markets for seahorses but despite the hype, common seahorses sell into the aquarium trade at common aquarium trade prices. The authors do not claim any expertise in Chinese medicine, but they suspect that the same could be said of that market. Having suggested that farming seahorses is not necessarily a licence to print money, it is not to say that a reasonable profit might not be made from growing seahorses to sell into the aquarium and Chinese medicine markets, especially if the species raised meets the product requirements.

Seaweeds

Production system	Ranching Long-line Land-based mariculture
Broodstock/seedstock availability	No commercial supply
Temperature/water preferences	Cold to tropical depending on species
Current market status/potential	Established international demand; domestic demand unexplored
Sector status	Undeveloped in Australasia

In terms of tonnes of produce, the farming of seaweeds is by far the largest sector of global aquaculture. You may never have heard of this, and that is because most seaweed farming occurs in East Asia, where market preferences and cost structures are vastly different from those operating in the Western world.

Seaweeds can be eaten, and this can be seen commonly in Japanese cuisine. Some seaweed products, for example *nori*, are on a weight by weight basis, quite valuable.

The other use to which seaweed is put is the extraction of chemicals. At one time, saltpetre was extracted from kelp in California and this was quite a significant enterprise. However, in recent decades far more effective sources of explosives have been found and this industry has waned. Currently seaweeds are used to produce phytocolloids, slimes and gels which are used in a wide variety of products, from toothpaste, to leather softeners to jellies upon which bacterial cultures are grown.

It's a long way from the local supermarket to the beaches of Zanzibar, but a recent radio report detailed how, on the south-east coast of that island, seaweed farming had induced significant social change. A crop, possibly the seaweed *Euchuma*, is grown on mono-lines at local beaches. Initially the males in the society disdained to work at this industry, but even though returns were low – 18c/kg – the money made by the women was enough to empower them within the local society.

One of the species of seaweed favoured in Asia is the species *Undaria pinnatifida*. This species has gone feral in Tasmania, and there have been attempts to turn the problem into a money earner, promoting harvest of the weed. So far, no massive industry has eventuated although preliminary work has proved promising. In common with most other pest species, the authorities are unlikely to want to see any culture technology applied to a feral weed.

Like any plant, seaweed uses nutrients such as phosphorus and nitrogen as key ingredients in its growing cycle. Strategically placed seaweed farms could help balance nutrient loads in areas where they are grossly out of balance, such as marine environments that have been compromised by human activities such as urbanisation and agricultural activities. One alternative that has been suggested is growing seaweeds inland, away from the sea, in tile drains used for evaporating saline groundwater pumped to the surface to save vast tracts of salt-threatened farmland.

Shrimp

Shrimp is the common name for prawns used in the USA. You may remember Paul Hogan suggesting, 'We'll put a shrimp for you on the barbie'. See 'Prawns' for more information on their farming.

Silver bream

Production system	Marine finfish sea cage
Broodstock/seedstock availability	Technology available
Temperature/water preferences	Temperate
Current market status/potential	Niche domestic demand
Sector status	Species with a possible future

Silver bream (*Acanthopagrus australis*) is found on the east coast of Australia. They are very handsome fish is are considered good eating. However, the costs of breeding and growing this species are much the same as those for pink snapper, yet the return in the marketplace from snapper is generally higher. It seems likely that the aquaculture industry will need to be a lot more mature before commercial farmers will diversify into silver bream.

Silver perch

Production system	Freshwater static ponds
Broodstock/seedstock availability	Good
Temperature/water preferences	Warm water
Current market status/potential	Niche domestic demand
Sector status	Mature

Silver perch (*Bidyanus bidyanus*) are an omnivorous finfish naturally found in the Murray-Darling and adjacent basins.

Silver perch are an opportunistic fish and the wild population ebbs and flows with the season. Since the alteration of the flood regime that once drove the ecology of the Murray–Darling Basin, anglers and environmentalists have noticed more ebbs than flows. European carp has in part been blamed for some of this dispossession. Fortunately, recent years have seen our hardy Aussie species make a bit of a comeback, and if they are not actually in the ascendancy, they at least no longer look to be on their way out. The danger sign may be that the river systems, once swinging between the fabled inland sea and a drought stricken string of waterholes has been more of the latter over the turn of the century: conditions more suited to adapted natives than a feral European species.

Silver perch are white-fleshed fish that has a flavour of its own. However, it also carries the flavour of the pond in the marbled fat of its flesh. Unpurged fish have restricted its wider market appeal but it has a good following in east Asian cuisine where it is sold live.

They display all the key attributes of a farmed species although they haven't proved to be adaptable in re-circulation systems. Whether this is the fault of the husbandry applied or whether the species isn't suited to the confined spaces found in production tanks is not established. However, it is a fast-growing and efficient species for pond culture.

The high level of production makes silver perch particularly suited to subsistence aquaculture.

Aquaculture of silver perch has been around for several decades now. Seedstock are readily available, and the parameters of growth and production are well understood.

Sleepy cod

Production system	Freshwater static ponds Re-circulation systems
Broodstock/seedstock availability	Good
Temperature/water preferences	Warm water
Current market status/potential	Niche domestic demand, possibilities for boutique markets and export
Sector status	Species with possible future

Sleepy cod and several closely related species (*Oxyeleotris* and *Bunaka* spp.) are not cod, but are members of the gudgeon/goby group of fishes: a separate kind of finfish entirely. Unlike many other members of the gudgeon/goby group, they grow to a largish size and live in freshwater (though they can withstand somewhat brackish conditions). They look rather like a freshwater version of a flathead.

Aquarium fish fanciers tell us that gobies and gudgeons are relatively easy to breed in captivity and it would seem that sleepy cod also do not prove too difficult to propagate. Hormone inducement is not needed. The adhesive eggs can be collected by spawning traps left in ponds containing several adult sleepy cod. Inside a hatchery, the eggs can be cared for using more or less standard technology until the young hatch out. Once hatched, the larvae seem to do better outside in plankton ponds where there is an abundance of live food, although survival can vary. Supplies of seedstock are available for on-growing.

