FINAL REPORT

TO

FISHERIES RESEARCH & DEVELOPMENT CORPORATION

Project title: Grow-out of snapper (*Pagrus auratus*) in sea cages

Project number: 92/62

Research Organisation: Fisheries Research Institute
NSW Fisheries
PO Box 21 CRONULLA, NSW 2230

Principal Investigator: Dr. Nino Quartararo

Non-technical summary

The aim of this project was to farm, on a pilot commercial scale, two indigenous species of marine fish: snapper, *Pagrus auratus*; and mulloway, *Argyrosomus hololepidotus*.

The project involved:

- development of hatchery techniques;
- intensive rearing of larvae;
- transport of live fish;
- design, construction and testing of seacages for research;
- grow-out of juvenile fish in tanks and seacages;
- identifying and treating disease outbreaks in seacages;
- obtaining production data; and
- obtaining preliminary marketing information.

Juvenile fish stocked in seacages were obtained from the NSW Fisheries Port Stephens Research Centre (PSRC). Fertilised eggs were obtained from wild fish induced to spawn with hormones. The eggs were hatched and the larvae reared intensively in the hatchery at PSRC. Juvenile fish were weaned off live food onto a dry artificial diet and then transported by road to the grow-out site at 50-60 days (post-hatch).

The first crop of snapper were initially grown for five months in tanks at the NSW Fisheries Research Institute (FRI), then stocked in seacages in Botany Bay and grown to market size. In contrast, a second crop of snapper and the mulloway were stocked directly from the hatchery into seacages in Botany Bay.

Two production cycles for snapper and one for mulloway were achieved. Data on time to market, feed conversion ratio, feeding rate and survival were obtained for both species. Both species were reared on a dry pellet diet developed by NSW Fisheries in a previous project.

Several probable "production" diseases were identified. Snapper appeared more prone to disease than mulloway. Effective treatments were devised for the two major diseases encountered during the project. The bacterial disease, *Vibriosis*, was treated with medicated feed and a gill fluke infestation with a medicated bath.

Snapper were sold either alive or freshly killed. The minimum market size was the NSW minimum legal length of 28 cm. This provided information on prices and consumer preferences. The price obtained for live fish was approximately double that obtained for freshly killed fish. The skin colour of snapper was found to have a significant effect on the market price. The use of shade covers for several months before harvest lightened the skin colour of snapper which improved their marketability.

At the end of the project, most of the mulloway were under the NSW minimum legal length of 45 cm. Consequently they could not be sold and instead, were tagged and released. The aim was to provide information on the possibility of enhancing wild stocks of mulloway by the release of fish originating from a hatchery.

Background

Australia already is in a position where it is forced to import much of its seafood. With demand continuing to increase and our premium capture fisheries declining and unlikely to produce more, there appears to be no alternative to the development of a large-scale aquaculture industry in this country.

NSW Fisheries with the aid of this and a previous grant from FRDC has been assessing the potential of snapper for mariculture since 1989. The previous study (see FRDC Final Report Project No. DAN13Z) concluded that snapper has good potential for mariculture in Australian temperate waters. The results of the previous study provided data on the growth of captive snapper reared on dry pellet diets and lead to the development of a series of diets formulated specifically for snapper. In addition, alternate sources of protein to fishmeal were evaluated as a means of lowering the cost of feed.

The present project was operated as a pilot-scale fish farm and built upon the information gained in the previous project. This project extended the previous work by:

- using hatchery produced juveniles instead of wild caught juveniles;
- examining mulloway in addition to snapper;
- growing fish in seacages at commercial stocking densities; and
- growing fish to market size and assessing their market potential.

Objectives

1. To develop techniques for growing-out juvenile snapper to market size in seacages at the commercial scale.

2. To acquire the husbandry skills necessary for holding wild caught snapper in sea cages as an integral part of value-adding for the live fish market.

Introductory technical information concerning the problem or research need

Many of the world's capture fisheries for quality white fleshed table fish are in danger of or already are being over-exploited. This is reflected by a decline in production over the past decade which coupled with an increasing demand for quality table fish has stimulated the growth of finfish aquaculture. In Japan, production of snapper (known as red sea bream) grew from 26,000 mt in 1984 to 73,000 mt in 1993. Norwegian production of Atlantic salmon increased from 22,000 mt in 1984 to an expected production of over 200,000 mt in 1996. The total production of the Mediterranean region, for two warmwater marine species seabass and gilthead seabream, has increased rapidly over recent years (by over 30 % from 1994 to 1995) and is expected to be over 40,000 mt in 1996.

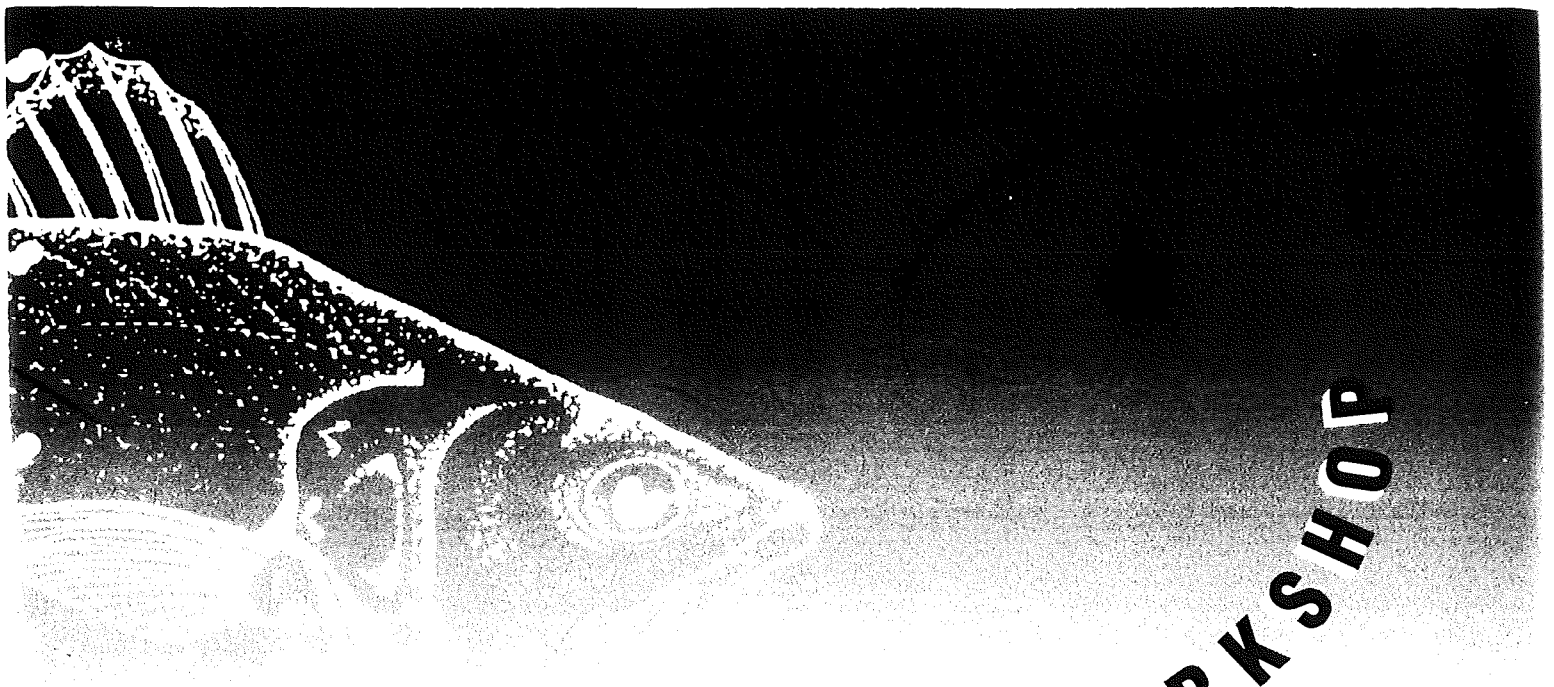
Currently, Australia imports over 50% of the seafood it consumes. In keeping with a world-wide trend, many of Australia's premium fish stocks have been over-exploited.

The NSW catch of snapper, which is considered a premium table fish, has declined by about 50% over the last decade with current production at around 500 mt *per annum.* Part of the short-fall in the supply of snapper has been made up by imports of fresh snapper from New Zealand (NZ). Over the last several years about 600 mt *per annum* of NZ snapper has been imported. The value of NZ snapper imported in 1993 was approximately five million NZ dollars F.O.B. (*The New Zealand Seafood Industry Economic Review 1993*, New Zealand Fishing Industry Board). The development of a snapper farming industry should therefore have a direct economic benefit because of the existing need to replace imports from NZ.

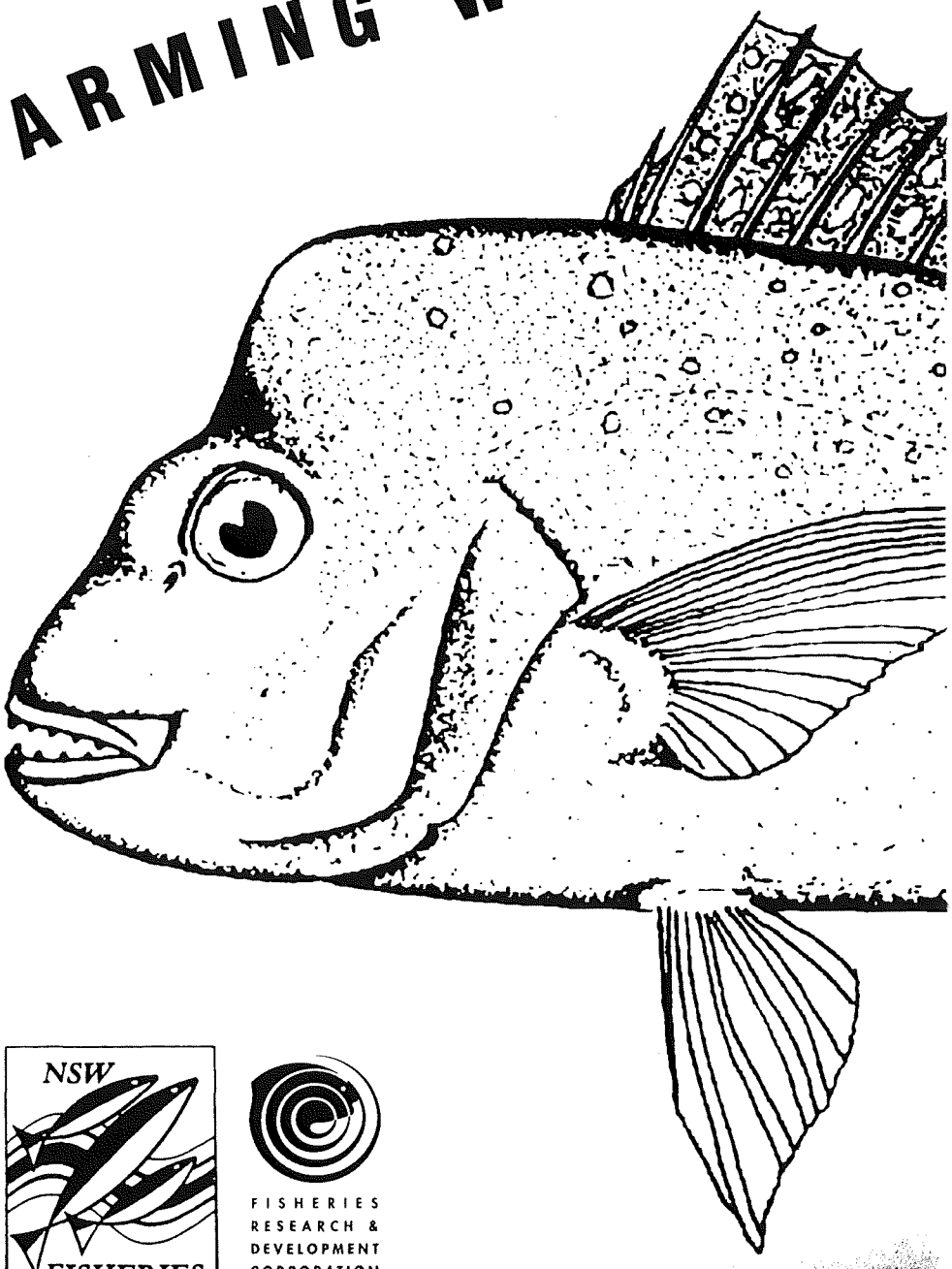
Farmed snapper could also supply a part of the growing market for live fish in Australia. Farmed fish have advantages over wild fish because of the greater degree of control over the timing of supply and handling.

Marine Finfish Farming Workshop

A workshop on Marine Finfish Farming was held on 23 June at Cronulla, NSW. The workshop attracted just over 100 participants. The purpose of the workshop was to disseminate the results of this project and other information on marine finfish farming. The Proceedings of the workshop has been published and ten copies are enclosed. Two papers in the Proceedings give a full description of the research methodology. The first, by Stephen Battaglene entitled- *Hatchery production of juvenile snapper and mulloway*, gives a full description of the methods used to produce the juvenile snapper and mulloway that were stocked in seacages in Botany Bay. The second, by Nino Quartararo entitled- *Grow-out of snapper and mulloway in sea cages*, gives a full description of the grow-out phase which was conducted in seacages in Botany Bay and includes: detailed results; a discussion of results; implications and recommendations; and a technical summary of all information developed. Another paper in the Proceedings, by Geoff Allan and Nino Quartararo entitled- *Developing diets for snapper*, gives details of the NSW Fisheries' snapper diet and a general background on fish nutrition. The Proceedings also contains papers on other topics pertinent to the development of warmwater marine finfish farming in Australia such as environmental impacts, cost-benefit analysis and site selection.



MARINE FINFISH FARMING WORKSHOP



NSW FISHERIES

FISHERIES RESEARCH & DEVELOPMENT CORPORATION

Marine Finfish Farming

Proceedings of a Workshop

Edited by Nino Quartararo
NSW Fisheries

CRONULLA, N.S.W.
NSW Fisheries Research Institute
1996

ISBN 0 7310 9401 8

Preface

On 23 June 1995, a workshop on marine finfish farming was held at the Kingsway Hotel, Cronulla NSW. The workshop gathered together researchers, commercial fisherman, fisheries managers, aquaculturists, represetatives from feed and equipment manufacturers and others for the presentation of the results of a pilot-scale project on marine finfish farming and to discuss issues facing the development of marine finfish farming in Australian temperate waters. The more important issues such as: environmental effects of marine fish farming; development of cost-effective diets; economic viability; site selection; and procedure for gaining approvals for a marine fish farm were each the subject of a paper. In addition, papers describing the establishment of other fish farming industries, e.g. barramundi in Queensland, were presented to try and crystallise the future of snapper and mulloway farming and to facilitate the formulation of strategies and policies to aid their development.

It was encouraging that most of the delegates stayed for the the panel discussion following the formal proceedings. It reflected the high level of interest in marine finfish farming and provided an opportunity for open discussion of the issues that interested delegates the most. The two issues that received most attention were the availability of sites for fish farms and the supply of fingerlings for grow-out.

The workshop would not have been possible without funding from both NSW Fisheries and the Fisheries Research and Development Corporation (FRDC).

The workshop could not have happened without the help, input and support of a number of people. Firstly I would like to thank all of the speakers for their professionalism. Secondly, for helping me to organise and run the workshop, I thank the following staff of NSW Fisheries: David Barker; Stuart Fielder; Vanessa Gale; Ian Lyall; Brett Rankin; and Marnie Tanner.

These proceedings can be purchased from NSW Fisheries. Please contact NSW Fisheries by phone on (02) 566-7800 for further details.

Nino Quartararo

Marine Finfish Farming Workshop Proceedings

Table of Contents

Prospects For Aquaculture

Robert E. Kearney*

NSW Fisheries, Fisheries Research Institute, PO Box 21, Cronulla, NSW, 2230

***Present address**: School of Natural Resources, University of Canberra, PO Box 1, Belconnen, ACT, 2616.*

INTRODUCTION

World production from capture fisheries has increased by only approximately 20% in the last ten years. It is apparent that most of this small increase has come from increased harvest of lower quality fish, such as sardines and anchovies, which are mostly not destined directly for human consumption. There has in fact been a decline in the production of quality white fleshed table fish which have traditionally formed the basis of the fresh fish market throughout the world.

At the same time as the production of quality fish is declining, or at best stabilising, the demand for such fish is increasing rapidly. Reasons include:

- the world's human population continues to grow,
- improved fish processing gives rise to more user friendly products,
- as quality increases so does consumer confidence particularly in out-of-home consumption,
- increased awareness of the health advantages of fish, in particular the benefits of ω3 fatty acids,
- improvements in transport have increased access to markets, and
- increased number of affluent people, particularly in Asia.

It follows then that the market for premium fish and crustaceans is expanding, and in the light of stagnating or declining capture fisheries production the potential for alternative sources of fish, (which in the absence of molecular recombination, aquaculture remains the only one) must indeed be extremely bright.

World aquaculture production has more than doubled in the last ten years with 1993 output

estimated by FAO at approximately 19.0 million tonnes. Many predict it will double again in the next 15 years. Certainly aquaculture expansion is an exciting prospect and one in which Australia should be involved.

THE AUSTRALIAN PERSPECTIVE

Even though Australia has the world's third largest 200 mile economic zone, its fish resources are meagre. The waters surrounding this island continent are nutrient poor and primary productivity is much lower than most other areas of the world's oceans. Australia's fisheries production is less than 200,000 tonnes per year, which in world perspective is less than 2% of the production of countries such as China and Japan. While there is some potential for expansion in Australia's total fish catch, it is most unlikely that there is room for a significant increase in the yield of quality species.

Many of Australia's premium fish and crustacean species are already overexploited; e.g. southern bluefin tuna, gemfish, eastern rock lobsters, abalone and orange roughy. Australia currently imports more than 50% of the seafood consumed in this country. Imports in some categories completely dominate domestic production; e.g. we import 100% of the fish used for fish finger production and almost 100% of that used by the major fast food chains.

On the more positive side, Australia is a major exporter of quality seafood, e.g. lobsters, abalone, prawns, orange roughy and southern bluefin tuna. We have the expertise and the infrastructure to support quality export industries and we have the added advantage that the world's most rapidly expanding markets, that is in Asia, are relatively close to our door-step. We also enjoy a reputation for waters which are relatively pollution-free.

Australia therefore has an ability to export to great advantage provided we have the product. We obviously have the need to replace imports, and all Australians will agree that we need more quality fish for local consumption. Our capture fisheries will not meet these potentials. Not surprisingly, the country is looking to aquaculture; the opportunity is unquestionably there.

Australia's record in aquaculture is mixed. We have had outstanding success in oyster production for both edible product and pearls, and most recently the Atlantic salmon industry has established its bona fides and turned a profit. Other sections of the industry, for example marine and freshwater prawns and yabbies have struggled, and failures have been all too numerous. There are obvious potentials but equally obvious pitfalls and problems.

THE ROLE OF NSW FISHERIES IN AQUACULTURE RESEARCH

It is the mission of NSW Fisheries to conserve, develop and share the fisheries resources of the State to maximise benefits for present and future generations. In support of this mission the Research Division of NSW Fisheries is charged with identifying and researching commercial opportunities in aquaculture in order to assist the Government to further develop an environmentally responsible aquaculture industry. NSW Fisheries is proud of its record in aquaculture research, and of the opportunities it has identified.