Sleepy cod are an ambush predator, normally hiding and waiting for something edible to swim near. Their camouflage is excellent. One of the authors recollects snorkelling through a waterfall plunge pool in the tropics, idly looking down at the bottom. All of a sudden, what was previously a line here, and a curve there, coalesced into quite a siseable sleepy cod with what appeared to be a disproportionately large mouth. Small fish in the area may well have failed to see the hidden sleepy cod, and if they approached too close, it would have had dire consequences.

The predatory habit of sleepy cod suggests two implications for farming. The first is that sleepy cod could be prone to significant cannibalism, especially in the crowded nursery stages, and this has been found to be the case, requiring fish to be graded for size often enough to ensure that the mouths of the larger fish do not get bigger than the width of their slower growing siblings. Keeping them full of tucker may also dissuade them from looking at their siblings with culinary intentions. The other implication is that sleepy cod might be disinterested in non-moving food. This latter implication has been found not to hold: domesticated sleepy cod will take pelleted food.

Once grown a bit, the older fish appear to be well suited to re-circulation systems. They are at the boutique end of the market and command the high price needed to meet the high break-even costs of such systems.

Sleepy cod do not appear to reach filleting size (at least what is regarded as filleting size in Australia). They almost never reach 1 kg in weight. The final product has to be whole fish. Indications are that a 500 g fish could be grown in about 18 months. They travel well in a plastic bag with water, and can even survive for some time out of water.

There is a limited demand for sleepy cod in the marketplace. There is real interest in the major Asian markets where a closely related fish, the marbled goby, is much sought after: they are reputed to be worth more than $40 per kg. In Australia, sleepy cod are likely to be able to command a significant proportion of that amount.

Slipper lobsters

Production system	Land-based mariculture Re-circulation systems
Broodstock/seedstock availability	Poor
Temperature/water preferences	Temperate
Current market status/potential	Poor domestic demand, possible export demand
Sector status	Not possible at this stage

The rock lobsters we are familiar with are only one of a diverse group of decapod crustaceans. Some vary widely in shape from the classic ‘lobster’ form. Slipper lobsters look like a rock lobster whose head somebody has stood on and flattened. Like rock lobsters, they live in holes in rock or coral, but slipper lobsters cling close to surfaces, and their flatter form helps to camouflage them from predators.

In New South Wales, recreational divers frequently take slipper lobsters. They say that the eating qualities are just as good as the more commonly known lobsters, however, the unusual shape, and lack of familiarity to the buying public means that slipper lobsters tend to command a lesser price than rock lobsters.

Bugs are sometimes referred to as slipper lobsters. See the section on ‘Bugs’ for more information.

To the best of the author’s knowledge, no attempts have been made to develop aquaculture technology for slipper lobsters.

Snakehead

Production system	Ponds/intensive freshwater
Broodstock/seedstock availability	Noxious in Australia
Temperature/water preferences	Tropical
Current market status/potential	Boutique market, possible export demand
Sector status	Noxious – forget this fish

A comment before you read further about snakeheads – 'Don't even think about getting them!'

Snake heads (*Channa* spp.) are a fish often used for farming in Asia, they are hardy and there is a demand in the marketplace, but, they have massive pest potential. It is illegal to import them, it is illegal to hold them live.

Snappers

Production system	Finfish sea cages
Broodstock/seedstock availability	Some species available
Temperature/water preferences	Temperate to tropical dependent on species
Current market status/potential	Established international and domestic demands
Sector status	Developing

In the tropics there are a suite of species known by the name 'snappers'. Common examples are the red emperor, mangrove jack, golden snapper, red snapper, and others. See 'Tropical snapper' for general information and relevant sections for the individual species.

In the southern parts of Australia there is a quite distinct fish known as 'snapper' which is related to breams and tarwhine. To distinguish this from the tropical species, the southern fish is now generally referred to as 'pink snapper' (see section on 'Pink snapper' for more information).

Something totally new

Every now and then somebody comes up with a species that is totally new – sometimes called the 'Million dollar fish (*Givus yadoughii*)'. This species makes a regular appearance on the investment market and should be thoroughly investigated before any commitment to its commercialisation is considered. Usually the proponents are trying to sell broodstock or seedstock rather than getting their dollars from growing the animal itself, or maybe there is a company being floated and the proponents are selling shares. It is possible for something new to come along and it might be something good, but experience has shown that it is wise to seek proof to support the value. Developing the technology to grow a new species can take a decade before it is well enough understood to generate a positive cash flow for the producers.

Probably the best place to start checking out these wonder fish is in the marketplace. If they don't have at least a niche market, how do you know anyone's going to buy them? Fishmongers and restaurateurs are notoriously conservative when it comes to dealing in new perishables. Even if it has a niche market, explore the depth of the market by making thorough enquiries. Of course you can always test the market depth by growing the bin of fish that broke the market's back. But by then it's too late.

However, like all generalisations, this isn't always the case, for example when Barcoo grunter hit the market they were an unknown quantity. Not unlike silver perch in appearance, they were marketed as jade perch and have developed a following in East Asian cuisine. One advantage it did have was that its husbandry wasn't dissimilar to that of silver perch and could be grown in the same ponds, seedstock was readily available and nutrition requirements were similar. It grew quickly to market size and the cost of production was manageable. It also proved a hit in re-circulation systems; something that silver perch had failed to do. Jade perch fry are now being shipped to Asia in large numbers.

Jade perch has proved the exception to the rule but it was thoroughly tested before it became an established species. Just be cautious before parting with hard-earned dollars and remember if something seems too good to be true, it probably is!

Sooty grunter

Production system	Freshwater static pond Re-circulation system
Broodstock/seedstock availability	Available
Temperature/water preferences	Tropical
Current market status/potential	Undeveloped
Sector status	Developing

Sooty grunter (*Hephaestus fuliginosus*) is a hardy species that is well suited to farming in inland ponds. In some ways it is a higher temperature equivalent of silver perch. Seedstock is available from limited sources. In some places (for example inland Queensland and Central Australia) the species available for aquaculture is limited and sooty grunters provide an alternative. They tend not to grow very large though. The name 'sooty grunter' may not be the most likely to attract high paying purchasers of fish, but if 'black bream' is deemed to be an acceptable trade name, then this might help in the marketplace.