We have a long history in the breeding and propagation of native freshwater fish dating back to the late 1960's. Since that time we have developed techniques for the extensive and intensive breeding of our major native species, including silver and golden perch, Murray cod, trout cod and eastern freshwater cod. Our pioneering work has not only played a major part in preventing the demise of these tremendously important species and led directly to increasing their populations in impoundments, but has also provided the basis for the establishment of a small but thriving aquaculture industry which provides fingerlings.

Our current research projects are concentrated on those species we have identified as having the greatest potential to support the expansion of the aquaculture industry in this State. They include the following:-

Silver perch

Silver perch has many attributes which make it a tremendous candidate for extensive, semi-intensive, or even intensive, fresh water aquaculture. We believe the species is at least equal to the channel catfish, which forms the basis of a 200,000 tonne industry in the United States, and tilapia, which is grown in many countries throughout the world.

The establishment of a silver perch industry will not be without its problems. There will be problems with disease, off-tastes, unexplained mortalities, predation, and a number of factors which affect quality control. There will also be obstacles to establishing a constancy in supply, and even in the availability of land and water to enable production to approach optimum levels. All of these issues are currently being addressed. Promotion of this industry was facilitated by two workshops at Narrandera and Grafton attended by approximately 400 people.

Marine fish

A number of species of marine fish are being investigated, with snapper and mulloway on top of the priorities. Snapper were bred at our research facilities at Port Stephens for the first time three years ago and have been produced each year since. Larvae have been grown to market size in less than two years in both ponds and cages, and adult fish have achieved sexual maturity in captivity.

Mulloway have been bred for two years and grown to a little less than a kilo within twelve months in captivity. There are problems with inducing this species to feed voraciously and this remains priority for ongoing work.

The potential for restocking depleted areas with mulloway, or of seeding selected locations, constitutes a parallel goal of our marine fish breeding program. It also re-enhances the linkages between our aquaculture and capture fisheries research.

Scallops

Scallops have been bred intermittently over the last six years but it is only in the last eighteen months that our broodstock management techniques have been developed to the point that spawning is reliable. Grow-out trials in lantern cages and on strings are showing promise but these are still early times.

The potential for reseeding areas with poor natural recruitment, such as Jervis Bay, or for enhancing production in new areas, again combines capture fisheries and aquaculture research strategies.

Oysters

NSW Fisheries researchers have developed many innovations for the Sydney rock oyster industry, particularly in the last 20 years. Current research is concentrated on the development of triploid oysters which have been shown to not only hold condition throughout the year because of their inability to spawn, but also to grow approximately 37% faster than normal oysters. A mass selection program should also lead to the development of faster growing trends of sexually active oysters. Geneticists are confident that increases in growth rates of 30% can be anticipated from a genetic selection program.

Feed development

The cost of feed normally represents between 30 and 70% of the operating costs of intensive or semi-intensive aquaculture industries. Australia currently imports the majority of these aquaculture feeds, and even for locally manufactured feeds, imported fishmeal is a major component. For the reasons I outlined in the introduction, Australia will never be a significant producer of fishmeal. Our aquaculture industry will therefore be at a major disadvantage for as long as our feeds are either imported or comprised primarily of imported ingredients. Therefore, in order to remove our disadvantage we must work to replace fishmeal in aquaculture diets.

On a more positive note, Australia is the world's most efficient producer of vegetable and animal proteins through our competitive advantage in broad-acre agriculture. While many of these agricultural products have not traditionally formed the basis of aquaculture diets, we believe they have great potential to do so. Indeed Australia's future in large scale aquaculture production is dependent upon replacing fishmeal. Crops such as lupins and canola, and livestock by-products such as meatmeal and bloodmeal in the right combinations with addition of minerals and/or artificial amino acids, can be used for viable aquaculture diets. We are confident that with excellence in research these diets will be able to be developed to be at least competitive with

imported diets based on fishmeal, and hopefully to form the basis of a major export industry. Our agricultural producers are participating in this research with an optimistic eye to the Asian aquaculture feed market, which is predicted to be of the order of three million tonnes *per annum* by the turn of the century.

Other species which we believe have potential for aquaculture in New South Wales, but for which a lack of resources has restricted research, include abalone, golden perch, sand whiting and kingfish.

CONCLUSIONS

NSW Fisheries is convinced of the long-term potential for aquaculture in this State. We are also mindful of the many problems that will constantly need to be faced. We are heartened by the example of the US catfish industry, but heed the warning expressed by the collapse of the Taiwanese prawn industry, and the halving of production from the Chinese prawn farming industry in 1994. We must certainly be aware of the possibility that the collapses in several Asian aquaculture industries are due to large scale degradation of the environment critical to aquaculture production. While diseases are normally quoted as a proximal cause, it is most likely that degradation of water quality and other environmental problems have led to the increase in disease.

The Australian aquaculture industry will need to face its future mindful of the long-term issues, but also aware of the pressures from competing, and at times conflicting, users of coastal or inland resources. There will undoubtedly be competition for sites for future aquaculture activities and for water. There will be problems of contamination of water from other sources, and problems of downstream effects of aquaculture production. There will be opposition from residents who consider aquaculture unsightly, and from preservationists who just don't want change.

Clearly aquaculture represents an exciting potential. Indeed it can be argued that the increasing demand for fish will make aquaculture essential for Australia's future. It is our belief that aquaculture must succeed, it is only a matter of how well and how quickly.

For aquaculture to even approach its full potential in this country, Governments and industry must cooperate. The recent example of promoting the development of the silver perch industry by cooperation between NSW Fisheries and Australian Native Fish Pty Ltd, and in particular the significant amount of funding provided by this company for aquaculture research, is a pertinent example. The recent creation of the Cooperative Research Centre for Aquaculture, and of the continued high level of support from the Fisheries Research and Development Corporation are further examples of structured cooperation.

The presence of the large number of participants at this workshop is proof of the interest and of the willingness to exchange ideas and information. The workshop is a vital step in the process of the structured expansion of the NSW aquaculture industry. I am certain that the presentations that will be given today will clearly demonstrate the excellence of the science that has already gone into pioneering the fish breeding and propagation industries in this State. I am also confident that participants will leave the workshop convinced that active cooperation between investors and government is essential for the future of aquaculture in NSW.

Hatchery Production Of Juvenile Snapper And Mulloway

Stephen C Battaglene*

NSW Fisheries, Port Stephens Research Centre, Taylors Beach Rd, Taylors Beach, NSW 2316

**Present address: ICLARM Coastal Aquaculture Centre, PO Box 438, Honiara, Solomon Islands.*

INTRODUCTION

A reliable supply of juvenile fish or seed stock is a fundamental requirement for fish farming and it is one of the most critical factors in the commercial success of new marine fish farming ventures (Shepherd and Bromage 1988). Fish hatcheries have been in existence in Australia since the 1860's. Exotic species like Atlantic salmon *Salmo salar* were produced at first, and later a wide range of native freshwater species were bred. However, the development of marine finfish farming in Australia has only occurred over the last decade. Total production was estimated to be about 5000 t in 1993, valued at AUD$72.5 million (D. O'Sullivan pers. comm. 1995). Three species are currently commercially cultured: Atlantic salmon in Tasmania; southern blue fin tuna *Thunnus maccoyii,* in South Australia; and barramundi *Lates calcarifer,* in Queensland, South Australia and New South Wales.

The temperate waters in NSW are unsuitable for the culture of salmon or tropical species in sea cages. New species are therefore required for farming in temperate waters and they have been chosen following consideration of the market potential, industry value, technical feasibility, production economics and compatibility with existing aquaculture industries (Treadwell *et al.* 1992; Searle and Zacharin 1994). Research programs to determine the breeding requirements of newly selected marine species (Table 1), are currently established in most states of Australia (Battaglene and Bell 1991; Searle and Zacharin 1994; O'Sullivan 1994).

NSW Fisheries has been conducting research into the breeding of marine fish at the Port Stephens Research Centre (PSRC) since 1990. Research has focused on snapper, *Pagrus*

auratus, and mulloway, *Argyrosomus hololepidotus*. Other species investigated include sand whiting, *Sillago ciliata*, Australian bass, *Macquaria novemaculeata* and yellow-finned bream, *Acanthopagrus australis.*

WHY DO WE NEED TO BREED MARINE FISH ?

All aquaculture operations are dependent, to some level, on the reliable supply of fertilised eggs, or juveniles (Pankhurst and Pankhurst 1989). Usually, it is not practical to base an aquaculture industry on the collection of wild-caught seed. Notable exceptions do exist, for example, yellowtail *Seriola quinqueriata* in Japan (Davy 1990), and tuna farming in South Australia (Nicoll 1993). However, in most cases appropriate techniques for the controlled reproduction and larviculture of new species need to be developed (Shelton 1989; Sorgeloos and Leger 1992).

The collection of juvenile snapper and mulloway from the wild is not a feasible option for potential NSW fish farmers because of the current level of exploitation by commercial and recreational fishermen. In any case it would be very difficult to catch juveniles in sufficient numbers and in a suitable condition for farming.

WHY SNAPPER AND MULLOWAY?

Snapper was selected as the species with the most immediate potential for marine farming in NSW because it is well known and regarded, has a good established domestic market profile, wild stocks are declining, and an export market exists in Asia for farmed fish (Battaglene and Bell 1991). Snapper is a very important commercial and recreational species in Australasia (Bell *et al.* 1991; Francis 1994). The biology of snapper is well understood in New Zealand (e.g. Scott and Pankhurst 1992; Scott *et al.* 1993; Francis 1994) and Japan (for reviews see Foscarini 1988; Fukusho 1989) but not Australia (Henry 1988). The total annual catch of snapper in Australia is about 2000 t. In NSW catches have declined from 1000 t in 1980 to 440 t in 1990. In 1991-92 snapper prices at the Sydney Fish Markets averaged AUD$7.76/Kg (McNee *et al.* 1993).

Snapper was formerly named *Chrysophrys auratus* in Australia and New Zealand, and *Pagrus major* (red sea bream) in Asia. It is now recognised as a single species with

Table 1: Cultured Australian marine fin-fish produced, or under investigation for, commercial farming or enhancement programs.

Common Name	Scientific Name	Climate	State
Atlantic salmon[a]	*Salmo salar*	Coldwater	TAS
Sea trout[a]	*Oncorhynchus mykiss*	Coldwater	TAS
Greenback flounder[b]	*Rhombosolea tapirina*	Coldwater	TAS
Long-snout flounder	*Ammotretis rostratus*	Coldwater	TAS
Striped trumpeter	*Latris lineata*	Coldwater	TAS
Banded morwong	*Cheilodactylus spectabilis*	Coldwater	TAS
Black bream	*Acanthopagrus butcheri*	Temp/Cold	TAS & WA
Yellowfin bream	*Acanthopagrus australis*	Temperate	QLD
Southern blue-fin tuna[a]	*Thunnus maccoyii*	Temperate	SA
Australian bass[a]	*Macquaria novemaculeata*	Temperate	NSW and QLD
Snapper[b]	*Pagrus auratus*	Temperate	NSW, SA & WA
Mulloway[b]	*Argyrosomus hololepidotus*	Temperate	NSW & SA
Sand whiting	*Sillago ciliata*	Temperate	NSW & QLD
Trumpeter whiting	*Sillago maculeata*	Temperate	NSW
WA Jewfish	*Glaucosoma hebraicum*	Temperate	WA
Dolphin fish	*Coryphaena hippurus*	Trop/Temp	QLD
Barramundi[a]	*Lates calcarifer*	Tropical	QLD, SA & NSW
Coral trout	*Plectropomus leopardus*	Tropical	QLD
Golden snapper	*Lutjanus johnii*	Tropical	NT & QLD
Mangrove jack	*Lutjanus argentimaculatus*	Tropical	QLD
Estuary cod	*Epinephelus tauvina*	Tropical	QLD

[a] Produced commercially.

[b] Experimental grow-out.

independent and reproductively isolated populations in Japan and Australasia (Paulin 1990). However, there are taxonomists who are not yet convinced these populations are conspecific (Taniguchi *et al.* 1986; J. Paxton pers. comm. 1994). Irrespective of these concerns, the aquaculture production of red sea bream in Japan (Foscarini 1988; Fukusho 1989, 1991) and the Mediterranean (Sweetman 1992) provides a firm technical basis for the development of farming in Australia. Additional information is also available on the culture of other sparids, for example, gilthead sea bream *Sparus auratus* in France (Barnabe 1990).

Snapper was first artificially bred in Japan in 1887, although commercial farming did not start till the 1960's (Davy 1990). In contrast, snapper was first bred in New Zealand (Pankhurst and Pankhurst 1989) and Australia (Evans 1989) in the late 1980's. Government research hatcheries producing relatively small numbers of juvenile snapper are now established in New South Wales, South Australia and Western Australia.

Mulloway was selected because it is widely distributed, has a good domestic market profile, is highly fecund, euryhaline, and grows quickly in captivity (Battaglene and Bell 1991; Gray and McDonall 1993).

Mulloway has an Indo-Pacific distribution and is an important commercial and recreational species in Australia and southern Africa. The total annual catch of mulloway in Australia between 1964 and 1990 has varied from 550 to 225 t. In NSW catches have declined from 450 t in 1974 to 160 t in 1990. In 1991-92 the average wholesale price at the Sydney Fish Market was AUD$5.85/Kg (Kailola *et al.* 1993).

Unlike snapper, little information was available on the biology of mulloway and it had not been bred in captivity before. Several other fish in the same family are cultivated overseas including red drum, *Sciaenops ocellatus*, orangemouth corvina, *Cynoscion xanthulus* and white seabass, *Atractoscion nobilis* (Orhun 1989; Holt *et al.* 1990).

HOW DO YOU BREED MARINE FISH?

The production and rearing of marine fish larvae usually involves collection of broodstock; hormone induction; incubation of eggs and yolk-sac larvae; feeding of live food to larvae; and

final weaning of juveniles onto artificial foods. There are currently two problem areas in the provision of seed stock in Australia. First, difficulties have been experienced ensuring a reliable supply of captive or wild-caught broodstock and consequently good quality eggs. Second, the conditions necessary for successful larval rearing of most species have not been determined and many species have not been reared through to metamorphosis. Consequently the early larval rearing stage has been a major "bottleneck" in the production of marine fin-fish.

Overcoming problems with the rearing of larvae (larviculture) took up to 20 years of research and development before commercial production of some species began in Europe (Stanley 1991; Treadwell *et al.* 1992). Although the time required to develop culture techniques for new aquaculture species in Australia could now be expected to be shorter, the transfer of technology between countries and species is not always appropriate or trouble free (Stanley 1991; Treadwell *et al.* 1992).

Eggs can be obtained by: plankton collection from the wild; spontaneous spawning or stripping of eggs from wild-caught adults; stripping or spontaneous spawning of wild or captive adults in which ovulation has been induced by hormone injection; spontaneous spawning of captive adults with or without environmental manipulation (Hunter 1984; Shelton 1989; Tucker and Jory 1991).

Most research programs and some commercial hatcheries using new species begin by obtaining eggs from wild fish, particularly if they can be readily caught in mature condition. However, the use of captive broodstock has many advantages. Some species are difficult to catch in spawning condition and successful spawning, even with hormone treatment, can be impaired by the stress of capture (Pankhurst and Sharples 1992). Captive broodstock can also often be manipulated to spawn over longer periods than wild fish (Lam 1983). Furthermore, domesticated broodstock, i.e. broodstock from successive generations of hatchery fish are usually easier to spawn, and can produce better quality eggs (Foscarini 1988).

The ultimate aim of most fish hatcheries is therefore to induce spawning in captivity usually through the manipulation of environmental parameters such as photoperiod, temperature, and

salinity (Lam 1983; Shelton 1989). In general, long or increasing photoperiod and/or high or rising temperature stimulates gonadal growth in spring and summer spawners whereas the reverse conditions stimulate autumn or winter spawners (Lam 1983). Special care needs to be given to ensure captive broodstock are not stressed by inappropriate manipulation of environmental parameters, disease, and human disturbance (Sumpter *et al.* 1987). In addition, the diet of broodstock is an important factor determining both the quantity and quality of eggs produced from captive broodstock (Watanabe *et al.* 1984a,b).

Many fish may complete gametogenesis (development of viable eggs and sperm) but fail to spawn in captivity (Pankhurst and Pankhurst 1989; Zohar 1988). Hormones are often used to induce final oocyte maturation, ovulation, courtship behaviour and spawning (Donaldson and Hunter 1983). For each new species, the following aspects of hormone induction and conditions necessary for successful production of fertilised eggs need to be determined: choice of hormone, hormone dose, method and timing of administration. Similarly, the determination of the time between hormone administration and ovulation (latent period), and the need for intervention and hand stripping of gametes (eggs and sperm) varies between species. Successful hormone-induced ovulation, fertilisation and egg incubation requires an understanding of the breeding season, size and age at maturity, type of spawning (e.g. synchronous or asynchronous), fecundity and the nature of eggs produced (e.g. pelagic or demersal). Selection of spawning tanks, spawning protocols and control of environmental parameters particularly temperature is also species-specific. These factors can also vary for different sources of broodstock (captive versus wild) collected at different times during the breeding season. The large number of procedural variations possible means that no single study or series of studies has investigated all the relevant variables for a single species (Donaldson and Hunter 1983).

A good understanding of the biology and ecology of selected species can make the culture of marine fish more economical by limiting the naturally high larval mortality (Blaxter 1988; Foscarini 1988). The more important developmental and behavioural traits influencing larval survival in intensive culture systems are shown in Figure 1. Ideally all factors influencing survival should be experimentally tested to find optimal rearing protocols. In practice this level of sophistication has rarely been achieved (Shepherd and Bromage 1988).

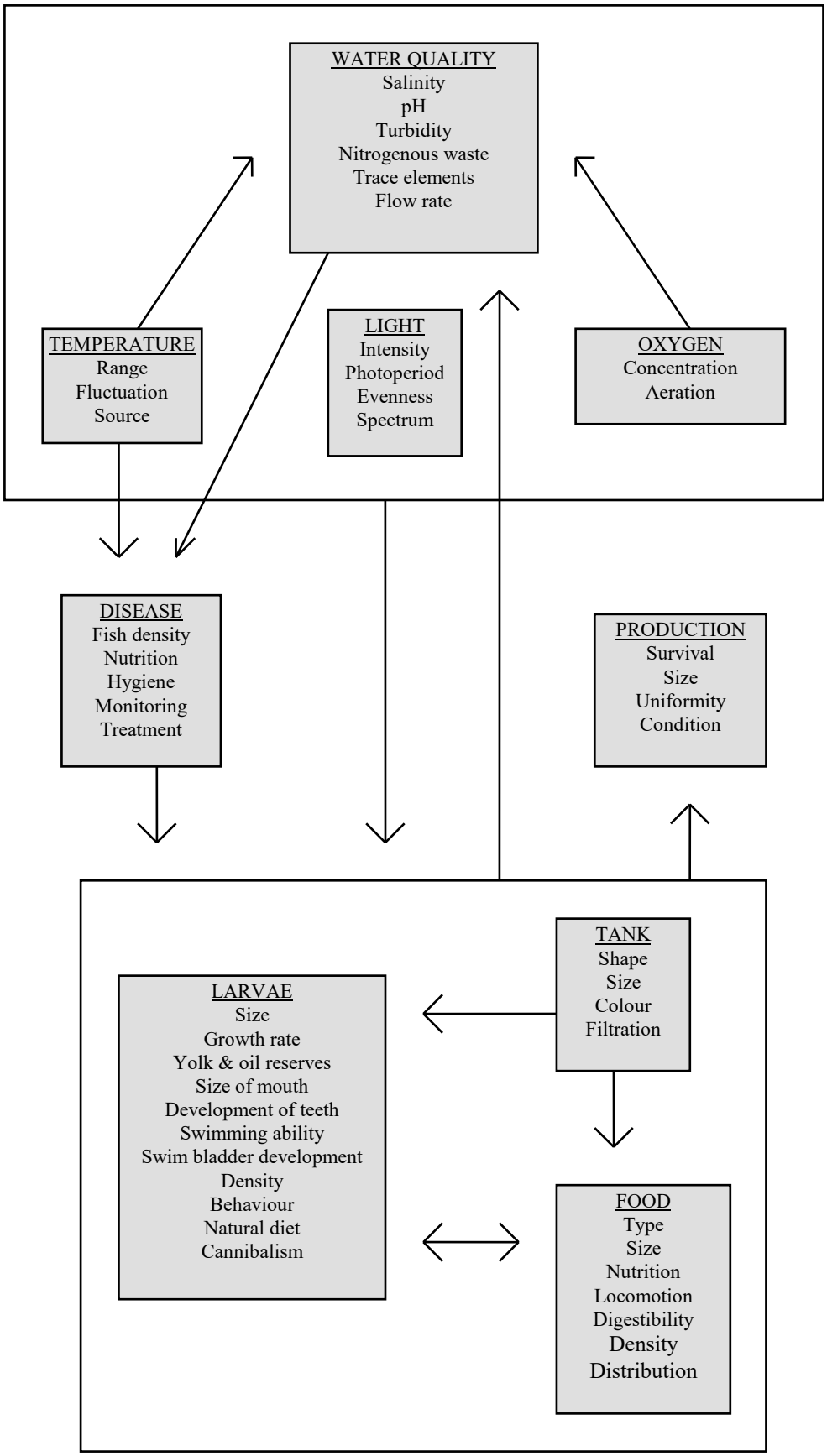


Figure 1: The relationship of major categories of factors influencing the survival and growth of intensively reared marine fish larvae.