Southern bluefin tuna

Production system	Marine finfish sea cage
Broodstock/seedstock availability	Available to selected operators
Temperature/water preferences	Cool to temperate
Current market status/potential	Established international demand
Sector status	Mature

Southern bluefin tuna (*Thunnus maccoyii*) is a true ocean finfish, ranging thousands of kilometres over the oceans of the Southern Hemisphere. A similar species, northern bluefin tuna, is found in the Northern Hemisphere. Its similarity to the well-known northern bluefin tuna may have assisted its market acceptance.

See the section entitled 'Tunas' for more general information on this group of species.

Southern bluefin tuna is a much sought after species in the Japanese sashimi market. Sashimi-grade fish must be absolutely fresh. One of the authors worked as a commercial bluefin tuna fisher in his youth and he recollects the decks of the fishing boat being littered with tuna lying in the sun, and staying there till the boat managed to get back to port at the end of the day. The fish were in a condition adequate for the local canning works, but degradation had certainly set in. This was not the best way of keeping the value of the fish.

In the latter decades of the last century, southern bluefin tuna were really over-fished and the capacity of the resource to renew itself was compromised. Fishery management changed and quotas were introduced. All of a sudden, individual commercial fishers had an incentive to get the best from each individual fish, rather than spending their time and money on bigger and faster boats to catch the ever-dwindling stocks. An obvious way of increasing the return was to crack the Japanese sashimi market. But how to do it? After several approaches were tried, fishers decided to keep their catch alive in net cages, so that they would be ready for harvest and packing in time to match the departure of flights to Japan. On the face of it, fast, wide-ranging fishes such as tuna would appear to be the last kind of fish to be happy in captivity, but they were, and it was found that adding food not only improved the condition of the stock, but added value: the bluefin tuna fishery moved into the realm of aquaculture.

At this stage the life cycle is not closed. Aquaculture and a wild fishery are inextricably linked in this case, but the authors can't help but wonder what will happen to the price should tuna ever be bred in captivity.

In South Australia feedlotting of wild caught tuna can be considered a classic aquaculture success, bringing much needed income and employment to remote areas. But there has also been a downside too. In one instance poor siting of cages led to a disastrous drop of water quality during a storm, killing fish. Fingers have also been pointed at the practice of feeding tuna whole fish harvested elsewhere, potentially introducing unwanted pathogens. These problems have been, or are being, addressed and tuna farming is moving to a much more sustainable mode. For instance, Skretting Australia has developed a dry diet at their Hobart mill that is as efficient as the frozen bait fish currently fed to caged tuna.

Spiny crayfish

Production system	Freshwater flow-through
Broodstock/seedstock availability	Poor
Temperature/water preferences	Cold water
Current market status/potential	Since the closure of the wild fishery this market has remained dormant
Sector status	Undeveloped

Murray crayfish, Glenelg River crayfish and the closely related species of spiny crayfish (*Euastacus* spp.) are found all along the Great Dividing Range catchment that runs the length of the east coast of Australia and across Victoria to the South Australian border. They grow big. They have big spiny claws. They look spectacular.

It has been suggested that spiny crayfish may offer potential for aquaculture. However, they grow slowly compared to other kinds of crayfish. A slow-growing cycle generates poor cash flow and allows plenty of time for disasters to destroy profitability. A key concern about them as an aquaculture species is their aggression. Their dietary requirements have not been established, and we are still in the dark as to their habitat requirements.

Forget spiny crayfish.

See the section on 'Crayfish' for more information on related species.

Spirulina

Production system	Land-based freshwater ponds
Broodstock/seedstock availability	Available
Temperature/water preferences	Warm to tropical
Current market status/potential	International commodity market
Sector status	Developed

Spirulina is a small floating alga. Its scientific name is *Arthrospira*. There was a time when the scientific name included the word *spirulina* and this is where it got its common name. Scientists being what they are, few things are left alone for long, and they reclassified it, hence the new scientific name.

As dried spirulina is sold as a health food, you would have to concede that there's a healthy market for it around the world.

As far as floating algae goes, spirulina is large, but each plant is still way too small to be seen by the naked eye. A bottle of water with a lot of spirulina in it is a thick lime-green colour.

There are not many spirulina farms in Australia, and not all that many in the rest of the world for that matter, but some general similarities of layout exist. Generally seed cultures of the alga are grown in small tanks of about 1000 litres. Once the culture has taken, the tanks are then emptied into nursery ponds, of maybe a quarter of a hectare or less. Once the algae have multiplied enough to be dense enough in these ponds, the water (containing the spirulina) is moved into larger ponds.

The water initially going into the ponds should be pretty sterile. You want to give the spirulina a free go at all the nutrients without any competing organisms. The fewer contaminant species at harvest, the better the price. On the scale of farming needed, getting sterile water is a big ask. One of the best sources is groundwater.

It is common practice for pond water to be slowly circulated, usually from one end of the pond to the other via a maze of baffles. In depth, ponds are generally shallower than about a metre. Mild aeration may be added by letting the water fall over shallow drops, or by spraying a fine jet of water onto the surface. The jet assists to keep the water moving too.

Depending on the nutrient status of the incoming water, few additives are needed. This is important as spirulina is sold as a health food, and it is an important marketing point that there are no 'additives'. The pH is checked to see that it is around 8 or so, and water is also checked to see if there are enough phosphates and nitrates. Sudden changes in water quality can kill the alga, and are to be avoided.

Light is essential to the growth of plants, but paradoxically, it can also be a problem. In tropical Australia there is a lot of light and initial attempts at farming had significant mortality. It was found that the density of spirulina had to be above a certain level so that the spirulina in the middle of the water column, and at the bottom, were shaded by those above. As the water in the ponds moves gently, the lower spirulina are mixed upward, and in turn shade the others.

Spirulina is harvested by allowing pond water to fall through a fine mesh filter. The water drains away and a green slime is left. This is scraped off and placed in a container. Harvest is continuous. Once a pond is up and going, a small proportion can be creamed off steadily on a daily basis.