The interactions among the factors influencing larval survival also need to be considered in the determination of optimal rearing conditions (Figure 1). Larval density and temperature are particularly important factors because they can influence larval survival, development and growth. In general, initial larval rearing trials with new species should be conducted at low densities within the environmental range of the species in the wild. This provides the best chance of rearing larvae through to metamorphosis and establishing 'normal' development and growth rates. Success with rearing new species will depend on: a reliable supply of eggs; the development and behaviour of the larvae (i.e. intrinsic biology); the facilities available; and the experience of the researchers.

Although, there has been considerable progress and improvement in larviculture over the past decade, especially in larval nutrition, technical methods and disease diagnosis and control, the determination of optimal larval rearing conditions needs to be undertaken for each new aquaculture species (Hunter 1984; Blaxter 1988; Shepherd and Bromage 1988; Sorgeloos and Leger 1992). Clearly, it should be easier to establish hatchery protocols for species that are related to species already cultivated. Two relevant species for which rearing protocols have been developed overseas are: the European sea bass, *Dicentrarchus labrax,* family Moronidae; and gilthead sea bream *Sparus auratus,* family Sparidae (Barnabe 1990).

WHAT RESEARCH HAS BEEN DONE WITH SNAPPER AND MULLOWAY IN NSW ?

The overall goal of research conducted at PSRC has been to develop techniques for the large-scale production of juvenile marine fish in NSW. Specifically the aims were to induce ovulation in snapper and mulloway broodstocks and rear to metamorphosis the larvae in sufficient quantities to be able to assess their growout potential on a pilot scale.

The major objectives achieved to date are:

- determination of when fish mature in the wild;
- development of collection and transportation techniques;
- examination of the effects of hormone treatments on ovulation and spawning in wild-caught and captive fish;
- determination of the latent period, number of eggs, fertilisation and hatch rates for fish induced to ovulate using hormones;

- descriptions of the development and growth of larvae reared intensively on rotifers and brine shrimp;
- determination of the timing of, and factors influencing initial swim bladder inflation in intensively cultured larvae;
- comparisons of the relative difficulties of producing the two species and suggestions where future research should be directed.

A summary of research findings follows.

REPRODUCTION

In general final oocyte maturation, ovulation and spawning did not occur in captive or wild-caught snapper or mulloway without the use of hormones. The only exceptions were for a relatively small number of snapper that were ovulating when collected from the wild. Inappropriate environmental conditions, e.g. temperature and salinity, may be responsible for the failure of fish to spawn when held in the research pool at the Fisheries Research Institute (FRI) at Cronulla and the broodstock ponds at Port Stephens. Stress effects, particularly handling, are probably also involved, particularly with wild-caught fish or those held in smaller tanks. Snapper appear particularly susceptible to stress (Carragher and Pankhurst 1991; Pankhurst and Sharples 1992).

Induced Maturation, Ovulation and Spawning

Three hormones were used in the current study to induce final maturation, ovulation and in some cases spawning (Table 2). The most frequently used was human chorionic gonadotropin (hCG), followed by Ovaprim a proprietary mixture of luteinising hormone-releasing hormone analogue (LHRHa), domperidone a dopamine antagonist, and finally LHRHa cholesterol based pellets.

HCG is commonly used to induce ovulation in fish because it is highly effective for a wide range of freshwater and marine fish species, is uniform and standardised, relatively cheap, easily available, and can be stored for a long period (Donaldson and Hunter 1983; Rowland

1983; Shelton 1989). It proved effective at inducing ovulation in mulloway, and to a lesser extent snapper, but was far less effective at inducing spawning. HCG proved ineffective at inducing ovulation in snapper with oocytes less than 550µm (Table 2).

Ovaprim and LHRHa, which work by a different mechanism to HCG were used on snapper in an attempt to increase the proportion of females which ovulated and spawned. The use of Ovaprim increased the number of batches of ovulated eggs and latent period but did not lead to an increase in the number of eggs produced or improve fertilisation. LHRHa pellets were only used on one occasion with captive snapper following unsuccessful attempts to induce ovulation using hCG and Ovaprim. The slow release pellets proved effective at stimulating both maturation and ovulation but not spawning.

Clearly the presence of a spermiating male is the most fundamental requirement for successful spawning, although females of some species will release eggs without the presence of males. The physical influence of 'natural' conditions such as water temperature and depth, lighting and tank size may also play an important role in stimulating spawning. Snapper, for example, will spawn in sea cages and large public aquariums (Smith 1986; Foscarini 1988) but have not yet spawned in the research pool at the Fisheries Research Institute. Controlled experiments to investigate spawning stimuli are currently being conducted at PSRC.

Fish which ovulate but do not spawn have to have their eggs stripped, necessitating additional handling and stress. Stripped fish usually produced fewer fertilised eggs than those resulting from spontaneous spawnings (Foscarini 1988). One of the most significant problems encountered in the hormone induction trials at PSRC was knowing when fish had ovulated so that they could be stripped. It was particularly difficult to determine when to strip snapper because they appear to ovulate on a daily cycle and they did not respond well to handling stress. The viability of ovulated eggs retained in the ovary decreases rapidly in many warmwater species, a condition which is often termed 'overripening' (Bromage *et al.* 1994). Conversely, eggs can be stripped too close to ovulation (Bromage *et al.* 1994), although 'underripening' appears to less of a problem.

One of the problems in determining stripping times was the variation in latency periods and fertilisation rates observed with snapper collected using different methods and/or on different occasions. The optimum time to strip fish for maximum fertilisation is species-specific and temperature dependent and has been determined for relatively few species (Bromage *et al.* 1994). More detailed studies are required to determine the timing of ovulation and optimal stripping times in snapper. The influence of hormone-induced ovulation on egg quality also needs to be assessed.

It is generally easier to get male fish to undergo spermatogenesis (sperm development) and spermiation than it is to induce female fish to undergo vitellogenesis (egg development) and ovulation (Donaldson and Hunter 1983). In the current study, spermatogenesis was completed in both wild and captive males for both snapper and mulloway; males often spontaneously spermiating on capture. A single dose of hCG, usually lower than that required for females, was often sufficient to increase milt quality and volume. Further information on the effect of hCG on milt production and quality is available for New Zealand *Snapper* (Pankhurst 1994).

The availability of spermiating males from the wild was generally greater than that of vitellogenic females for both species. Males also matured at a smaller size than females collected from the wild. There were occasional problems in the collection of males and poor milt volumes, particularly towards the end of the breeding season.

Spawning Season and Source of Broodstock

Mulloway are group synchronous spawners in which maturation, ovulation and spawning generally occur once during the breeding season. Whereas snapper are asynchronous or multiple spawners spawning at 24 h intervals for periods of up to three months. Snapper proved to be the easier fish to collect from the wild and to hold in captivity. Successful hormone treatment preceded the natural spawning season and ceased prior to the end of spawning in the wild.

Snapper were induced to ovulate from August to December (Table 2). However, only females line-caught early in the season, presumably before they started ovulation and spawning,

Table 2: Comparison of the larval development and culture of snapper and mulloway at the Port Stephens Research Centre

Species	Snapper	Mulloway
Larval Development		
Mean water temperature (°C)	18.8-23.9	22.6-24.0
Size of eggs (mm)	0.9-1.0	0.8
Size of oil globule (mm)	0.2	0.3
Hatching time (h)	28 at 22°C	29 at 25°C
Size at hatch (mm)	3.1	2.3
Size 6 DAH	3.2	3.1
Size 19 DAH	5.6	6.3
Size 29 DAH	11.8	10.2
Swim bladder inflation (DAH)	7-11	3-4
Mouth open (DAH)	3	2
Start feeding (DAH)	6	4
Yolk-sac absorbed (DAH)	3	3
Caudal bending (DAH)	19	12
Metamorphosis (DAH)	25	34
Metamorphosis (mm)	8.6(0.5)	12.1
Scale formation (mm)	9.1-13.7	15-26
Larval rearing		
No. of trials	11	7
Mean length of trials (days)	19-75	25-51
Stocking density (larvae/l)	0.6-31	5-50
Rotifers (DAH)	3-6	3-4
Brine shrimp	18-25	12
Weaning (DAH)	24-55	24-39
Start cannibalism (DAH)	26	22
Survival (%)	0.8-68	0-55

produced large numbers of fertilised eggs. The availability of mature female snapper depended on water temperatures which fluctuated according to the East Australian Current (Cresswell 1994). Variations in sea conditions were unpredictable, strong currents made trapping difficult and, combined with the problems of stress-induced atresia, made the use of wild-caught snapper undesirable in the long term. The use of line-caught fish partially overcame the problem of stress but similar problems with weather conditions applied to long-lining. The long-term solution to the problems encountered in obtaining snapper eggs appears to be domestication of broodstock and environmentally induced spawning in captivity as is currently practiced in Japan with snapper (Foscarini 1988; Fukusho *et al.* 1986). First generation snapper and mulloway are currently being held in sea cages at FRI for this purpose.

Mulloway proved more difficult to collect than snapper. Mature mulloway females are typically large (8+ Kg) and difficult to collect from shallow water. In contrast, mature females from off-shore reefs appear to be smaller at around 5 Kg. Fish captured at depth (>20 m) were particularly difficult to keep alive because of suspected trauma due to over-inflation of the swim bladder. The procedures used to deflate the swim bladder and handle the fish are described in Talbot and Battaglene (1993). To highlight the difficulties involved in obtaining broodstock, 19 fish were caught off reefs in January 1995, but only two small fish (<4 Kg) were successfully transported back to the hatchery. Furthermore, during the study only three female mulloway were successfully collected from the wild, transported and hormone-induced to ovulate. The long-term solution to the supply of mulloway eggs is the same as that for snapper; captive stocks held in temperature and photoperiod controlled tanks. Mulloway held in the research pool at FRI matured in captivity but those held in a 50 000 l tank at PSRC did not. Fish grew quickly at both locations but were particularly susceptible to external parasites and needed to be treated prophylactically with formalin and malachite green. They also ceased feeding when the water temperatures rose above 25 °C, suggesting they may be sensitive to high water temperatures.

It appears that the start of the breeding season for snapper and mulloway can be brought forward by collecting fish from the northern distribution of their range. Likewise, the breeding season can be extended by collecting fish from the southern distribution of their

range at the end of the season. For example, snapper spawn in the north from late May to August, in Port Stephens from July to December and in southern Australia between late October and early March. However, the extent to which this will be a practical consideration is debatable and care should be exercised if fish from different stocks or breeding populations are interbred. Some research on stock discrimination has been carried out for snapper (MacDonald 1982; Francis and Winstanley 1989), and mulloway (Black and Dixon 1992).

Larviculture

Larval mortality in snapper and mulloway peaked during two key larval development phases: at first feeding and during weaning. Early larval mortality is difficult to quantify but was generally higher than that which occurred at weaning. Early larval mortality often peaks during or soon after the transition from yolk-sac and oil reserves to exogenous (external) feeding. Clearly, many factors can influence larval survival besides food resources (Figure 1). Blaxter (1988) listed five potentially critical periods through which larvae have to pass to allow development to proceed. They were: hatching, first -feeding, respiration, swim-up (initial swim bladder inflation) and metamorphosis. The first four critical periods occur early during larval rearing and are interrelated.

There is increasing evidence that broodstock nutrition, and in particular the level of some highly unsaturated fatty acids (HUFA) incorporated into eggs, is an important determinant of early larval size and survival (for reviews see Watanabe 1985; Tucker 1992b). Special care was taken in the current study to boost the nutritional profile of food given to captive broodstock. Wherever possible fish were fed a wide range of food including pilchards, prawns, squid and vitamin supplements.

Failure of larval fish to develop functional swim bladders is a common problem in intensive culture. The results of experiments conducted at PSRC indicate the following conditions should be used to maximise swim bladder inflation:

- broodstock should be maintained on a balanced diet high in HUFA;
- eggs should be incubated and hatched in separate containers to those in which the larvae are reared;

- surface skimmers should be used for the first two weeks of rearing, starting at feeding or from hatch if the water surface is oily;
- larval feeding should be delayed until just before or preferably after initial swim bladder inflation;
- larvae should be kept in the dark until just before or if possible after initial swim bladder inflation;
- low aeration or no aeration should be used to avoid turbulence;
- light intensities should be chosen according to the distribution of larvae in the tank, the percentage of larvae feeding and the amount of feeding per individual; and
- light intensities and aeration should be adjusted as the larvae grow.

Eggs and yolk-sac larvae were incubated in 60 l flow-through incubators similar to those described by Hogan (1988). Larvae were transferred in covered buckets to rearing tanks. Intensive larval rearing trials were conducted in either 10 000 l flat-bottomed tanks or 2000 l conical-bottomed tanks. The latter tanks had biological filters and flow-through salt water exchange. Water quality parameters were measured daily and a sample of 10 larvae were siphoned from the tank daily to monitor feeding, growth and development. Daily assessment of larvae was an important factor in the successful culture of all four species. It was particularly important in the detection of disease as discussed below.

In common with most marine fish hatcheries world-wide, first-feeding larvae were fed rotifers *Brachionus plicatilis* and then brine shrimp *Artemia sp* (Persoone *et al.* 1980; Fukusho 1989; Sorgeloos and Leger 1992). Rotifers were usually fed for the first three weeks and then brine shrimp up until metamorphosis and weaning. Rotifers and brine shrimp were cultured as described by Battaglene and Talbot (1989), Talbot *et al.* (1990) and Talbot and Battaglene (1991). The density of rotifers fed to first feeding larvae ranged from 5 to 15 rotifers/ml and for brine shrimp from 0.2 to 4.4 nauplii/ml (Battaglene 1995). Similar feeding rates have been used for a wide range of marine fish larvae (see review Tucker 1992a).

Nominal feeding rates are often only of theoretical value (Tucker 1992a) and depend on the density of larvae, tank hydrodynamics and operating procedures. Large strain rotifers were usually fed daily and survival and growth may have been improved if more frequent feeding

had been logistically possible. The use of small strain rotifers, not available in Australia during the study, may have improved survival of intensively cultured snapper because they have small mouths. In Japan, snapper are initially reared on small strain rotifers (Fukusho 1989; Oozeki *et al.* 1992). In contrast mulloway larvae have a large mouth and may be capable of consuming brine shrimp at first feed (Battaglene and Talbot 1994).

Numerous studies have shown the importance of n-3 HUFA in the diet of marine fish larvae (Watanabe et al .1983; Tucker 1992b; Rimmer *et al.* 1994b). Enriching rotifers and brine shrimp with n-3 HUFA is therefore a requirement for rearing most marine fish larvae (Fukusho 1989; Sorgeloos and Leger 1992). The essential fatty acids for marine fish larvae are generally considered to be the C20 and C22 unsaturated fatty acids, particularly 20:5*n*-3 (EPA) and 22:6*n*-3 (DHA) (Watanabe *et al.* 1983, 1989; Rimmer *et al.* 1994b). Some marine fish require both EPA and DHA , although DHA is usually considered more important, it is prudent to provide both in foods for marine fish larvae (Tucker 1992b; Watanabe 1993). Tucker (1992b) recommends a dietary n-3 HUFA content of 2-4%, including at least 1% EPA and 1% DHA in the absence of species-specific information.

The HUFA requirements of snapper have been the focus of a lot of research in Japan (Kitajima *et al.* 1980; Watanabe *et al.* 1983,1989; Foscarini 1988; Izquierdo *et al.* 1989; Morishita *et al.* 1989; Tandler *et al.* 1989b; Watanabe 1993) but much less is known about the requirements of mulloway. Izquierdo *et al.* (1989) suggested that snapper larvae require a *n*-3HUFA content of 3.0% in brine shrimp.

The development of techniques for enrichment of live food and the availability of new enrichment products has meant that the quality of live feeds has increased in recent years. This is particularly true for the enrichment of brine shrimp and the results presented in some of the published scientific papers (Battaglene and Talbot, 1992 and 1994) were obtained using enrichment feeding of brine shrimp with a microencapsulated diet high in polyunsaturated fatty acids. In more recent trials we have used a superior brine shrimp boosting product (high DHA Super Selco, Artemia Systems NV Belgium), combined with a specially formulated marine fish larval weaning diet (ML diets, Fukui, Yokohama, Japan). In addition, small nutritionally superior brine shrimp of guaranteed quality (AF brand, Artemia

Systems) were used for the first few days of brine shrimp feeding in latter trials. The larval mortality of both species, but particularly snapper at weaning (described in Battaglene and Talbot 1992), was greatly reduced using these improved methods (Battaglene *et al.* 1993).

The improvement in larval survival was difficult to quantify in production trials because of the confounding influences of different initial stocking densities, cannibalism and disease outbreaks. However, an overall survival rate of 25 to 35% should be achievable depending on stocking densities and frequency of grading. Initial stocking densities ranged from very low <1 larvae/l to as high as 100/l (Table 2). Typical initial stocking densities for production of intensively cultured larvae of the same or similar species range from 12 to 72 larvae/l for snapper *(*Fukusho 1989), 10-20/l for red drum *Sciaenops ocellatus* (Holt *et al.* 1990), 30/l for *S. japonica* (Oozeki *et al.* 1992), 100/l for European sea bass *Dicentrarchus. labrax* and sea bream *Sparus auratus* (Chatain and Ounais-Guschemann 1990). A reduction in larval density is usually required at or before weaning depending on the initial number of larvae stocked, the survival rate and larval behaviour. Cannibalism of larvae was particularly evident for mulloway at weaning (Battaglene 1994).

Cannibalism is regarded as an alternative feeding strategy, more likely to be adopted by larvae and early juveniles which are carnivorous, when resources become limiting (Hecht and Pienaar 1993). It is a major problem in the culture of many marine fish larvae. Size variation is a primary cause and an effect of cannibalism and agonistic behaviour in larval fish (MacKinnon 1985; Katavic *et al.* 1989; Hecht and Pienaar 1993). Other factors influencing cannibalism include food and larval density, feeding frequency, light intensity, water clarity, and shelter (see review by Hecht and Pienaar 1993). Cannibalism was controlled in the current study by reducing larval densities, increasing feeding frequencies, removing dominant individuals, regular grading and keeping the larvae in the dark when food was unavailable or in short supply. The use of dark covers at night and before feeding in the morning increased growth and survival of larvae presumably by reducing cannibalism and agonistic behaviour.

Weaning, the transfer from live food to artificial foods is successful with most marine fish with a completely developed digestive tract (Person Le Ruyet *et al.* 1993). In the current study weaning was undertaken after metamorphosis, initially using chopped fish and squid and in

latter trials with commercial microparticles. The weaning strategy used varied slightly between trials but always involved a gradual transfer over a minimum of five days. Similar weaning strategies are used with snapper in Japan (Foscarini 1988; Kanazawa *et al.* 1989), although abrupt replacement is favoured with sea bass in Europe (Person Le Ruyet 1990). Mulloway proved easier to wean than snapper.

Initial low density larval rearing trials were not affected by disease. However, bacterial outbreaks occurred in high density trials with both snapper and mulloway. The bacteria were identified as belonging to the *Vibrio* group, and later tentatively identified as *V. tubiashii* (S . Nearhos unpublished data, 1993). *Vibriosis* is the most significant infectious disease occurring in marine fishes regardless of age and causes losses of 219.5 tonnes p.a. of snapper in Japan (Hirano and Yone 1972; Sano and Fukuda 1987). Rapid diagnosis and selection of an appropriate antibiotic, usually oxolinic acid (bath of 5mg/l for 5 days) proved an effective control mechanism against bacterial disease in experimental trials. The first larval run of a season was usually free of disease and in 1994 successive trials became infected at an earlier stage suggesting contaminated biofilters may have contributed to the outbreaks. Longer term solutions to the problem of disease control may include increasing hygiene and water quality through the use of UV sterilisers, improved rearing methods, less reliance on biofiltration and the use of vaccines.

SUMMARY OF RESEARCH FINDINGS

The research conducted at PSRC demonstrates that snapper and mulloway juveniles can be produced in at least moderately large numbers using hormone-induced ovulation of wild-caught broodstock and intensive larval rearing techniques. The research identified a number of 'bottlenecks' in the provision of seed stock. These bottlenecks are different for the two species and reflect the relative difficulty of culturing each and the varying amount of research conducted. Development of breeding techniques are most advanced for snapper.

With snapper the main bottleneck in production is the hormone-induced ovulation of wild broodstock. Poor egg supplies have limited seed stock production in commercial hatcheries. The techniques described in Battaglene and Talbot (1992) and Battaglene (1995) address this problem. The results suggest that the long-term solution to the reliable supply of snapper

eggs is the controlled spawning of domesticated broodstocks. Improvements in larval rearing techniques described in Battaglene (1995) have markedly increased the survival rate of intensively cultured snapper larvae.

The reliable supply of mature broodstock was a limitation in determining the potential of mulloway. However, from the small number of fish treated, it was relatively easy to induce ovulation in both wild and captive broodstock . Similarly, the intensive larval rearing of mulloway was relatively straightforward, although problems with cannibalism did occur in the latter stages of rearing.

FUTURE RESEARCH

The problems experienced with the supply of fertilised eggs from wild-caught broodstock are currently the focus of a large research program undertaken by NSW Fisheries in association with the Department of Aquaculture, University of Tasmania with support from the Cooperative Research Centre for Aquaculture. This research program was formulated in response to the problems identified in research conducted at PSRC. Another area of research being pursued is the possibility of extensive larval culture. The successful combination of intensive and extensive culture used for Australian bass (Battaglene *et al.* 1992) and currently used to produce barramundi in northern Australia (Rutledge and Rimmer 1991) could be extended to both snapper and mulloway.

HOW MANY JUVENILE FISH ARE REQUIRED?

The approximate number of juvenile fish required can be estimated as follows. If we make the following assumptions:

- production of 100 tonne *per annum*;
- average weight at harvest of 500 g; and
- survival rate to harvest of 40%;

then the number of fish harvested would equal 200,000 (= 100,000 / 0.5) and the number of juveniles stocked each year would be 500,000 (= 200,000 / 0.4). The annual production target would be achieved after an initial lag time needed for the first crop to reach market size.

The cost of juveniles is unknown and impossible to accurately estimate until commercial hatcheries become established. However using the cost of barramundi juveniles, and overseas estimates as a guide it appears that juveniles will cost between 25 and 50c each or about 1c per mm when purchased in reasonable numbers (e.g. over 100 000). Smaller numbers of juveniles could be much more expensive.

IMPLICATIONS FOR PROVISION OF SEED STOCK TO FISH FARMERS

The intensive techniques described above have been used to produce over 100 000 Australian bass, 30 000 snapper, 20 000 mulloway and 10 000 sand whiting at PSRC. Both snapper and mulloway juveniles have been stocked in sea cages and grown to market size in about two years (O' Sullivan 1994). However the production capacity of the PSRC is insufficient to supply commercial farms.

The establishment of a commercial hatchery is therefore a prerequisite to the development of finfish farming. There are currently no marine fin-fish hatcheries operating in NSW, although there are some sites and facilities that could be modified for use as hatcheries. The establishment of hatcheries will of course not be economically viable until the farming becomes large-scale. This "chicken and the egg" problem is a serious impediment to the development of the industry.

To assist in overcoming the problem NSW Fisheries should be in a position to provide fertilised eggs and yolk-sac larvae for both snapper and mulloway in sufficient quantities to allow commercial production up to 100 t. The eggs or larvae will then need to be reared either intensively in a newly established hatchery or extensively, possibly in prawn farming ponds.

REFERENCES

Barnabe, G., 1990. Rearing bass and gilthead bream. In: G. Barnabe (Editor), Aquaculture Vol. 2 , Ellis Horwood, New York, pp. 647-686.

Battaglene, S.C., 1994. Developments in hatchery production of mulloway *Argyrosomus hololepidotus.* Australian Society for Fish Biology, 21 st. Annual Conference, Canberra, ACT 2-3 September 1994. (Abstract only).

Battaglene, S.C., 1995. Induced ovulation and larval rearing of four species of Australian marine fish. PhD thesis, University of Tasmania. 215pp.

Battaglene, S.C. and Bell, J.D., 1991. Aquaculture prospects for marine fish in New South Wales, Fishnote DF/6, NSW Agriculture & Fisheries, Sydney.

Battaglene, S. C. and Talbot R.B., 1989. Mass production of rotifers. *Austasia Aquaculture*, 3:6-7.

Battaglene, S. C. and Talbot R.B., 1992. Induced spawning and larval rearing of snapper *Pagrus auratus* (Pisces: Sparidae) from Australian waters. *New Zealand Journal of Marine and Freshwater Research*, 26:179-185.

Battaglene, S.C. and Talbot, R.B., 1994. Hormone induction and larval rearing of mulloway *Argyrosomus hololepidotus* (Pisces:Sciaenidae). *Aquaculture*, 126:73-81.

Battaglene,S.C. and Talbot, R.B., and Allan, G.L., 1992. Supplementary feeding with brineshrimp, *Artemia salina* in the extensive brackish water culture of Australian bass, *Macquaria novemaculeata* (Steindachner). In: G.L. Allan and W. Dall (Eds), *Proceedings Aquaculture Nutrition Workshop*, Salamander Bay, 15-17 April 1991. NSW Fisheries, Brackish Water Fish Culture research Station, Salamander Bay, Australia, pp197-198.

Battaglene,S.C. and Talbot, R.B., Taylor, J.J., 1993. Advances in hatchery production of snapper, *Pagrus auratus*. Australian Society for Fish Biology, 20 th Annual Conference, Sorrento, Western Australia 27-28 August 1993. (Abstract only)

Bell, J. D., Quartararo, N. and Henry, G. W., 1991. Growth of snapper, *Pagrus auratus*, from south-eastern Australia in captivity. *New Zealand Journal of Marine and Freshwater Research* 25: 117-121.

Black, M. and Dixon, P.I., 1992. Stock identification of mulloway in Australian waters. Final report to FIRTA. Centre for Marine Science, University of NSW. pp38.

Blaxter, J.H.S., 1988. Pattern and variety in development. In: In: W.S. Hoar, D.J. Randall and E.M. Donaldson (Editors), *Fish Physiology*. Vol. X1, Part A. Academic Press, New York, NY, pp. 1-48.

Bromage, N., Bruce, M., Basavaraja, N., Rana, K., Shields, R., Young, C., Dye, D., Smith, P., Gillespie, M. and Gamble, J., 1994. Egg quality determinants in finfish: the role of over-ripening with special reference to the timing of stripping in the Atlantic halibut *Hippoglossus hippoglossus*. *Journal of the World Aquaculture Society*, 25:13-21.

Carragher, J. F., Pankhurst, N. W., 1991. Stress and reproduction in a commercially important marine fish, *Pagrus auratus* (Sparidae). In: A. P. Scott, J. P. Sumpter, D. E. Kime and M. S. Rolfe (Editors), Fish Symposium 91. Sheffield, Reproductive Physiology of Fish. pp 253-255.

Chatain, B. and Ounais-Guschemann, N.,1990. Improved rate of initial swim bladder inflation in intensively reared *Sparus auratus*. *Aquaculture*, 84:345-353.

Cresswell, G., 1994. Nutrient enrichment of the Sydney continental shelf. *Australian Journal of Marine and Freshwater Research*, 45:677-691.

Davy, F.B., 1990. Mariculture in Japan. *World Aquaculture* 21:36-47.

Donaldson, E.M., Hunter, G. A., 1983. Induced final maturation, ovulation and spermiation in cultured fish. In: W.S. Hoar, D.J. Randall and E.M. Donaldson (Editors), *Fish Physiology*. Vol. IX, Part B. Academic Press, New York, NY, pp. 351-403.

Evans, D., 1989. New Research Lab for Kinhill Marine Sciences. *Austasia Aquaculture*, 4:17.

Foscarini, R., 1988. A review: intensive farming procedure for sea bream (*Pagrus major*) in Japan. *Aquaculture*, 72:191-246.

Francis, M.P., 1994. Growth of juvenile snapper, *Pagrus auratus. New Zealand Journal of Marine and Freshwater Research*, 28:201-218.

Francis, R.I.C.C. and Winstanley, R.H., 1989. Difference in growth rates between habitats of south-east Australian snapper *(Chrysophrys auratus). Australian Journal of Marine and Freshwater Research*, 40: 703-710.

Fukusho, K., Fujimura T., Yamamoto, T., 1986. Broodstock and advanced spawning of the sea bream in an indoor tank with manipulation of water temperature. *Aquaculture*, 34:69-75.

Fukusho, K., 1989. Fry production for marine ranching of red sea bream. *lnternational Journal of Aquaculture and Fisheries Technology*. 1:109-117.

Fukusho, K. ,1991. Red sea bream culture in Japan. In: R. McVey (Editor), *Handbook of mariculture. Vol. II. Finfish aquaculture*, Roca Baton, CRC Press, 73-87pp.

Gray, C. A. and McDonall, V. C., 1993. Distribution and growth of juvenile mulloway, *Argyrosomus hololepidotus* (Pisces:Sciaenidae), in the Hawkesbury River, south-eastern Australia. *Australian Journal of Marine and Freshwater Research*, 44:401-409.

Hecht, T. and Pienaar, A.G., 1993. A review of cannibalism and its implications in fish larviculture. *Journal of the World Aquaculture Society*. 24: 152-161.

Henry, G., 1988. Snapper. NSW Agriculture & Fisheries, Agfact F1.0.3., Sydney, New South Wales. 6pp.

Hirano, K. and Yone, Y., 1972. A bacterial study on the death of fish during transport- III. The characteristics and the sensitivity to drugs of pathogens isolated from dead fish. *Bulletin of the Japanese Society of Scientific Fisheries*. 38(1): 64-70.

Hogan, A.E., 1988. A universal hatching system for fish eggs. *Australian Fisheries*, 47:30-32.

Holt, J.G., Arnold, C.R. and Riley, C.M., 1990. Intensive culture of larval red drum. In: G.W. Chamberlain, R.J. Miget and M.G. Haby (Editors), Red drum aquaculture. *Proceedings of a symposium on the culture of red drum and other warm water fishes*. 53-56pp.

Hunter, J.R., 1984. Synopsis of culture methods for marine fish larvae. In: H.G.Moser (Editor), *Ontogeny and systematics of fishes*. American Society of Ichthyology and Herpetology, Special Publication No. 1, Allen Press, Lawrence, Kansas. pp.24-27.

Izquierdo, M.S., Watanabe, T., Takeuchi, T., Arakawa, T. and Kitajima, C., 1989. Requirement of larval red seabream *Pagrus major* for essential fatty acids. *Nippon Suisan Gakkaishi*, 55:859-867.

Kailola, P.J., Abel, K. and Grieve, C.,1993. Mulloway. In: P.J. Kailola, M.J. Williams, P.C. Stewart, R.E. Reichelt, A. McNee and C. Grieve (Editors), *Australian Fisheries Resources*. Bureau of Resource Sciences and the Fishing Research and Development Corporation. Canberra, Australia. pp318-320.

Kanazawa, A., Koshio, S. and Teshima, S., 1989. Growth and survival of larval red sea bream *Pagrus major* and the Japanese flounder *Paralichthys olivaceus* fed microbound diets. *Journal of the World Aquaculture Society*, 20:31-37.

Katavic, I., Judgujakovic, J. and Glamuzina, B., 1989. Cannibalism as a factor affecting the survival of intensively cultured sea bass (*Dicentrarchus labrax*) fingerlings. *Aquaculture*, 77:135-143.

Kitajima, C., Arakawa, T., Oowa, F., Fujita, S., Imada, O., Watanabe, T. and Yone, Y., 1980. Dietary value for red sea bream larvae of the rotifer *Brachionus plicatilis* cultivated with a new type of yeast. *Bulletin of the Japanese Society of Scientific Fisheries*, 46:43-46.

Lam, T.J., 1983. Environmental influences on gonadal activity in fish. In: W.S. Hoar, D.J. Randall and E.M. Donaldson (Editors), *Fish Physiology*. Vol. IX, Part B. Academic Press, New York, NY, pp. 65-116.

MacDonald, C.M., 1982. Life history characteristics of snapper *Chrysophrys auratus* (Bloch and Schneider, 1801) in Australian waters. Victorian Department of Conservation and Lands, Fisheries and Wildlife Division, *Fisheries and Wildlife Paper 29*. 16pp.

MacKinnon, M.R., 1985. Barramundi breeding and culture in Thailand. Queensland Department of Primary Industries Study Tour Report, 1-21 June 1982. Sohgkhla, Thailand.

McNee, A., Abel, K. and Grieve, C., 1993. Snapper. In: P.J. Kailola, M.J. Williams, P.C. Stewart, R.E. Reichelt, A. McNee and C. Grieve (Editors), *Australian Fisheries Resources*. Bureau of Resource Sciences and the Fishing Research and Development Corporation. Canberra, Australia. pp 315-317.

Morishita, T., Uno, K., Araki, T. and Takahashi, T.,1989. Comparison of the fatty acid compositions in cultured red sea bream differing in the localities and culture methods, and those in wild fish. *Nippon Suisan Gakkaishi*, 55:847-852.

Nicoll, P., 1993. Port Lincoln carves out a bright future. *Australian Fisheries*, 52:14-23.

Oozeki, Y. Hwang, P. and Hirano, R., 1992. Larval development of the Japanese whiting, *Sillago japonica. Japanese Journal of Ichthyology*, 39:59-66.

Orhun, R. M., 1989. Early life history of white seabass *Atractoscion nobilis*. M. Sc. Thesis, San Diego State University, San Diego.

O'Sullivan, D., 1994. Snapper and mulloway focus for marine fish culture research in New South Wales. *Austasia Aquaculture*, 8:35-39.

Pankhurst, N.W., 1994. Effects of gonadotropin releasing hormone analogue, human chorionic gonadotropin and gonadal steroids on milt volume in the New Zealand snapper, *Pagrus auratus* (Sparidae). *Aquaculture*, 125: 185-197.

Pankhurst, N.W. and Pankhurst P.M., 1989. Induced spawning of snapper *Chrysophrys auratus*. Prospects for aquaculture. *Proceedings of Aquanz '88*. New Zealand Fisheries Occasional Publication No.4: 31-34.

Pankhurst, N.W. and Sharples, D.F., 1992. Effects of capture and confinement on plasma cortisol concentrations in the snapper *Pagrus auratus*. *Australian Journal of Marine and Freshwater Research*, 43:345-356.

Paulin, C. D., 1990. *Pagrus auratus*, a new combination for the species known as "snapper" in Australasian waters (Pisces: Sparidae). *New Zealand Journal of Marine and Freshwater Research* 24: 259-265.

Persoone, G., Sorgrloos, P., Roels, O. and Jaspers, E., 1980. (Editors). The brine shrimp *Artemia. Proceedings of the International Symposium on the brine shrimp* Artemia salina. Corpus Christi, Texas, USA, August 20-23, 1979. Universa Press, Wetteren, Belgium.

Person le Ruyet, J., 1990. Early weaning of marine fish larvae onto microdiets: constraints and perspectives. In: *Advances in Tropical Aquaculture*, AQUACORP IFREMER Actes de Colloque 9:625-642.

Person le Ruyet , J., Alexandre, J.C., Thebaud, L. and Mugnier, C., 1993. Marine fish larval feeding: formulated diets or live prey. *Journal of the World Aquaculture Society*, 24(2): 211-224.

Rimmer, M.A., Reed, A.W., Levitt, M.S. and Lisle, A.T., 1994b. Effects of nutritional enhancement of live food organisms on growth and survival of barramundi, *Lates calcarifer* (Bloch), larvae. *Aquaculture and Fisheries Management*, 25:143-156.

Rowland, S.J.,1983. The hormone-induced ovulation and spawning of the Australian freshwater fish golden perch, *Macquaria ambigua* (Richardson) (Percichthyidae). *Aquaculture*, 35:221-238.

Rutledge, W.P. and Rimmer, M.A., 1991. Culture of larval sea bass, *Lates calcarifer* (Bloch), in saltwater rearing ponds in Queensland, Australia. *Asian Fisheries Science*, 4:345-355.

Sano,T. and Fukuda, H., 1987. Principal microbial diseases of mariculture in Japan. *Aquaculture*, 67:59-69.

Scott, S.G. and Pankhurst, N.W., 1992. Interannual variation in the reproductive cycle of the New Zealand snapper *Pagrus auratus* (Bloch & Schneider)(Sparidae). *Journal of Fish Biology*, 41:685-697.

Scott, S.G., Zeldis, J.R., and Pankhurst, N.W., 1993. Evidence of daily spawning in natural populations of the New Zealand snapper *Pagrus auratus* (Sparidae). *Environmental Biology of Fishes*, 36:149-156.

Searle, L. and Zacharin, W., 1994. Aquaculture research needs in Tasmania. Joint industry / research workshop. Department of Primary Industry and Fisheries, Tasmania. Marine Research Laboratories- Taroona 29 April 1994.