Before the harvested alga can die or be bleached by the sun, it is taken to the drying plant and dried.

It is technically possible to grow spirulina in small quantities, using the techniques described in the micro-algae section, but economics preclude this from being a viable method for the scale of the investment. To make a profit, there has to be critical mass. To produce the volume required, a large farm is needed, and a large farm costs large money to establish. Spirulina is sold in a dried form, and the drying facility costs more money (start at a million dollars and go up). The point is that this is not a variety of aquaculture for the battler to attempt, but rather something that falls into the province of corporate aquaculture that can fund the total needed investment of four or five million dollars.

Sponges

Production system	Marine long-line
Broodstock/seedstock availability	Available
Temperature/water preferences	Warm to tropical
Current market status/potential	Unknown
Sector status	Possible future

In times gone by, sponges used for washing came exclusively from the wild. Only a few species were the right kind, but if appropriately treated after harvest, they provided a soft sponge. There is still a boutique market for these sponges and they do have a definite slot in the marketplace.

Other uses have been suggested for sponges. It seems that some species contain bioactive chemicals, that is, substances that might form the basis for pharmaceutical drugs. If they can be farmed in big enough quantities, the sponges may be refined to make a high value product. This has still to be established as an economically viable form of aquaculture, but the possibility is there.

Sponge aquaculture is not really an established industry, and certainly not in Australia. It has been suggested that the way to go about it is to take an existing sponge, cut it into small pieces and thread each of these onto a rope. The rope is kept in water, either as a dropper, a long-line between anchored buoys or along a mono-line strung between posts driven into the seabed in shallow waters. The rope and sponges are left to grow and after a given period, the farmer comes back to harvest the sponges.

The advantage of this system is that very little input is needed. No food, no culling or sorting. The disadvantage is that somebody else might come along and decide to harvest the cash crop a week or so early. Sponge farms would have to be watched. It has been suggested that sponge farming may be well suited to remote areas in Australia's north. Traditional owners in these regions may not be serviced by the infrastructure required for complex forms of aquaculture, but they would be well equipped to manage the sponge lines and more importantly, keep an eye out for new or unknown faces in the area.

Striped trumpeter

Production system	Marine finfish sea cage Possible intensive marine re-circulation system
Broodstock/seedstock availability	Research stage
Temperature/water preferences	Cool
Current market status/potential	Niche domestic demand
Sector status	Possible future

In the halcyon days when the Atlantic salmon industry was booming in Tasmania, other species were also looked at to supplement the crop. Striped trumpeter (*Latris lineata*) was touted as the next big thing.

The striped trumpeter is a handsome fish indigenous to the southern waters of Australia. Its sweet, white flesh makes it a prized table fish. In the local marketplace striped trumpeter achieves a premium price, but it is hardly known outside Tasmania.

Even though breeding trials have been going on for a number of years, commercial supplies of seedstock seem as remote as ever.

Sydney rock oyster

Production system	Inter-tidal shellfish culture
Broodstock/seedstock availability	Readily available
Temperature/water preferences	Temperate to warm temperate
Current market status/potential	Established international and domestic demands
Sector status	Mature, but suffering from decline

At one time the premier aquaculture industry in Australia was undoubtedly the Sydney rock oyster (*Saccostrea commercialis*) sector.

Times change. The level of pollution has increased in New South Wales. NSW oysters may now be farmed. Consumers have become wary since the Wallace Lakes event and other products have become available for entrées in restaurants. The once formidable Sydney rock oyster industry has gone into decline.

Tarwhine

Production system	Marine finfish sea cage
Broodstock/seedstock availability	Poor
Temperature/water preferences	Temperate
Current market status/potential	Niche domestic demand
Sector status	Conceptual

Tarwhine (*Rhabdosargus sarba*) is quite similar in appearance to silver bream (see the sections on 'Pink snapper' and 'Silver bream' for more information) but it has a humpier head, and its scales are larger in proportion to its body size. Despite an apparent likelihood of this species being domesticable, to the best of the authors' knowledge, nobody has really tried. It would seem most probable that the related species show more likely prospects, and these are being tried first.

Temperate wrasses

Production system	Marine finfish sea cage Re-circulation systems
Broodstock/seedstock availability	Not currently available
Temperature/water preferences	Temperate
Current market status/potential	Established domestic demand, possible international demand
Sector status	Conceptual

In recent years, there has been an increasing demand for wrasse in the Australian Asian food market. Since most of the market is in the southern parts of the continent, supply has focused on local species, such as the blue throat wrasse (*Notolabrus tetricus*) as well as similar-looking wrasses.

Temperate wrasses are generally not aquaculture species per se, but are distributed in the live fish trade: fish hooked from the wild are kept alive and maintained in fish tanks. Once in tanks, intensive aquaculture technology is applied. This is another example of an interrelationship between wild fisheries and aquaculture, where one benefits the other.

The life cycle of temperate wrasses has yet to be closed in captivity. The cycle has been closed for other wrasses (see the section on 'Napoleon wrasse' for more information) and this would suggest there is no overwhelming impediment for this to be done with temperate wrasses. Perhaps there are just not enough dollars there yet.

Tiger abalone

Production system	Land-based mariculture Ranching
Broodstock/seedstock availability	Technology understood, stock not readily available
Temperature/water preferences	Cold water
Current market status/potential	Established international demand
Sector status	Conceptual, but may have a future

It is undecided whether tiger abalone are a subspecies or colour variation of blacklip abalone. It bears the same scientific name: (*Haliotis rubra*). It is similar in appearance to the Japanese species, *ezo awabi* (*Haliotis discus hannai*). This is the species against which the Japanese judge all other abalone. If an abalone looks like an *ezo awabi*, it can achieve a high price in Japan. The Japanese do not consume all the abalone in the world, but the Japanese marketplace does have a very important role in setting the international price.

Tiger abalone broodstock grow true to type and growers source their seedstock by collecting tiger males and females from the wild. As the name indicates, there are a series of stripes on the foot, and usually to a lesser extent, on the shell. Growers don't notice any production advantage in growing tigers but there could be a market advantage at any given time, depending on the state of the increasingly volatile world abalone market.