Shepherd, J.C. and Bromage, N.R., 1988. *Intensive Fish Farming*. BSP Professional Books. Oxford, London, Edinburgh, Boston, Palo Alto, Melbourne, 404 pp.

Shelton, W.L., 1989. Management of finfish reproduction for aquaculture. *Reviews in Aquatic Sciences*, 1:497-534.

Smith, P. J., 1986. Spawning behaviour of snapper, *Chrysophrys auratus*, in captivity. *New Zealand Journal of Marine and Freshwater Research* 20: 513-515.

Sorgeloos, P. and Leger, P., 1992. Improved larviculture outputs of marine fish, shrimp and prawn. *Journal of the World Aquaculture Society*, 23:251-264.

Stanley, S., 1991. The development of new species for aquaculture. Finfish Workshop, Lufra 9-13th July 1991, Division of Sea Fisheries, Tasmania. 8pp.

Sumpter, J.P., Carragher, J.F., Pottinger, T.G. and Pickering, A.D., 1987. Interaction of stress and reproduction in trout. In: D.R. Idler, L.W. Crim, and J.M. Walsh (Editors), *Reproductive Physiology of Fish* 1987. Memorial University Newfoundland, St Johns pp. 299-302.

Sweetman, J.W., 1992. Larviculture of Mediterranean marine fish species: current status and future trends. *Journal of the World Aquaculture Society*, 23:330-337.

Talbot, B. and Battaglene, S., 1991. Brine shrimp in aquaculture. NSW Agriculture & Fisheries, Advisory note 9/90, NSW, Sydney. 4pp.

Talbot, B. and Battaglene, S., 1993. Fishing for the future-catch and release fishing. NSW Fisheries, Fishnote DF/27, NSW, Sydney. 4pp.

Talbot, B., Smith, I. and Piddington J. 1990. Mass production of the rotifer *Brachionus plicatilis*. NSW Agriculture & Fisheries, Advisory note 2/90, NSW, Sydney. 4pp.

Tandler, A., Harel, M., Wilks, M., Levinson, A., Brickell, L., Christie, S., Avital, E. and Barr, Y., 1989. Effect of environmental temperature on survival, growth and population structure in the mass rearing of the gilthead seabream, *Sparus auratus*. *Aquaculture*, 78:277-284.

Taniguchi, N., Fujita, M. and Akazaki, M., 1986. Genetic divergence and systematics in sparid fish from Japan. In: T. Uyeno, R. Arai, T. Taniuchi and K. Matsura (Editors), Tokyo, *Ichthyological Society of Japan*. pp. 849-858.

Treadwell, R., McKelvie, L. and Maguire, G.B.,1992. Potential for Australian Aquaculture. Australian Bureau of Agricultural and Resource Economics, Research Report 92.2, Canberra, 81 pp.

Tucker, J.W., Jr.,1992a. Feeding intensively-cultured marine fish. In: G.L.Allan and W. Dall (Editors), *Proceedings Aquaculture Nutrition Workshop*, Salamander Bay, 15-17 April 1991. NSW Fisheries, Brackish Water Fish Culture Research station, Salamander Bay, Australia, pp.129-146.

Tucker, J.W., Jr.,1992b. Marine fish nutrition. In: G.L.Allan and W. Dall (Editors), *Proceedings Aquaculture Nutrition Workshop*, Salamander Bay, 15-17 April 1991. NSW Fisheries, Brackish Water Fish Culture Research station, Salamander Bay, Australia, pp.25-40.

Tucker, J.W.Jr. and Jory, D.E., 1991. Marine fish culture in the Caribbean region. *World Aquaculture*, 22:10-27.

Watanabe, T., Ohhashi, S., Itoh, A., Kitajima, C. and Fujita, S., 1984a. Effect of nutritional composition of diets on chemical components of red sea bream broodstock and eggs produced. *Bulletin of the Japanese Society of Scientific Fisheries*, 50:503-504.

Watanabe, T., Arakawa, T., Kitajima, C. and Fujita, S., 1984b: Effect of nutritional quality of broodstock diets on reproduction of red sea bream. *Bulletin of the Japanese Society of Scientific Fisheries*, 50:495-501.

Watanabe, T., 1985. Importance of the study of broodstock nutrition for further development of aquaculture. In: C.B. Cowey, A.M. Mackie and S.G.Bell (Editors), *Nutrition and feeding fish*. Academic Press, London. pp395-414.

Watanabe, T., Kitajima, C. and Fujito, S., 1983. Nutritional values of live organisms used in Japan for mass propagation of fish: a review. *Aquaculture*, 34:115-143.

Watanabe, T., Izquierdo, M.S., Takeuchi, T., Satoh S. and Kitajima, C., 1989. Comparison between eicosapentaneoic and docosahexaenoic acids in terms of essential fatty acid efficacy in larval red seabream. *Nippon Suisan Gakkaishi*, 55:1635-1640.

Watanabe,T., 1993. Importance of docosahexaenoic acid in marine larval fish. *Journal of the World Aquaculture Society*, 24: 152-161.

Zohar,Y., 1988. Gonadotropin releasing hormone in spawning induction in teleosts: basic and applied considerations. In: *Reproduction in Fishes: Basic and Applied Aspects in Endocrinology and genetics*. INRA, 44:47-62.

Grow-Out Of Snapper And Mulloway In Sea Cages

Nino Quartararo

NSW Fisheries, Fisheries Research Institute, PO Box 21, Cronulla, NSW 2230

Introduction

For the past six years NSW Fisheries has been conducting research on marine finfish farming. This research has been funded by both NSW Fisheries and the Fisheries Research and Development Corporation (FRDC).

The aquacultural potential of two indigenous species of marine fish is being evaluated. Initially the research focused on snapper (*Pagrus auratus*), but recently has also included mulloway (*Argyrosomus hololepidotus*), known commonly in NSW as jewfish. The aim of the research reported here was to obtain information on the aspects of nutrition, growth, husbandry and disease control pertinent to aquaculture. This information will aid both the initiation and development of sustainable marine finfish farming in Australian temperate waters.

The research was carried out in two stages. The first stage involved growth and feeding trials in tanks at the Fisheries Research Institute (FRI), Cronulla. The second stage involved grow-out trials in seacages in Botany Bay.

Tank trials

Background

The trials were conducted using juvenile snapper caught from the wild by a variety of methods including: beach seining; handlining and trapping. Most of the fish were caught in the Port Hacking estuary close to FRI. The snapper used for the trials were judged to be "young of the year" (0+) and when caught varied from 70 to 120 mm fork length with an average weight of about 20 g. During the trials fish were housed in flow-through tanks at FRI which were supplied with either ambient temperature or heated seawater.

Summary of results

Growth

Wild juvenile snapper adapted well to captivity and were weaned easily onto dry pellets. The growth rate of snapper in captivity was approximately double that of wild snapper. Juvenile snapper (≈ 8 months old) grew to market size (250 mm fork length) in just over 12 months giving a total time to market of about 21 months (Bell *et al*.,1991).

Increasing the water temperature significantly increased the growth rate of juvenile snapper. A trial conducted over winter, during which the ambient seawater temperature varied from 13 to 18°C, showed that the growth rate of juvenile snapper was almost doubled by rearing them in water heated by 3-5°C (Allan and Quartararo, 1996).

Nutrition

A reference diet for snapper, based on the results of work done in Japan, was formulated using local ingredients. The reference diet was 64% fishmeal and resulted in faster growth and better feed conversion than several commercial diets for other marine carnivorous fish species. The apparent feed conversion ratio (FCR, dry weight of feed given/live weight gain) was 1.6 for the reference diet (Quartararo *et al.*, 1992).

Fishmeal is the protein source of choice for fish feeds although increasing demand, reduced supply and increasing cost have stimulated a major research effort to replace fishmeal with alternative, cheaper sources of protein. A range of cheaper diets for snapper were derived from the reference diet by replacing varying amounts of the fishmeal with a mixture of poultry offal meal and soybean meal. However, for many species of marine carnivorous fish the replacement of dietary fishmeal by cheaper sources of protein can result in poor growth and feed conversion efficiency (see for example Reigh and Ellis, 1992). Based on feeding trials conducted by NSW Fisheries, it is recommended that diets for snapper using soybean meal and poultry offal meal as alternative protein sources to fishmeal should contain at least 30% fishmeal (Allan and Quartararo, 1996).

For further information on nutrition and growth of juvenile snapper in tanks the reader is referred to Allan and Quartararo, 1996.

Taste tests

Formal taste tests found that the overall acceptability, judged by a combination of factors such as flavour, colour, texture, oiliness etc. of captive snapper fed pellets was similar to that of freshly caught wild snapper of similar size (Prescott and Bell, 1992).

Sea cage trials

Sea cages (Plate 1)

Frame

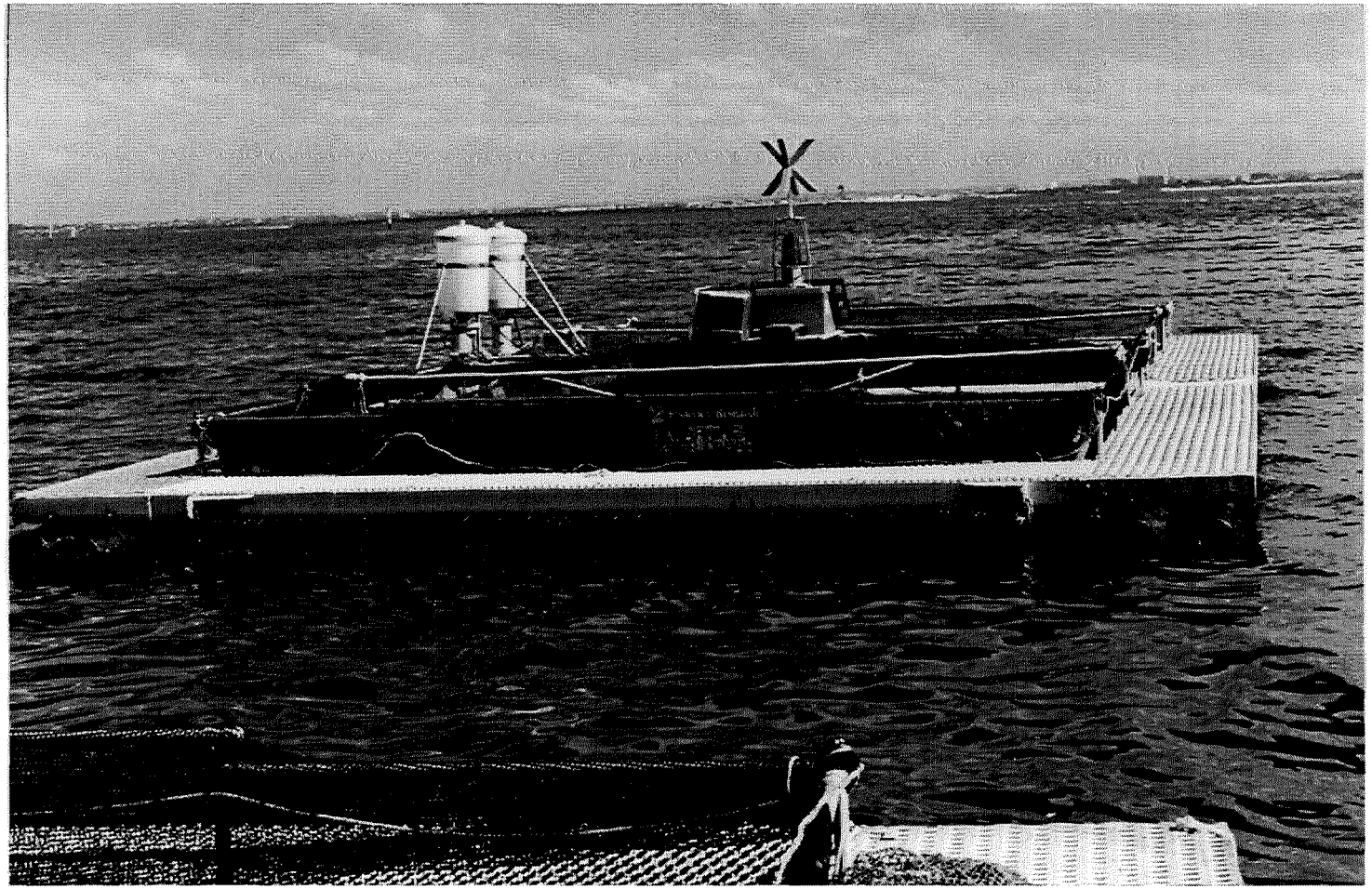
The seacage frames were welded from 150 x 75 mm PFC steel and then hot-dip galvanised. Each frame was rectangular (13 x 7 m approx.) and divided by a cross member into two equal compartments (5 x 5.5 m approx.) in which the netcages were hung (diagram 1). After galvanising, the frames were delivered to a local shipyard where the flotation was bolted on, the net supporting rails and steel mesh walkway were fitted and the navigation light installed. The completed frames were launched by crane and towed to their site in Botany Bay.

Flotation

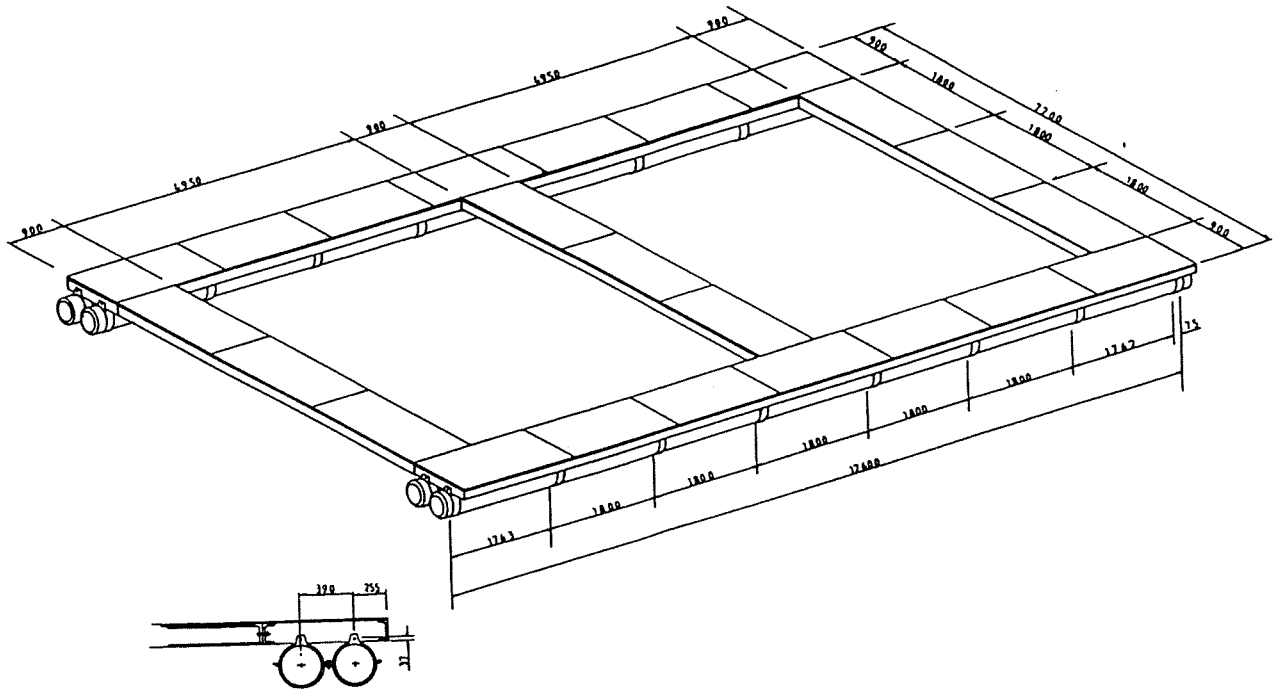
The floats were made from 315 mm diameter polyethylene tubing with polyethylene caps heat-welded to both ends. The tubes were attached to the frame with brackets especially designed for floating marinas and pontoons (Industrial Pipe Systems P/L, Kingsgrove, NSW, Australia). The flotation on the seacages withstood the conditions in Botany Bay for two and a half years and there was no significant decrease in buoyancy of the seacages over that time. Although it did not prove necessary, the flotation tubes could have been filled with foam to prevent loss of buoyancy if the tubes were holed accidently.

Netcages

The netcages were made from UV-resistant knotless nylon netting. Juvenile snapper and mulloway from the hatchery were stocked initially in nursery (net)cages made of 4 mm mesh with a volume of approximately 30 cubic metres (2.5 x 5 x 2.5 m). The fish were then transferred to initial grow-out cages which were made of 12.5 mm mesh with a volume of approximately 100 cubic metres (5 x 5.5 x 3.5 m). Final grow-out cages were made of 22 or 25 mm mesh and were of the same volume and dimensions as the initial grow-out cages.



<u>Plate 1:</u> Seacages in Botany Bay



<u>Diagram 1</u>: Design of the seacage frame, walkway and flotation

Predator nets

Sharks and other underwater predators were excluded by a 90 mm mesh netcage which enclosed both smaller netcages containing the fish. There was also a removable bird net covering the top of each netcage.

Moorings

The seacages were moored fore and aft by two one tonne blocks of concrete chained in series. The blocks were attached to a heavy ground chain which in turn was attached to a 26 mm rope bridle from the seacage. Each seacage was positioned such that its long axis was approximately perpendicular to both directions of tidal current flow. The seacages were positioned in this way so that the physical conditions in the cages were as uniform as possible. The moorings were checked and maintained regularly by divers. Apart from the wear that moorings normally experience, there appeared to be an increased rate of corrosion of shackles (and mausing wire) which resulted in shackle failure due to pin loss. The corrosion may have been due to an electrolytic process associated with the automatic feeder and/or navigation lights and therefore may have been slowed or prevented by sacrificial anodes.

Site

Depth

The depth at the site of the seacages in Botany Bay is between 5 and 6 m at mean low water. At mean low water, the netcages were approximately 1 to 1.5 m clear of the seabed. For commercial scale operations, it is advisable that netcages extend to mid water only, e.g. for a 10 m site the floor of the netcages should be at least 5 m above the seabed. The clearance between the bottom of the netcage and the seabed is important for the dispersal of particulate matter, such as uneaten food and faeces.

Current

The current at the site of the seacages in Botany Bay averages between 8 and 12 cm/sec over a tidal cycle. A peak current of 17 cm/sec was recorded at the site for a 1.6 m high tide (high tide range 1.1 - 2 m). In Japan, where snapper (red sea bream) have been farmed for over 20 years, sites with currents between 5 and 15 cm/sec are favoured (Ikenoue and Kafuku, 1992).

While the environmental management of a site and the water quality maintenance within netcages is dependent on current flow, excessive current can however cause problems. When juveniles are first stocked in a netcage their swimming ability may not be well developed. If the current is too strong they may have difficulty maintaining station and reaching the feed. In such cases the seacages should be moved to either another site or to another part of the same site where the current is less. Some shielding from current flow is given by the finer mesh nets used to hold juveniles. Excessive current can distort netcages (especially if they are badly fouled and/or are of fine mesh) and significantly decrease their effective volume. This increases crowding of the fish which can cause stress. It can also result in higher feed wastage. The distortion (by current) of the netcages in Botany Bay was reduced by hanging ballast bags in each corner and in the middle of the two faces of the netcage perpendicular to the current. The ballast bags consisted of polypropylene bags half-filled with smooth river rock (≈20 kg). Each ballast bag was suspended by rope from the net rail so that it was about 30 cm above the floor of the netcage. If needed, a metal pipe frame resting on the floor of the seacage will help to further reduce distortion (G. Johnson pers. comm.); the dimensions of the pipe frame should be slightly less than (e.g. 90%) those of the floor of the netcage.