Trepang

Production system	Ranching
Broodstock/seedstock availability	Technology developed, no commercial supply
Temperature/water preferences	Tropical (depending on species)
Current market status/potential	Established international demand
Sector status	Species with a possible future

Trepang, beche-de-mer or simply sea slugs, are holothurians that lie or roll on the seabed, sifting through mud and sand to find the odd nutritious morsel. There are a series of species and they go by names such as 'sand fish', 'red surf fish', black lolly fish' and 'teat fish'. All in all, the names appear much more interesting than the slugs themselves.

After harvest, trepang are dried so that they shrivel down to a blackened sausage.

Historically, the only cuisine that utilised trepang was the Chinese, where they are considered to provide health benefits. One of the authors has eaten trepang in a Chinese restaurant, and considers that it would have to have a great number of health benefits: people wouldn't eat them for their taste, which is something like the flavour and texture of a kitchen sponge, with a black bean sauce poured over it.

There is also a Japanese market, where the trepang are not dried but eaten raw, very fresh and almost alive. They need to be this way to ensure a crisp texture. Again, not overwhelmingly attractive to the author who tried it.

The authors' gastronomic prejudices aside, there are a great many potential customers who want to eat trepang and are prepared to pay for it. In recent times there have been more and more of these customers and the demand for trepang has risen. Supply, on the other hand, is not so well catered for. Trepang fisheries have a propensity to boom and bust. One year hundreds of tonnes may be taken by collectors, then the next no more trepang are to be found.

Around the turn of the 20th century, hatchery technology was developed for trepang. It would seem not too difficult to produce a plethora of sluglets, the question remains on what to do with them once they have been produced. So far, attention has been directed to re-seeding areas that have held good populations of trepang in the past but do not do so currently. It has yet to be proven that liberation of large numbers of sluglets into an area will result in larger slugs in the course of time, but the possibility looks good. However, who will bear the cost of stocking if they cannot claim ownership of the final profit? It may be that this is an area where aquaculture technologies are best adopted by fishers to assist the sustainability of their harvest.

Trochus

Productions system	Ranching
Broodstock/seedstock availability	Technology known and simple No commercial supply
Temperature/water preferences	Tropical
Current market status/potential	Niche international demand
Sector status	Conceptual/pilot

Trochus are a marine gastropod mollusc that look like a snail with a twisted shell. They have been common on tropical coral reefs.

The animal inside the shell is edible, but not of very high demand in the marketplace. The money is in the shell: when the shell is cut, it is a shiny material much sought after for production of high quality buttons.

In years gone by, enthusiastic harvesting of wild trochus resulted in a dearth of these shellfish in most natural habitats across the top of Australia and in adjacent Indonesia.

Trochus can be bred without too much technical effort. A water change with a heat shock of a few degrees is usually sufficient to induce spawning and fertilisation occurs without too many dramas. Trochus larvae quickly settle and take up life as tiny versions of adults.

The technology used so far has not focused on industrial aquaculture production of adult shell. Rather, the technology is being directed toward re-seeding wild areas with juveniles in the hope that this will increase natural stocks, usually to the benefit of indigenous subsistence harvesters.

Tropical abalone

Production system	Land-based mariculture Ranching
Broodstock/seedstock availability	Technology available No commercial supply
Temperature/water preferences	Tropical
Current market status/potential	Established international demand
Sector status	Pilot

In the northern parts of Australia a variety of abalone species are found, one of which, the asses ear abalone (*Haliotis asinina*), has been the focus of some interest. Despite occasional attempts, there are no commercial abalone fisheries in the Australian tropics.

Asses ear abalone are not your usual run-of-the-mill abalone. They have a shell, but compared to most abalone species, the shell is proportionately small, and doesn't cover much of the underlying foot. They are green in colour.

In Asia, there has been some effort to culture asses ear abalone and apparently some success. In Australia there has been limited efforts to research this species. It appears possible to get them to breed in captivity, but difficult to get them to do it when the farmer wants them to, making it difficult to produce to commercial timetable or scale. Nor has the species endeared itself to the processing sector because of the uneven texture of the meat. This, and the fact that this species does not resemble the market 'ideal' means that the prices received for asses ear abalone are generally not as good as those for the more acceptable southern species.

It is possible to keep most abalone species in aquaria, but only the asses ear abalone is actively sought after and moved around in the aquarium trade. There are commercial possibilities here.

There are other species of abalone that grow in the tropics. Some are of a form that would appear to be more acceptable in the marketplace, but few reach a significant size. China and Taiwan produce several thousand tonnes annually of a local, tropical species, the South China Sea *H. diversicolor supatexta*, but they are not a high value product and although they have market acceptance, the cost of production under Australian conditions, when added to the transportation cost, may preclude their commercial cultivation.

Tropical snappers

Production system	Marine finfish sea cage Land-based mariculture
Broodstock/seedstock availability	Limited, depending on species
Temperature/water preferences	Tropical
Current market status/potential	Niche domestic and international demand
Sector status	Species with possible future

Not to be confused with the southern 'Pink snapper', tropical snappers are of the genus *Lutjanus*. There are many species, but perhaps the best-known are mangrove jack, red emperor, golden snapper and red snapper. See the sections devoted to these species for more information on each species.

Another fish referred to as a tropical snapper is the goldband snapper. See the section on 'Goldband snapper' for more information.

As with many marine finfish, the larvae of tropical snappers are quite small, making them difficult to feed using traditional rotifer technology. At the Darwin Aquaculture Centre, technology using copepods was developed and this proved to be a suitable food for juvenile golden snapper. Fish were conditioned and spawned and the life cycle was closed with several generations grown in captivity, proving the technology, and potentially offering a supply of juveniles to the market.

The name 'snapper' has some magic in it, and may help to market these fishes to people unfamiliar with them.

Trout cod

Production system	Unknown
Broodstock/seedstock availability	Technology known but seedstock unavailable
Temperature/water preferences	Warm water
Current market status/potential	Not highly prized when it was available through the wild fishery. Not tested since classified endangered and removed from fishers' entitlements
Sector status	Species listed as endangered

Trout cod (*Macullochella macquariensis*) are a slightly slimmer version of the well-known Murray cod (see the section on 'Murray cod' for more information on that species). Unless you are familiar with the two species, it can be tricky distinguishing them on their looks alone. Some of the main distinguishing features on the trout cod are the stripe through the eye, not unlike those found on a black duck; the blue sometimes found on their lips; the undershot jaw; the relatively thicker caudal peduncle (tail piece, as distinct from the tail fin) and the speckled markings rather than the carpet snake pattern of the Murray cod.

In the wild, the habitat of trout cod has been dramatically altered and nowadays, there are not as many trout cod as scientists seem to think there should be. Their conservation status is classified as endangered. A fair amount of research has been undertaken on the breeding of trout cod for restocking purposes. The technology of spawning trout cod and rearing juveniles is established, but they are also an extremely aggressive fish and like the Murray crayfish, may not be easily domesticated. However, because of their endangered status, it may not be possible to obtain a permit to farm them. Apart from that, old time professional fishers would throw them back because they weren't considered worth sending to market as they were downgraded against the highly prized Murray cod.

Tubifex worm

Production system	Freshwater flow-through
Broodstock/seedstock availability	Available
Temperature/water preferences	Cold to warm
Current market status/potential	Niche domestic market
Sector status	Established niche

Tubifex worms have been a component of the aquarium trade for a very long time. They are a red/brown worm, not much thicker than a piece of cotton and about 4 cm long. It has been suggested that the name 'tubifex' was adopted from overseas, and the Australian product that goes by this name should more properly be called a lumbricid worm. This may or may not be so, but the product exists and the market knows them as tubifex.

The trick in growing tubifex is to get water with very high nutrient content (maybe in small lumps) combined with sufficient oxygen. There has to be growing substratum (soil) too. A few small-scale trout farmers found they had perfect conditions at the outlets of their ponds. They made a few minor constructions and, hey presto, they were in polyculture. The tubifex can be scooped out of the culture beds with the hand.

One of the authors is more gastronomically experimental than the other. When presented with his first sight of tubifex at the Snobs Creek fish hatchery in Victoria, he dipped in, scooped out a teaspoonful, and ate them. He reports that 'tubifex don't taste too bad, sort of like a fresh mussel'. The other author decided that one opinion was sufficient. They both agreed that some time was liable to elapse before tubifex worms were likely to be accepted as food for people, however, they would be nutritious if we ever came to that.

Selling a live product as a source of food for aquarium fish does not, on the face of it, appear to be an industry of massive potential, and to some extent this is true, the total turnover is not great. But the margins may well be significant. Tubifex is generally sold by volume: by the litre or cupful, but this can be equated to weight (one litre = one kilogram). If you compare the price per quantity you find it more than favourably compares with most aquaculture products. Given the low volume of potential sales, it's not the sort of aquaculture production that you would quit your day job for, but it can be a nice little added income earner that pays beer money, or maybe even funds the new kitchen you have been wanting.

Turtles

Production system	Land-based mariculture
Broodstock/seedstock availability	Supply limited
Temperature/water preferences	Tropical
Current market status/potential	Established international demand
Sector status	Developing

Turtles are not fish, and by some definitions, are not an aquaculture species, but they grow in water so are included in this listing.

There have only been limited attempts at farming turtles in Australia. Generally these did not involve closing the life cycle, but, like the crocodile industry, relied on wild animals depositing their eggs, and collectors harvesting the eggs or young turtles for on-rearing. One of the authors remembers being on Heron Island on the Great Barrier Reef one evening when a turtle hatching occurred. The little turtles appeared out of the sand and made their way down to the lagoon. The sea birds weren't too numerous and didn't have a devastating impact, but waiting in the shallow water was a mess of fish, including large numbers of rays whose flaps lifted and fell out of the water. In the wild there is a massive attrition of just-hatched turtles. If the eggs are collected and the juveniles taken care of, this mortality can be dramatically reduced.

In days of yore, turtles were considered a delicacy. One of the authors remembers in his youth consuming tinned turtle soup and it wasn't half bad. Indigenous peoples on the country's northern shores still are partial to turtle. There is a market there.

There is another reason to develop breeding technology. There is strong belief that turtle numbers are declining and that something needs to be done to boost the stocks or their conservation status will be under threat. It may well be that aquaculture technologies can contribute to wild populations of turtles being restored to healthy levels.

White shrimp

Production system	Land-based mariculture
Broodstock/seedstock availability	Prohibited in Australasia
Temperature/water preferences	Temperate
Current market status/potential	International commodity
Sector status	Illegal in Australasia

White shrimp (*Penaeus vannamai*) is a species of prawn upon which a large proportion of the world's prawn farms are based. However, it is not an Australian species. It would be unlikely that stocks would ever be allowed to be imported into Australia, so the main value this species has is the knowledge gained from farming it, and the possible transfer of that knowledge to similar prawn species farmed in Australia.

Worms

Production system	Land-based
Broodstock/seedstock availability	Plentiful
Temperature/water preferences	Dependent on species
Current market status/potential	Undeveloped
Sector status	Pilot

If you ask a biologist, worms ain't just worms: there are lots of different kinds. Unlike biologists, the authors can only think of a limited number of uses for worms in aquaculture.

Garden worms are not really an aquaculture product, but they are amphibious and can be used to feed some fishes. They are a pretty expensive feed item, and are not used for general on-growing of table fish, but can be used for aquarium species, conditioning broodstock and form part of the weaning process for freshly caught fish from the wild.

Marine worms have been proposed for aquaculture. See the section on 'Marine worms' for more information.

'Tubifex' worms grow in fresh water and may be sold directly or used as fish food. See the section on 'Tubifex worms' for more information.

Wrasse

Production system	Marine finfish sea cage
Broodstock/seedstock availability	Technology available Limited stock availability
Temperature/water preferences	Temperate to tropical dependant on species
Current market status/potential	Established international demand, depending on species
Sector status	Developing

Fish of the family Labridae are collectively called 'wrasse', or sometimes erroneously 'parrot fish'. There are also other closely related species that loosely fall into the group.