Salinity

The site of the seacages in Botany Bay is close to the heads of Botany Bay and is a well flushed marine site. The surface salinity at the site was measured daily when the weather permitted . In the period from when the seacages were first stocked in May 1993 to December 1995, the minimum surface salinity recorded was 30 ppt.

Water Temperature

Weather permitting, the surface water temperature was recorded on a daily and sometimes bi-daily basis depending on how many times the fish were fed on the day. The mean monthly water temperature at the seacages in Botany Bay varied from about 15 to 23°C (Figure 1).

A sinusoid of the form: $T = A + B\sin(Ct + D)$

where T is temperature in °C; t is the number of months from May 1993 and, A, B, C, and D are constants; was fitted by least squares to the mean monthly temperatures (Figure 2) and is

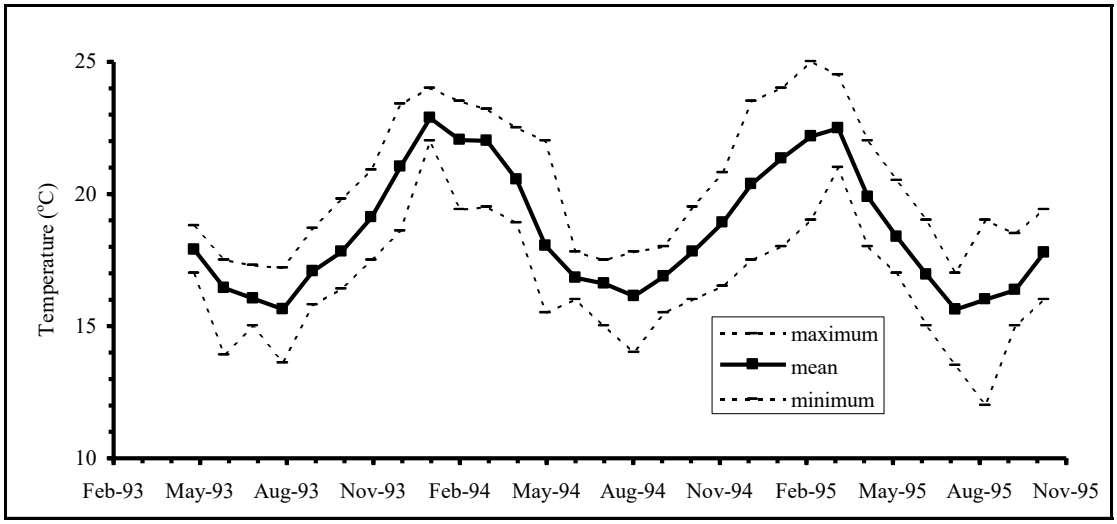


Figure 1: Maximum, mean and minimum monthly surface water temperatures recorded at the seacages in Botany Bay.

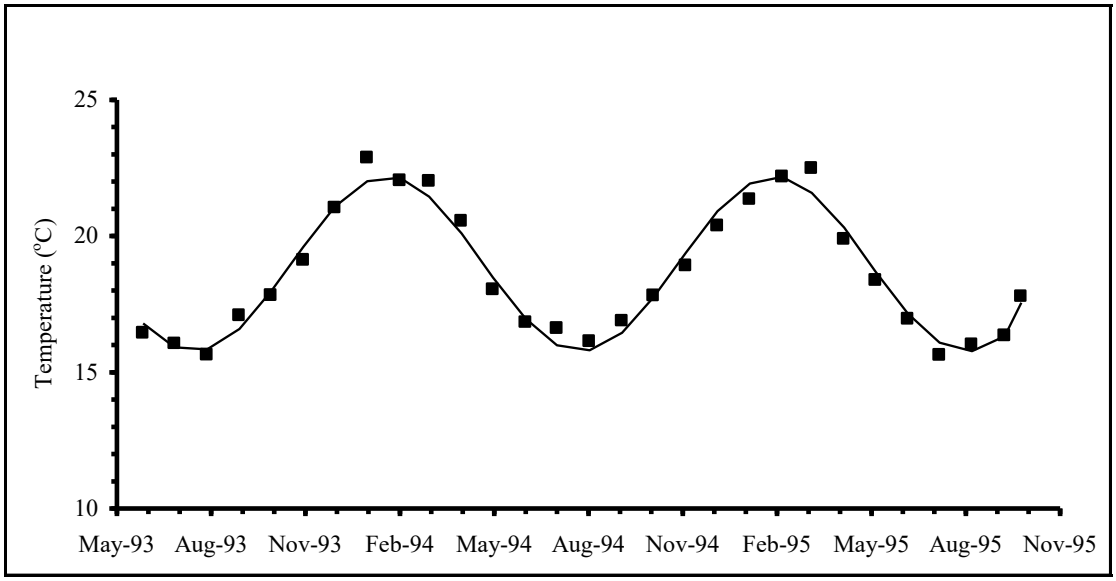


Figure 2: Sinusoid fitted by least squares to the mean monthly water temperatures recorded at the seacages in Botany Bay (see text for details).

used to display temperature in the some of the following figures. The value of the constants giving the best fit were: A = 18.9843; B = 3.21082; C = 0.51781 and D = 3.37239.

Security

The substantial investment required to set up a fish farm and the high value of the fish dictate that security must be an important aspect of site selection. The seacages in Botany Bay were sited close to the Control Room on the Caltex Wharf. The Control Room is manned 24 hours a day which probably deterred some potential poachers. There is no doubt that poaching of fish by angling in the netcages did occur. The number of fish poached by anglers is unknown. More serious were the release by vandals of a whole netcage of juvenile snapper (≈5,000 fish) three weeks after stocking and the loss of approximately half the snapper in a netcage just prior to harvest. These incidents dictate that effective security for fish farms in estuaries will require 24 hours a day surveillance.

3.3 Seacage operation

Stocking of juveniles

Juvenile snapper were stocked in seacages for two consecutive seasons. The first season's (crop 1) snapper were hatched on 16/10/92 and on day 54 post-hatch (30-35 mm TL) ≈10,000 were transported by road from the hatchery at the Port Stephens Research Centre (PSRC) to FRI. A second batch of ≈6,000 fish was transferred later. At FRI they were reared in 4,000l flow-through tanks for about five months and then stocked in a seacage in May 1993 when their mean FL and weight were 90 mm and 18 g respectively. The second season's (crop 2) snapper comprised of two hatchings. The first hatching, on 19/9/93, yielded ≈5,000 juvenile snapper which were stocked directly in a seacage but were released by vandals on 1/1/94. The loss of the first hatching was significant since the fish were the progeny of captive broodstock held at FRI. The second hatching, on 13/11/93, yielded ≈7,000 juvenile snapper which were stocked directly in a seacage on 6/1/94 (day 54, 30-35 mm TL).

The mulloway were hatched on 23/1/94 and after weaning, as with the crop 2 snapper, were stocked directly in a seacage. Approximately 6,000 juvenile mulloway were stocked in a seacage on 16/3/94; age 52 days post-hatch, mean TL between 30 and 35 mm.

Juvenile fish of both species were transported from the hatchery in 750 l insulated tanks at a maximum stocking density of approximately 10,000 fish per tank. The seawater in the tanks was oxygenated continuously. The tops of the tanks were removable allowing easy access to

the fish. Fish were transferred between containers and into the netcages with buckets. The fish were placed in 400 l Engel bins and taken to the seacages by punt. The seawater in the bins was oxygenated continuously during transport.

Feeds and feeding

At FRI, crop 1 snapper were fed to apparent satiation up to ten times daily, seven days per week. The frequency of feeding was decreased as the fish grew; at the end of the tank stage they were being fed four times daily. Initially the fish were fed on barramundi crumbles (Aqua-feed Products Australia, Deception Bay, QLD, Australia) and minced pilchards, and then as they grew they were weaned onto 3 mm snapper pellets (Allan and Quartararo, 1996). After transfer to the seacage, crop 1 snapper were hand-fed pellets to apparent satiation until harvest. Fish were fed twice daily except for short periods during the colder months of the year (June-August) when they were fed once daily. Pellet size was increased from 3 mm to 6 mm and then to 10 mm for final grow-out.

Both the mulloway and crop 2 snapper were initially fed by an automatic feeder (Seafood Technologies P/L, South Melbourne, VIC, Australia). Electrical power for the auto-feeder was generated by a solar panel which also supplied the navigation light on the seacage. The auto-feeder made it practicable to approach demand feeding conditions. Demand feeding is known to promote optimal growth rate (Hepher, 1988). However, the use of auto-feeders can result in poor feed conversion ratios due to excess wastage of feed which itself is undesirable from an environmental viewpoint (see for example Battaglene, 1996). Using an auto-feeder also tends to decrease the contact time between a farmer and his fish which for example, could result in the farmer missing premonitory signs of a disease outbreak.

Net changing

The fouling of nets requires them to be changed and cleaned regularly. The rate of fouling and consequently the frequency with which nets need changing is dependent to some extent on the site. As a rule, the smaller the mesh size the more frequently the net needs to be changed. From the experience with the seacages in Botany Bay, the suggested times between net changes are: 10-14 days for 4 mm mesh nursery nets; 21-28 days (summer) or 28-42 days (winter) for 12.5 mm mesh initial grow-out nets and 28-35 days (summer) or 42-63 days

(winter) for 22 or 25 mm mesh final grow-out nets. If shading is used before harvest to lighten the skin colour of snapper, then the above times for the final grow-out nets could normally be increased.

Changing a net involved slipping the clean net under and around the fouled net, dropping three sides of the fouled net and pulling it out slowly from under the fish. Fouled nets were strung up and dried for about a week and then cleaned with a high pressure water jet and left to dry.

Data collection

Random samples of approximately 100 fish were taken periodically to assess growth. To obtain a sample of fish, the nets were lifted and the fish crowded near surface so that they could be dip netted easily and placed in an anaesthetic bath. The length and weight of individual fish were recorded and the fish returned to the sea cage after partially recovering from the anaesthetic. The fish were not measured until after their first winter in the seacage to minimise losses due to the effects of handling stress and trauma.

Daily records were kept of feed given, estimated percentage eaten, surface water temperature, salinity, dissolved oxygen (DO), mortalities, fish behaviour and weather conditions.

Observation of fish

Under most conditions an underwater viewer was adequate to inspect the fish and nets. Removal of small numbers of dead fish from the floor of the seacage was done using swimming pool net with an extendible handle. Diving in the seacages with the aid of a snorkel and mask was done on a regular basis to inspect the fish and nets and to remove dead and moribund fish during disease outbreaks.

Harvesting

Small groups of up to 100 fish to be sold live were handlined using long shanked (size 1/0) hooks with a flattened barb. The fish were hooked out of the seacage and placed in a transport tank where the hook was removed (by jiggling its shank) avoiding, if possible, handling the fish. In the majority of cases de-hooking resulted in no damage to the skin apart from that

around the mouth caused by the hook. This method is relatively slow and the fish can sometimes "go off the bite" before the required number are caught. An alternative method for harvesting live fish was to lift the net and crowd the fish at the surface where they were easily caught by scoop nets. This latter method of harvesting is quicker than handlining but has the potential to cause more skin damage than handlining.

For fish being marketed as freshly killed, the net was lifted and the fish were transferred by hand nets to a bin containing a seawater-ice slurry. After about 30 minutes in the slurry, the fish were stacked in fish boxes, iced and sent to market.

Results

Growth

Crop 1 snapper

Crop 1 snapper (hatched 16/10/92) were partially harvested between 3-6/10/94 at 23+ months of age. Only fish longer than the NSW minimum legal length for snapper (280 mm TL or 250 mm FL) were marketed. Just before harvest 400 fish, caught at random, were transferred to another seacage to be kept as potential broodstock. The distributions of length and weight (whole) of a random sample of approximately 100 of these fish are shown in Figure 3. The mean (± SD) length and weight were 250 ± 15 mm and 379 ± 68 g respectively. Forty four per cent of the fish in the sample were longer than the minimum legal length.

Of the fish remaining in the seacage (after removal of broodstock) 36% were longer than the minimum legal length. The legal sized fish were harvested, cleaned (gilled and gutted) and sent to market. One hundred fish were measured before and after cleaning to estimate the ratio of dressed to whole weight. The mean dressed weight was 364 g which was 91% of the mean whole weight of 398 g. The undersized fish were retained for on-growing. The stocking density at harvest was between 5 and 6 kg per cubic metre. The remaining 64% of fish were on-grown and sold in several batches either alive or freshly killed. The batches comprised only legal sized fish; undersized fish were retained for on-growing. The final batch was sold on 14/3/95 when the fish were 29 months of age.

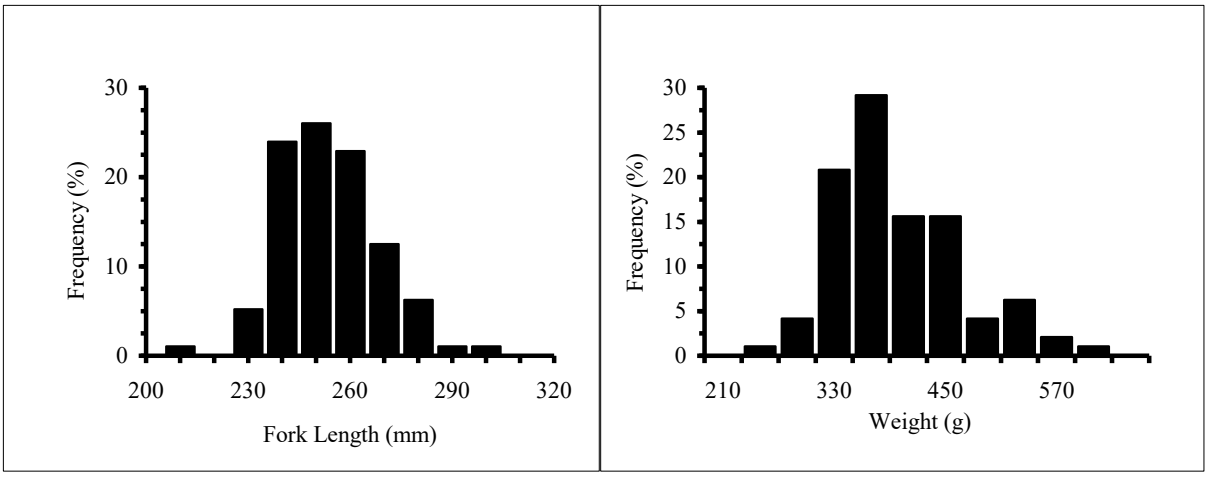


Figure 3: The distributions of fork lengths and weights of a random sample of approximately 100 crop 1 snapper on 3/10/94. The mean (± SD) length and weight were 250 ± 15 mm and 379 ± 68 g respectively. Forty four per cent of the fish in the sample were longer than the minimum legal length

The distributions of fork length and weight of a sample of 120 fish from the final batch are shown in Figure 4. The proportion of undersized fish in the final batch of crop 1 snapper was 2.5%.

Crop1 snapper retained as potential broodstock were measured at 31+ months of age; mean FL and weight were 319 ± 17 mm and 749 ± 116g respectively. The growth of crop 1 snapper is shown in Figure 5. It should be noted that after the first harvest (10/94), further growth data for crop 1 snapper were obtained from the fish retained as broodstock. The stocking density of the broodstock fish varied from 1.7 to 3.4 kg per cubic metre over the time the data were collected.

Crop 2 snapper

Crop 2 snapper (hatched 13/11/93) were stocked directly from the hatchery into a seacage at 54 days of age. The group was fed by auto-feeder for 10 months and then split into two groups which were stocked in separate seacages. One group (auto-fed group) continued to be fed by auto-feeder for a further six months and then by hand to apparent satiation whilst the

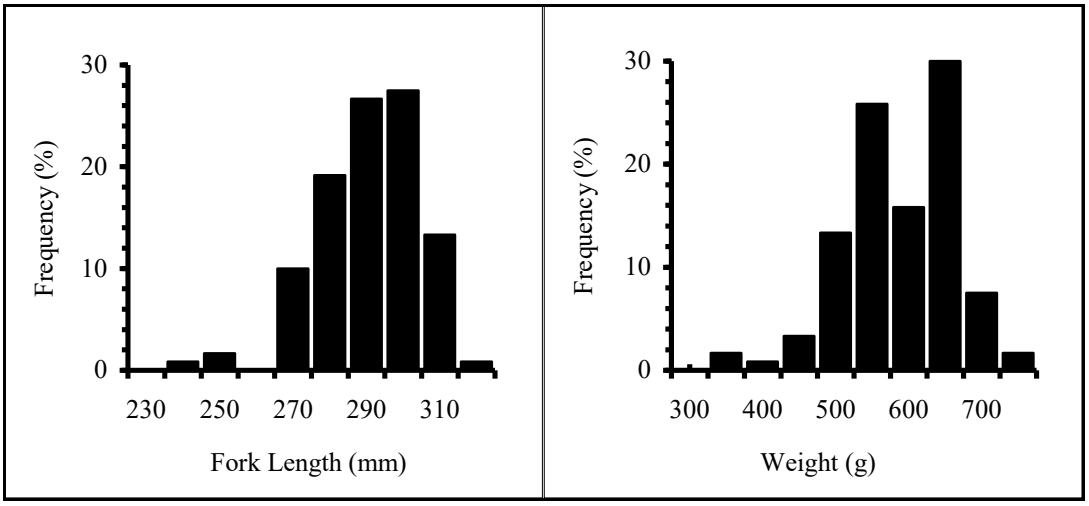


Figure 4: The distributions of fork lengths and weights of a sample of 120 snapper from the final batch of crop 1 snapper. These fish represent the slowest growing fish in the original group. Age of fish was 29 months. Mean FL and weight were 286 ± 14 (SD) mm and 561 ± 14 (SD) g respectively.