Traditionally, Australians of European extraction from the south of the continent do not favour wrasses, criticising them as having soft flesh. Not everybody in Australia has the same prejudices. In the tropics, wrasses such as the tusk fish are considered good eating by all and sundry. Wrasse can bring a premium in the Asian food market, and kilo for kilo Napoleon wrasse is one of the highest value species in the world markets. (See the section on 'Napoleon wrasse' for more information.) Further south, the local Asian food market seeks out temperate wrasse. See also the section on 'Temperate wrasse'.

Yabby

Production system	Static-water ponds
Broodstock/seedstock availability	Readily available
Temperature/water preferences	Warm water
Current market status/potential	Niche domestic demand with some export opportunities; market depth untested but suspected to be great
Sector status	Mature

Yabbies (*Cherax destructor* and related species) are one of the 'big three' freshwater crayfish. They are found naturally over a large area of south-eastern Australia covering most of Victoria, NSW and SA as well as a good part of Queensland and parts of central Australia. They have been introduced into WA where they are harvested from farm dams commercially. Tasmania is the only state where it's not found in the wild, in fact, to protect native crustaceans from this feral invader it is declared a noxious species. See the section on 'Crayfish' for more information on related species.

While all three crayfish share a lot of similar features, yabbies are perhaps the hardiest of the lot, surviving a range of water qualities and extremes of temperatures. Their strong survival sense and ability to colonise by following the faintest of water flows has enhanced their range and made them a good aquaculture candidate. Yabbies can be bred in ponds as well as hatcheries and have a high social density.

With its wide climate range it is the most commonly farmed freshwater crayfish species and possibly the one with the most farming and marketing potential. The large claws are full of meat and the species looks most like the Northern Hemisphere version of a lobster. However, prices are generally lower than those offered for redclaw and well below those received by marron farmers. Part of this downgrading could be that in times of plenty in the bush, wild-caught stock flood the market and drive prices down. In between these gluts, farmers are unable to maintain regular supplies and the chance to build public awareness and acceptance is lost.

Since the mid-1980s, farmers in Western Australia's Wheatbelt, an area as large as Victoria, have been organised by market wholesalers and exporters to harvest the introduced yabbies that have gone feral in their farm dams. The development of this extensive resource has allowed economies of scale and a regular of supply of stock, an essential component for marketing, has underwritten a vibrant cottage industry. Other states have seen the success of this approach, and some have allowed the yabby resource in their farm dams to be commercially harvested.

Yellowfin tuna

Production system	Marine finfish sea cage
Broodstock/seedstock availability	Available to selected groups
Temperature/water preferences	Temperate
Current market status/potential	Established international demand
Sector status	Pilot

Australia has access to stocks of a variety of tuna species. Not all of them are sought after in the marketplace, but yellowfin tuna definitely is. It is not too dissimilar to bluefin tuna (you guessed it, the big difference is in the colour of the fins).

Attempts are being made in WA to adapt cage-farming technology to local stocks of yellowfin tuna. If the successes of the South Australian southern bluefin tuna farming industry can be duplicated, far more value will be obtained from a finite natural resource. This provides yet another example that can be had from synergies between the wild fishery and aquaculture.

See the sections entitled 'Tunas' and 'Southern bluefin tuna' for more general information on tuna farming.

Zebra fish

Production system	Aquarium (re-circulation system)
Broodstock/seedstock availability	Available
Temperature/water preferences	Temperate to tropical
Current market status/potential	Limited but continuing domestic demand
Sector status	Established but limited in scope

The editors told the authors that this section of the book had to be an 'A' to 'Z' listing, so the authors racked their brains for an aquaculture species starting with 'Z'. We came up with 'zebra fish'. But be reassured, zebra fish do exist. They are a smallish aquarium fish species. They can be bred and they can be sold in the aquarium trade.

Zebra fish might even have other functions: a recent news report suggested that zebra fish were the species next on the to-do list for chromosomal gene mapping. This may well be true, but probably is more an indication of how easily they may be kept in captivity in your average biology laboratory, rather than any inherent suitability for genetic analysis. It may also be that, being fish, they are not so likely to require high profile ethics approval before research can be undertaken.

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24

Epilogue

This is the last chapter of our book. We'd like to thank you for reading some of the knowledge we've spent a lifetime accumulating.

We wish you well for the future and would like to think that if you do go ahead and do something in aquaculture you'll feel free to keep in touch.

In many cases the contents of this book will have been difficult to absorb. You've been patient and we hope that you feel your patience has been rewarded. We set three criteria when we compiled this volume. As with everything in aquaculture, they are interrelated.

1 To open your minds to the wide range of possibilities and opportunities within the aquaculture industry.
2 To alert you to the harsh realities and pitfalls of aquaculture.
3 To provide you with an understanding of the principles of aquaculture and develop a confidence in your own aquacultural judgement so that you can make your own aquacultural decisions

We hope we've succeeded.

We'd like to leave you with some key phrases. Better still, we'd like you to tell us what they are.

1 The key words in aquaculture are…and…?
2 These cannot be achieved without…
3 The guiding star of all fish farmers is …?
4 The underlying rule of nutrition is …?
5 The most common disease you'll find on a fish farm is …?
6 The most convenient pharmaceuticals available to the aquaculturist are … and … ?
7 If you haven't adequate predator control you're not … about aquaculture.
8 Without an adequate water quality management system it will be … to sustain a commercial aquaculture venture.
9 The three most important aspects of selling are …, … and …?
10 The three most important aspects of marketing are …, … and ….?
11 There are no … in aquaculture.
12 If you select the … site and/or system design you're … before you start.

Ladies and gentlemen, it has been a pleasure working with you. As we part from this section of the aquacultural journey, Ric and John would like to leave you with these thoughts.

There are any number of books and papers written about water quality, fish disease, the biology of the various species, operating a small business and marketing, but very little about husbandry. It is skills in husbandry that separates the good fish farmer from the poor one – a successful venture from a less than successful venture. Husbandry is the one thing the farmer has totally under his or her control.

The relationship of temperature and water quality to food uptake and metabolism is one of the most critical balancing acts in aquaculture. Each species has its preferred environmental niche: its comfort zone. Understanding and being able to recreate the circumstances of that niche is the art of fish husbandry.