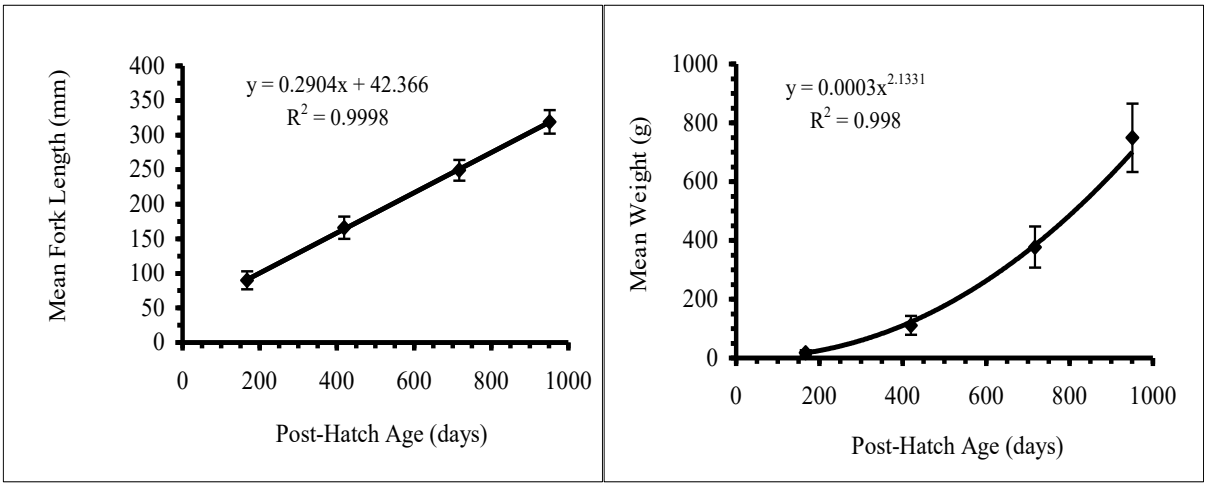


Figure 5: Growth of crop 1 snapper. Sample sizes were approximately 100. Error bars show the SD. The line and power curves shown were fitted by least squares.

other (hand-fed group) was fed by hand to apparent satiation. The distributions of length and weight of the two groups at about 24 months of age are shown in Figure 6. Growth of the auto-fed group was superior to that of the hand-fed group (Figures 6 and 7). Several factors apart from the difference in feeding history must however be borne in mind when comparing the growth of the two groups. The stocking density of the hand-fed group was about 20% higher than the auto-fed group. This may at least partially explain the slower growth rate of

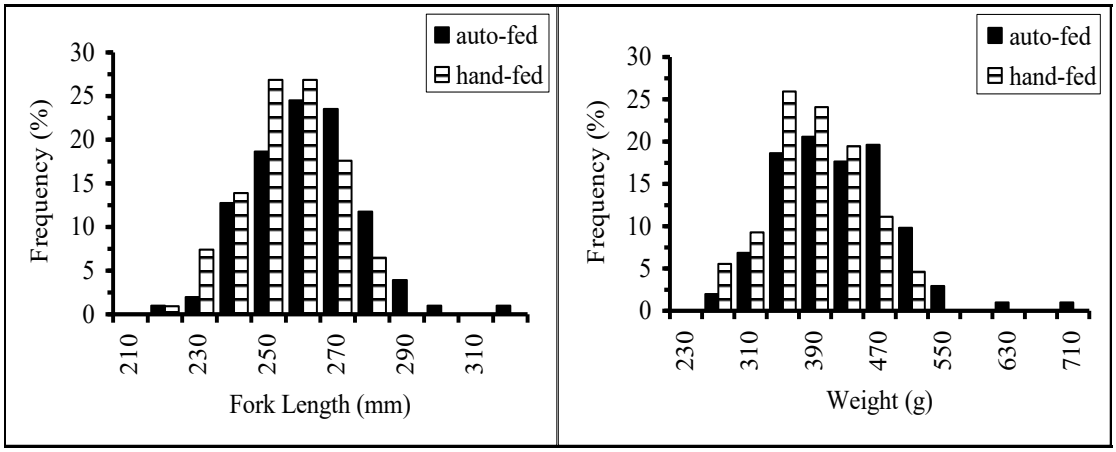


Figure 6: Distributions of fork length and weight of crop 2 snapper with different culture histories. Auto-fed group were sampled on 3/11/95; post-hatch age 720 days; mean FL and weight were 257 ± 17(SD) mm and 400 ± 74(SD) g respectively . Hand-fed group were sampled on 9/11/95; post-hatch age 726 days; mean FL and weight were 250 ± 14(SD) mm and 366 ± 58(SD) g respectively. Sample sizes were approximately 100.

the hand-fed group, although the stocking density of the hand-fed group at <10 kg per cubic metre was not high by Japanese standards (Foscarini, 1988). Another factor that may have adversely influenced the growth of the hand-fed group was that when the original group was divided, the auto-fed group remained in the original netcage and the hand-fed group was transferred to a different seacage. The transfer would have stressed the fish and checked their growth; at least temporarily. Some evidence for this is seen in the growth data (Figure 7). The difference in growth rate between the two groups was most pronounced from autumn to the start of winter 1995 (Figures 7 and 8). During this time it was necessary to treat the fish for chronic parasitism which affected the hand-fed group more than the auto-fed group and which may have accounted for the slower growth of the hand-fed group.

The overall relationship between growth rate and water temperature shown in Figure 8 has been reported for snapper (red sea bream) in Japan (Ikenoue and Kafuku, 1992) and for gilthead bream, *Sparus auratus*, (Kadmon *et al*., 1985). It is possible that the slowing of growth in late autumn may have been due, at least partially, to the onset of gonadal

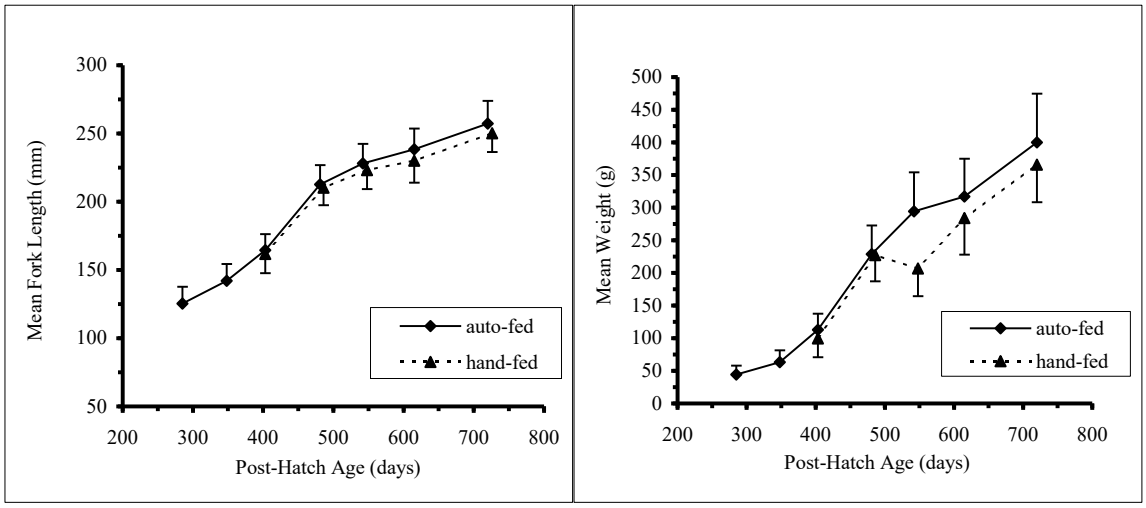


Figure 7: Growth of crop 2 snapper with different culture histories (see text for more details). Error bars give the SD. Each data point represents the mean of a sample of approximately 100.

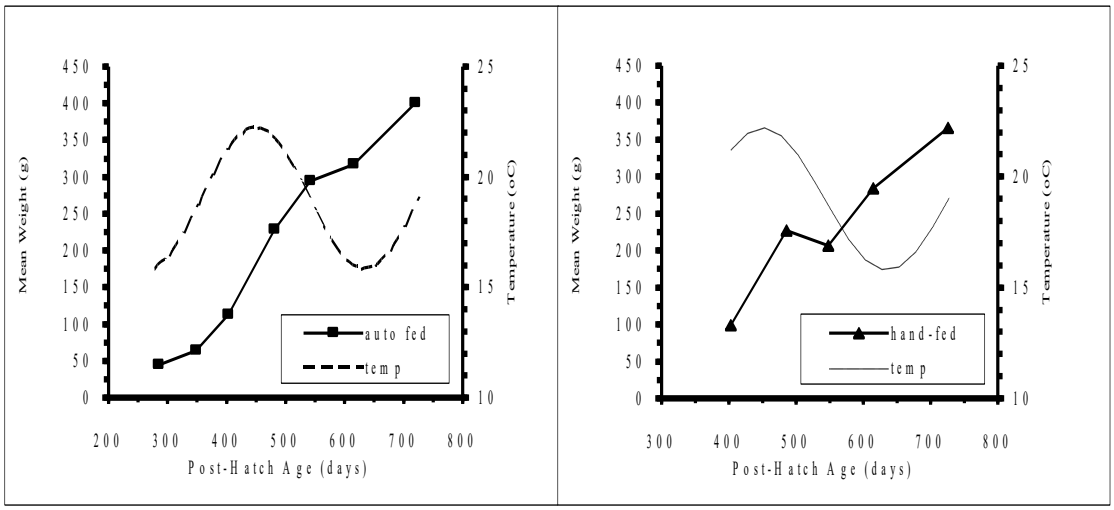


Figure 8: Relationship of water temperature and growth of crop 2 snapper with different culture histories.

development (Kadmon *et al*., 1985). The relationship between growth rate and water temperature suggests that it may be possible to avoid holding snapper for a second winter by stocking juveniles in seacages much earlier, e.g. September or October, than was possible in the present project. The most reliable method of producing juveniles early in the season would involve controlled spawning of captive broodstock. This would not appear to be a problem technically, since crop 1 snapper have been successfully induced to spawn naturally in temperature/photoperiod controlled rooms at PSRC (Cleary *et al*., 1995).

Mulloway

As with crop 2 snapper, juvenile mulloway were stocked directly into a seacage after being transported by road from PSRC. The growth rate of mulloway in seacages was faster than that of snapper (Figures 8, 9 and 10) and the slowdown in growth during winter was less pronounced for mulloway compared to snapper. The minimum legal size for mulloway in NSW is 450mm. Linear extrapolation from the last two TL means suggests that the mean TL of the mulloway would reach 450 mm approximately 800 days post-hatch. On the 28/11/95 (post-hatch age 674 days), six fish of a total of 1505 were greater than the minimum legal length. An indication of the weight of legal-sized fish can be gained from the weight of the heaviest fish in a sample taken to estimate the mean weight: 1180 g ; and TL 455 mm. The largest fish overall was 492 mm TL, however its weight was not taken since it was not in the random sample taken to estimate mean weight. The distributions of TL and weight (Figure 11) are asymmetrical (the weight distribution in particular suggests a log-normal distribution) a common finding for young growing animals. It implies that grading of mulloway during grow-out in seacages may be necessary to optimise production. The stocking density was just over 10 kg per cubic metre on 28/11/95 and was projected to be about 15 kg per cubic metre at harvest.

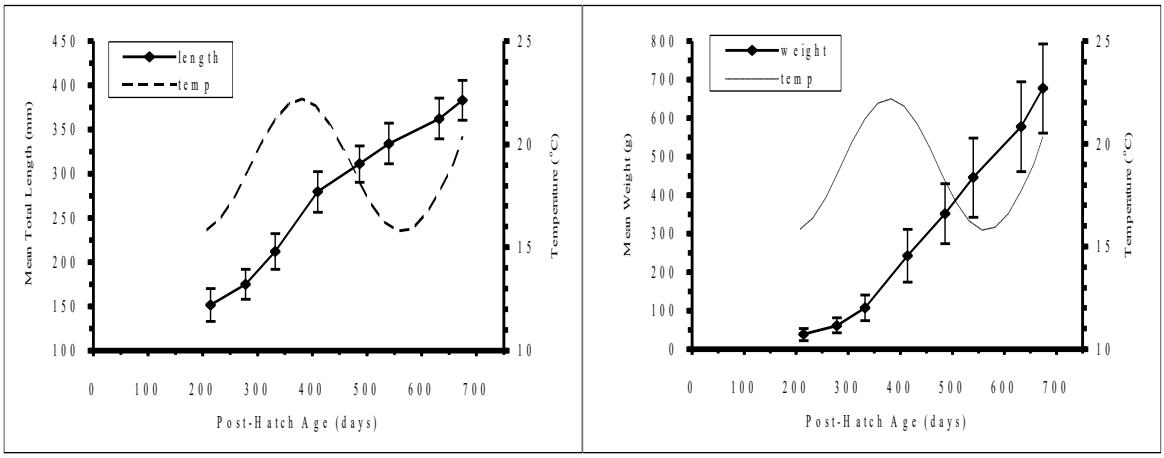


Figure 9: Growth of mulloway in seacages and its relation to water temperature. The error bars give the SD. Sample sizes were usually 100 approximately. The last mean TL was of all of the fish (1505) remaining on the 28/11/95. The last mean weight was estimated from 338 fish chosen randomly.

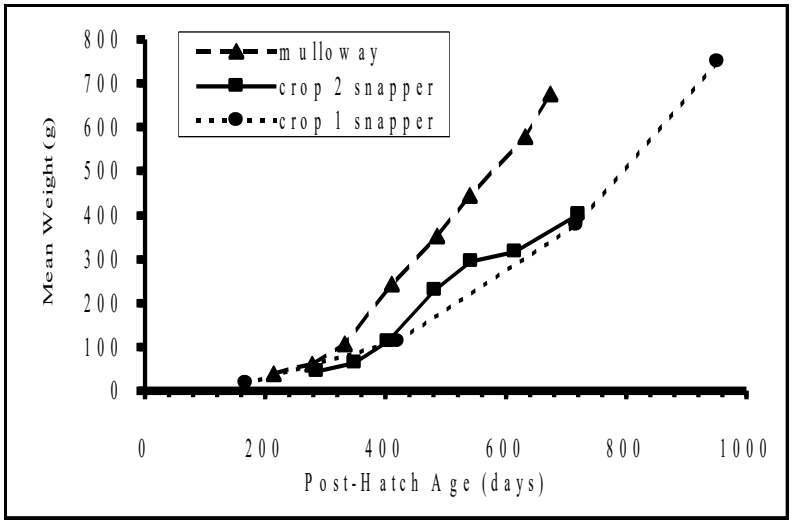


Figure 10: Comparison of the growth of snapper and mulloway in seacages. The data shown for crop 2 snapper were obtained from the auto-fed group.

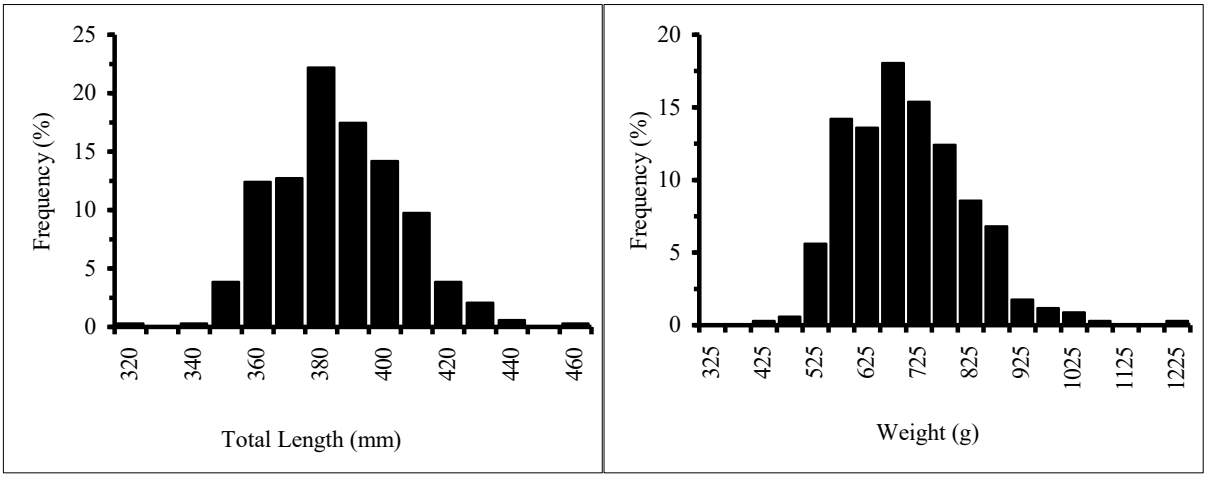


Figure 11: Distributions of total length and weight of mulloway reared in seacages. Fish were measured on 28/11/95; age 674 days post-hatch; mean total length and weight were 383 ± 22(SD) mm (n=1505) and 677 ± 116(SD) g (n=338) respectively.

Length-Weight Relationships

The length-weight data for both snapper and mulloway were well fitted by power curves and the curves for crop1 and crop 2 snapper were almost co-incidental (Fig. 12).

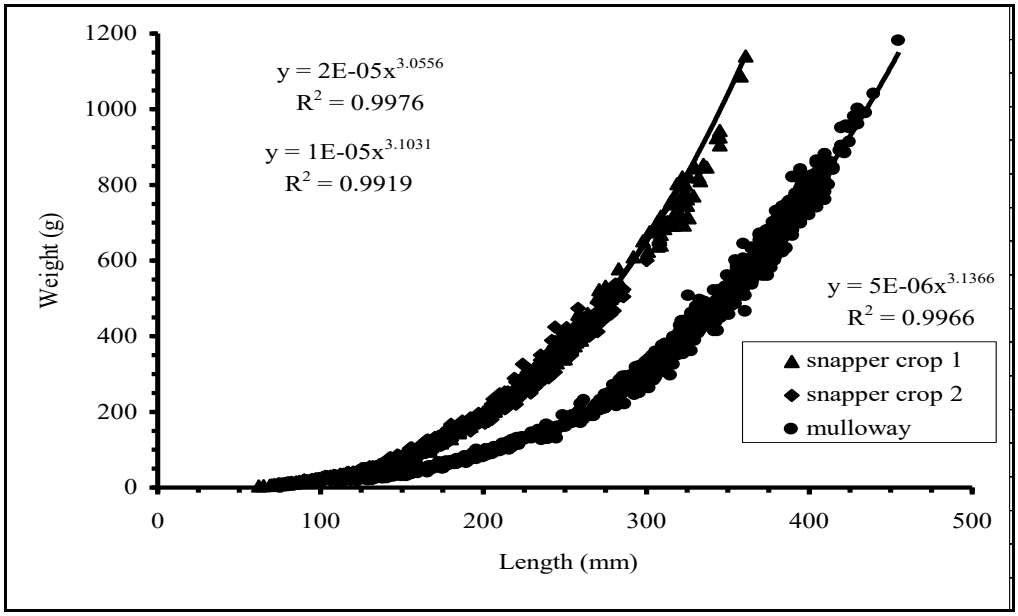


Figure 12: Length-weight relationships for snapper (Length is FL) and mulloway (TL) reared in seacages in Botany Bay. Random samples of approximately 100 fish were measured periodically.

Survival Rates

Crop 1 snapper

Crop1 snapper were reared in tanks at FRI for about five months before being stocked in a seacage in May 1993. Approximately 16,000 juveniles were received from the hatchery. The fish were counted and graded through a 10 mm grate barramundi grader on 1/4/93 about four months after they were received from the hatchery. The total number of fish was 7,826 which represents a survival rate of ≈49 % for the tank rearing stage. A total of 5,398 fish were retained by the grate. Approximately 5,000 of these larger fish were stocked in a seacage in May 1993.

The fibreglass tanks (at FRI) used to rear crop 1 snapper juveniles were circular with flat bottoms. The tanks contained 4000 l of continuously aerated seawater which flowed through at 10-12 l/min. The maximum stocking density in the tanks was < 10 kg per cubic metre. The tanks were cleaned by flushing, and siphoning the bottom after feeding. The two most common causes of mortality were streptococcosis and developmental abnormalities. Outbreaks of streptococcosis were controlled by oxytetracycline bath for 10 - 12 hours on

three consecutive days. During treatment the water flow to the tank was turned off and the fish were not fed.

Crop 1 snapper were transferred from FRI to the seacages by road and then boat. Dip nets made from knotless netting were used to handle the fish during the transfer. The method of transfer, the relatively large size of the fish (mean FL 90 mm) and the falling water temperatures in Botany Bay resulted in poor survival (Figure 13). Most of the losses in the first two months were due to vibriosis which was probably precipitated by the stress and trauma associated with the transfer of the fish to the seacage and exacerbated by the falling water temperatures. The overall survival of crop 1 snapper in the seacage was ≈30% (≈1,500 fish at first harvest). The sum of recorded mortalities and number of fish at first harvest was ≈1,200 less than the number originally stocked. These 1,200 fish could not be accounted for and were added to the mortalities in the first month (May 1993) to calculate cumulative survival for that month (Figure 13).