When you realise that genotype and nutrition are also part of the balancing act, and that they will give a different result under different environmental influences, you will see how important hands-on experience is going to be to working in the aquaculture industry. You will see how impossible it is to provide a site-specific model or a working manual in a book such as this. The reality is that you will have to write your own manual. You will also realise that the skills you acquire are going to be something of real value; something you will be able to add to your repertoire.

Keep an eye on the details and the overall performance of the production system. Everyone has their own management style: use your strengths and strengthen your weaknesses. Get off the place from time to time so you can rearrange your mental focus. Most importantly, continue to seek knowledge: seek it from reading; visit other fish farms and other aquacultures; observe nature.

A word of warning: there is a lot of voodoo aquaculture being practiced. Back your own judgement. Listen, take aboard what you feel might be useful, and leave the rest where it belongs, on someone else's farm.

Form a network of like-minded souls and keep in touch with the industry by subscribing to industry journals for news on industry trends. Don't be frightened to share. Information's a bit like gossip: if you don't pass it on, no one gives you any.

Improve your knowledge in specific areas by doing training programs, attending workshops and above all by visiting successful fish and crayfish farmers.

We've personally found aquaculture fascinating and fulfilling. There's nothing more challenging than unravelling the mysteries of Nature; there's nothing more stimulating than creating a sustainable business; and there's nothing more rewarding than harvesting your own crop of fish or crayfish.

Good luck and may the GWQEHN be with you.

John Mosig and Ric Fallu

Oh, you didn't get all the answers?

1. The key words in aquaculture are *BALANCE* and *STABILITY*.
2. These cannot be achieved without *CONTROL*.
3. The guiding star of all fish farmers is of course *GWQEHN*.
4. The underlying rule of nutrition is *NO ONE NUTRIENT IS USED IN ISOLATION*.
5. The most common disease you'll find on a fish farm is *BMV – BAD MANAGEMENT VIRUS*.
6. The most convenient pharmaceuticals available to the aquaculturist are *SALT* and *OXYGEN*.
7. If you haven't adequate predator control you're not *REALLY SERIOUS* about aquaculture.
8. Without an adequate water quality management system it will be *IMPOSSIBLE* to sustain a commercial aquaculture venture.
9. The three most important aspects of selling are *SERVICE*, *SERVICE* and *SERVICE*.
10. The three most important aspects of marketing are *PRESENTATION*, *PRESENTATION* and *PRESENTATION*.
11. There are no *SHORT CUTS* in aquaculture.
12. If you select the *WRONG* site and/or system design you're *BEATEN* before you start.

And remember: the first question you must ask yourself before you carry out any operation or invest in any equipment is how much control is it going to give me over the balance and stability of my system. Once you've answered that you can then quantify the economic benefits it will bring to your business.

Glossary

Aerobic	a process or condition where dissolved or free oxygen is present.
Aerator	any device that increases the dissolved oxygen level of the water.
Anaerobic	a process or condition where there is no dissolved or free oxygen.
APVMA	Agricultural Pesticides And Veterinary Medicines Authority.
Batter	the slope of the side of a pond measured as a ratio of height to width, that is, a batter of 1:3 is 1 metre vertically for every 3 metres horizontally.
Biomass (biota)	the total population of pond organisms.
Blood worm	a small, red worm found in the organically rich substrate of yabby ponds. Favoured food of crayfish.
BOD	biochemical oxygen demand – the total oxygen usage of the organisms in the pond.
CFS	constant flow system – a pond with a constant flow of water through it.
Detritus	detritus is made up of the rotting vegetable and animal material found in the pond. It is a valuable source of crayfish nutrition as they gain protein from the bacteria breaking down the detritus.
DO	dissolved oxygen available to the biomass.
Drip room	the area used to keep yabbies wet during purging by spraying water over them.
EC	electronic conductivity.
Elastrator ring	commercial rubber ring for castrating lambs. Used to hold the nippers of aggressive male yabbies when in breeding boxes.
Epistylis	a common group of protozoan organism found growing on the shells of crayfish.
FCR	food conversion ratio – the amount of weight gained in relation to feed used.
Fecund	fruitful, fertile; productive.
Freshet	a flush of fresh water, usually associated with local weather and river conditions.
GAV	Gill Associated Virus.
GUD	Goldfish Ulcer Disease.
Herbage	plant material that is terrestrial or aquatic.
KPI	Key Performance Indicators.
M.A.P.	a concentrated water-soluble fertiliser commonly used in aquaculture to generate plankton blooms.
MUP	Minor Use Permit.
Moulting	the process by which crayfish shed and replace their external skeleton (exoskeleton) as they grow.
NPK	a chemical fertiliser made up of nitrogen, phosphorus and potassium.

ORP	oxidation-reduction potential.
Phytoplankton	microscopic aquatic plant life. Part of the plankton.
Plankton	the generic term used to describe the microscopic and macroscopic organisms that inhabit the pond. It includes the microbes breaking down detritus, the microscopic aquatic plants called phytoplankton, algae and zooplankton, and the small crustaceans feeding on the phytoplankton and each other. These individual members of the plankton are sometimes referred to as plankters.
PLs	post-larvae.
PTO	power take-off.
Prawn tray	a proprietary line of ventilated plastic containers used to handle and purge prawns and yabbies.
Purging	the process whereby stock are denied food for several days so that they evacuate their digestive system prior to sale.
R&D	research and development.
SFM	Sydney Fish Market.
SGR	specific growth rate expressed as a percentage.
SPF	specific pathogen free.
TAN	total ammonia nitrogen.
TDS	total dissolved solids.
'Tinny'	in this case, an aluminium punt or boat.
Tubifex worm	see 'blood worm'.
Venturi	a device by which the flow of water creates a vacuum on one side, thus drawing off material from a given area.
Volatile by-products	metabolically unstable waste products from livestock and fish processing.
WES	water exchange system: enables regular exchange of water as part of production management. Also known as flow-through systems.
Zooplankton	the microscopic and macroscopic crustaceans that live on phyto-plankton and each other. A favourite food of yabbies.

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Index