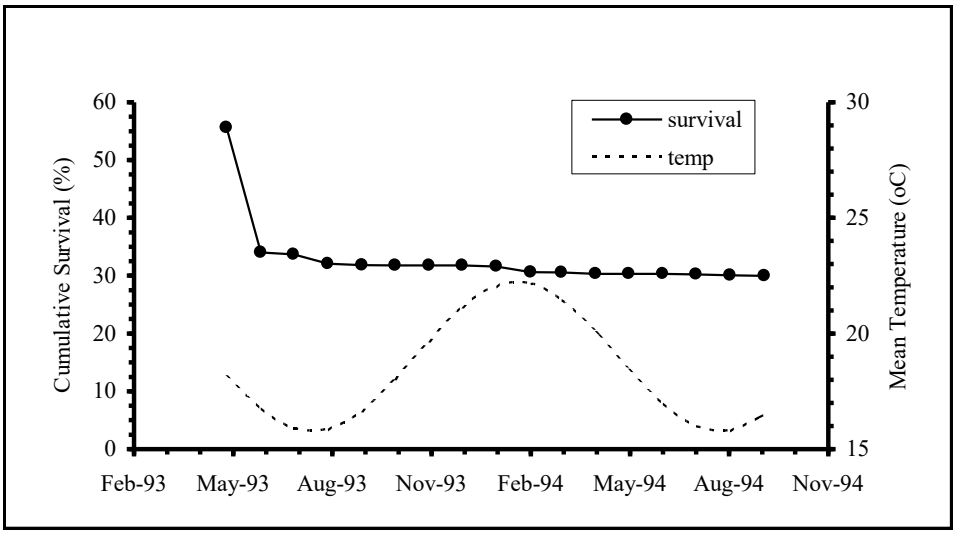


Figure 13: Cumulative survival of crop 1 snapper while in seacage. Twelve hundred fish could not be accounted for at harvest. These 1,200 fish were added to the mortalities recorded for the first month (May 1993).

Crop 2 snapper

In contrast to crop1, crop 2 was stocked directly from the hatchery into a seacage. The overall survival of crop 2 was ≈40% which was higher than that of crop 1 (compare Figures

13 and 14). It should be noted that ≈2,800 fish were unaccounted for at harvest; these fish were added to the mortalities recorded in the first month (January 1994). From November 1994, when crop 2 was split into two groups, to its harvest in December 1995, the survival rate of the auto-fed group (≈28%) was relatively low compared to that of the hand-fed group (≈80%). The relatively low survival rate of the auto-fed group was due to poaching just before harvest which resulted in the loss of a significant number of fish. The drop in survival in the second month (February 1994) was most probably due to the effects of transport and stocking in the seacage. The only other significant drops in survival occurred in late autumn/early winter of the first year the fish were in the seacage (Figure 14). The pattern of mortality for both crops of snapper was similar; most mortality occurred just after stocking and in the first winter.

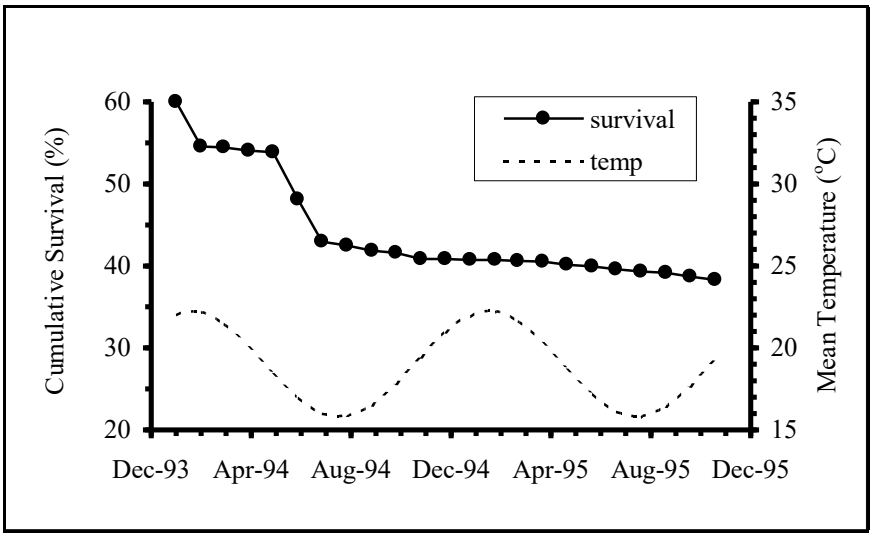


Figure 14: Cumulative survival of crop 2 snapper. Data from both the auto- and the hand-fed group are pooled. Two thousand eight hundred fish were unaccounted for at harvest. These 2,800 fish were added to the mortalities recorded in the first month (January1994). See text for details.

Mulloway

Approximately 6,000 juvenile mulloway were stocked in a seacage on 16/3/94. On the 28/11/95, the number of mulloway in the seacage was 1505. However 30 fish in good condition had been taken in the previous month for evaluation. As no mortalities were recorded over the time since they were taken they were added to the final number giving a

total of 1535 fish. This gives an overall survival rate of ≈26 %. About 4,300 fish could not be accounted for and were added to the mortlities recorded in the first month. Cannabalism, especially soon after stocking, may have accounted for the relatively low survival rate. The innate reticence of mulloway may have resulted in them adapting slowly to feeding in the seacage and may have stimulated cannabalism which is common in hatchery reared mulloway (Battaglene and Talbot, 1994). As with snapper, most of the recorded mortalities occurred during the first winter (Figure 15).

Feeding rates

Snapper

The mean daily feeding rate (to apparent satiation) for each month was calculated as a percentage of the estimated biomass. The mean daily feeding rate varied between about 0.5 and 2.5% and was related to water temperature (Figure 16).

Mulloway

The feeding behaviour of seacage mulloway was more difficult to observe clearly from the surface than it was for snapper. Mulloway in the seacages in Botany Bay were never observed to "break the surface" when feeding. When the fish were hungry, a small number would swim to within one metre of the surface at the start of feeding. Normally during feeding, the mulloway stayed close to the floor of the netcage and waited for pellets to sink before consuming them. The use of an interactive feeding system or possibly underwater

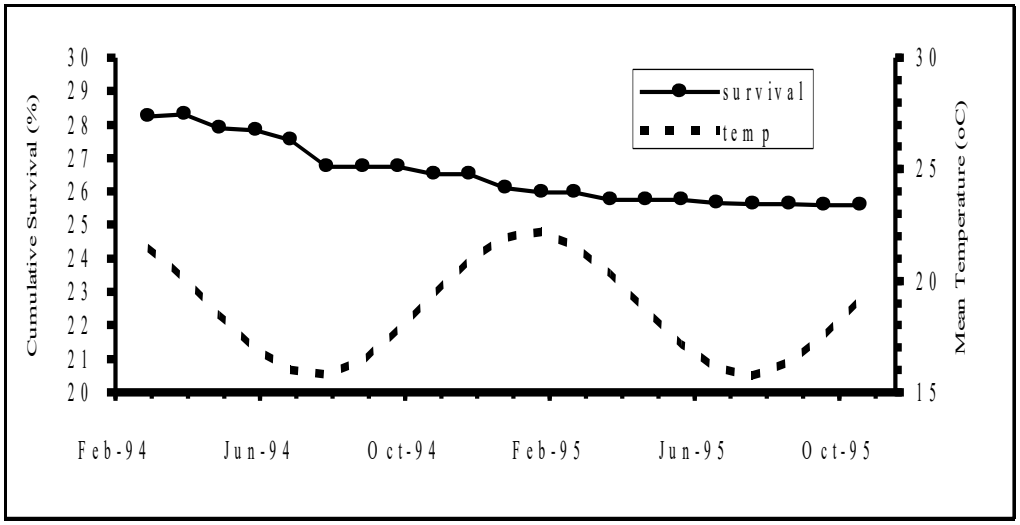
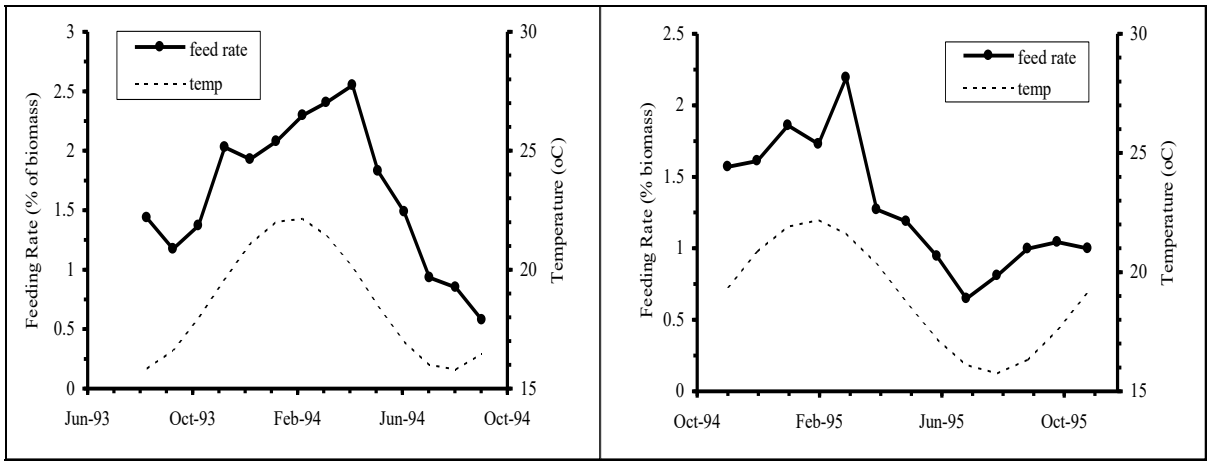


Figure 15: Cumulative survival of mulloway grown in a seacage.



Crop 1 *Crop 2*

Figure 16: Mean daily feeding rate (to apparent satiation) per month of snapper reared in seacages. Crop 1 snapper grew from 50 to 350 g approximately over the period shown; crop 2 snapper from 90 to 370 g approximately. Note that crop 2 data were obtained from the hand-fed group.

video cameras to observe the fish more closely during feeding would help to better define the feeding behaviour of mulloway in seacages. The feeding rate (to apparent satiation) for mulloway varied between about 0.5 and 1% and was related to water temperature (Figure 17).

Feed conversion

The apparent feed conversion ratio (FCR) is given by: dry weight of feed given / live weight gain. It was assumed that the snapper pellet had a moisture content of 10% and that 10% of feed was wasted when feeding to satiation. Wet feeds, such as pilchard (*Sardinops neopilchardis*) and other trash fish (fed only occasionally), and medicated feed were converted to a "pellet equivalent". For wet feeds, the "pellet equivalent" was given by: weight of feed divided by 3.5. Medicated feed was approximately 40% minced pilchard and 60% ground pellets; the "pellet equivalent " was calculated accordingly. Medicated feed was not fed to satiation to minimise the amount of antibiotic lost to the environment. Therefore wastage was not factored in when calculating the "pellet equivalent" of medicated feed. In calculating the FCR, no account was made for poaching, escapees or undetected mortalities.

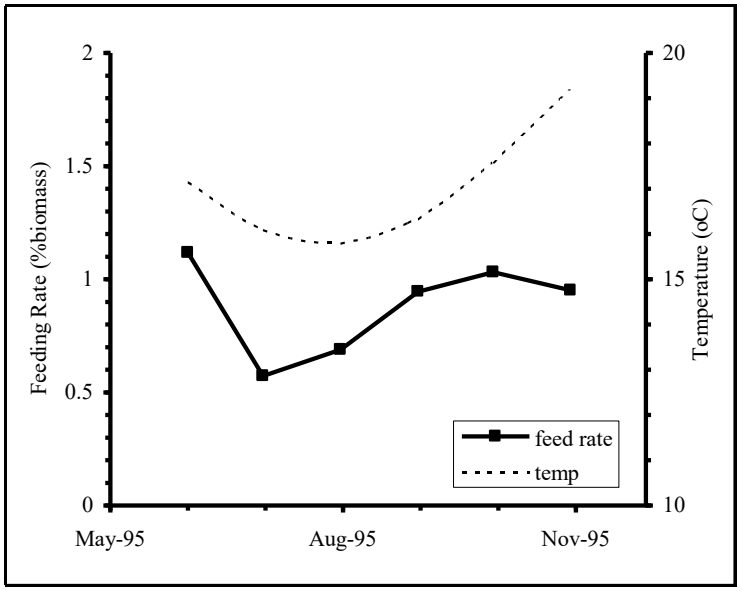


Figure 17: Mean daily feeding rate (to apparent satiation) per month for mulloway reared in a seacage. Mulloway grew from a mean weight of about 400 to 677g over the period shown.

The FCRs for both snapper and mulloway are presented in Table 1. The FCR of the auto-fed group (crop 2) from November 1994 to harvest, could not be reasonably estimated because a significant number of fish were poached just prior to harvest.

Table 1: Feed Conversion Ratios (FCR)[1]

	Feeding method	Time period	FCR
Crop 1 snapper	by hand[2]	Jun-93 - Oct-94	2.4
Crop 2 snapper	automatic feeder	Jan-94 - Oct-94	2.7
Crop 2 snapper	by hand[2]	Nov-94 - Oct-95	3.1
Mulloway	automatic feeder	Mar-94 - May-95	
	then by hand[2]	Jun-95 - Nov-95	2.2

[1] FCR = dry weight of feed given/live weight gain

[2] to apparent satiation

Impacts of poaching

Poaching affects the estimation of key production parameters such as survival, FCR and feeding rates. Poaching can result in: an apparent survival which is lower than the "true survival"; a higher (poorer) FCR; and a lower apparent feeding rate.

Although poaching at the seacages did apparently occur, in most cases the number of fish taken was relatively small judging by the feeding record and the behaviour of the fish recorded at the time. In contrast, a significant number of snapper (≈50%) were poached from the auto-fed group just prior to harvest. Apart from an obvious lack of fish in the netcage, the remaining fish were "spooked" and did not feed normally for several days after. As a consequence the FCR of the auto-fed group over the second year is not given in Table 1.

Market aspects

Skin colour

Farmed snapper are darker than- and lack the red-pink skin colour of wild snapper. The darker colour of farmed snapper is due to the relatively high light levels in the seacages. Due mainly to their darker appearance, farmed snapper have fetched lower prices than wild snapper of the same size. We found that a floating shade cover in the netcage for 3-4 weeks prior to harvest considerably lightens the colour of snapper which increases their market value. The shade cover was opaque and made from material used for floating swimming pool covers. The red-pink skin colour of wild snapper is due to carotenoids, such as astaxanthin, which are found in crustaceans that are a part of the diet of wild snapper.
In Japan, krill meal which is rich in astaxanthin, is added to the diet of red sea bream for several months before harvest to improve their skin colour (Ikenoue and Kafuku, 1992).

Taste

In contrast to the snapper reared in tanks (Prescott and Bell, 1991), snapper reared in seacages were not formally taste tested. Instead, they were sold to several restaurateurs/wholesalers for evaluation. Snapper were tasted raw, as *sashimi*, or cooked either pan-fried or steamed. Apart from skin colour, farmed snapper were judged by all to be excellent when served as *sashimi* or pan-fried. The texture of steamed snapper was considered slightly coarse for the Asian palate. Preliminary evaluation of mulloway indicate that they are excellent steamed.

Market size

The preferred weights for snapper appear to be about 500g and 1 Kg; smaller "plate-sized fish" (400-500g) for cooking and larger fish for *sashimi*. At this early stage, the preferred weight for mulloway would appear to be between 500 and 700g.

Price

Skin colour was the main factor determining the price of sea cage snapper on the market floor. Before the use of covers, prices for sea cage snapper were about two dollars less per kg than the average price of wild snapper of the same size; average price for wild snapper varied from $7.50 to $12/kg while price for seacage snapper varied from $5.50 to $10/kg. The use of covers to lighten skin colour resulted in better prices for farmed snapper. Prices for the lighter coloured fish were around the average price for wild snapper of a similar size. The price offered for live farmed snapper was $17/kg. This price is expected to fluctuate at about twice the market price of freshly killed wild snapper.

Diseases and predators

Vibriosis

Vibriosis is a well recognised "production disease" causing significant economic loss in the production of fish in marine seacages (Austin and Austin, 1987). Outbreaks of vibriosis usually occur after stress. Stress can be induced by such factors as rough handling, transport, overcrowding, poor water quality and environmental conditions eg. a sudden drop in water temperature. Snapper, in common with many other species, seem to be more prone to vibriosis in their first winter in a seacage (Ikenoue and Kafuku, 1992).

Typical signs of the onset of a vibriosis outbreak in a seacage were the appearance of white, roughly circular lesions on the sides of fish and a gradual increase in mortality over several consecutive days. As the outbreak progressed the number of inappentent, dark coloured, apparently moribund fish increased. The latter were sluggish and easily caught by dip net, several were sent alive or on ice to pathology for examination and attempted isolation of the causative organism. Macroscopic inspection revealed deep ulcers with a white necrotic centre and reddened (haemorrhagic) border. The ulceration was deep and in many cases

extended down into the underlying muscle. The ulcers usually occurred on the sides of the fish but in some cases extended from one side to the other forming a “saddleback” shaped lesion.

Vibriosis is likely to be an important "production" disease for snapper mariculture in NSW. The first outbreak of vibriosis occurred soon after crop 1 snapper juveniles were stocked in the seacage at the start of winter 1993. The predominant bacterium isolated from the skin lesions on moribund fish was identified as *Vibrio splendidus,* which is normally considered an opportunistic pathogen. There have been previous reports in Australia of infection with *V. splendidus* causing skin and other local lesions (Langdon, 1988). An antibiotic sensitivity test showed that *V. splendidus* was sensitive to oxytetracycline (OTC) which was then used to medicate the feed. Medicated feed was effective in controlling the outbreak. The outbreak was most probably precipitated by the stress and trauma of transport, and the falling water temperature. In addition the fish were stocked into a foreign environment after being reared initially in tanks. The resulting overall mortality in the first outbreak was high at just over 50%. Subsequent outbreaks of vibriosis in both crops of snapper were controlled early with medicated feed and resulted in only minimal mortality.

The long term reliance on antibiotics to control vibriosis and other bacterial diseases is undesirable. In the marine environment, the major portion of some commonly administered antibiotics, eg. OTC, is not absorbed by the fish but instead accumulates in the seabed beneath sea cages. The accumulation of antibiotic in the seabed results in conditions which promote the selection of bacteria resistant to the antibiotic. The possibility then arises that the resistance could be passed onto a human pathogen and that the antibiotic could no longer be used to treat the disease caused by that pathogen. The use of antibiotics to treat farmed fish also increases the probability that they could enter the human food chain. Again, the consequence could be the emergence of human pathogens that are resistant to those antibiotics. There are also marketing problems with the use of antibiotics. To minimize the amount of antibiotic entering the human food chain, fish are normally held for a set minimum period (withholding period) after being dosed with antibiotic. Suggested withholding periods for OTC can be up to 90 days depending on water temperature. At certain times, the forced

withholding of fish from the market can be costly. Also most of the major potential export markets for fish are very residue sensitive and test for antibiotics.

Improved husbandry techniques and the possible use of vaccines should be promoted for the long term control of vibriosis and other "production" diseases. However the development of a vaccine to control snapper vibriosis should be pursued only after a *Vibrio* species is shown to be the probable primary pathogen. It is possible that *V. splendidus* was acting only as a secondary pathogen. Improvements in husbandry and use of vaccines to control "production diseases" has enabled the salmon industry in Norway, which produces over 200,000 tonnes *per annum,* to markedly reduce antibiotic usage while continuing to increase production significantly (Anon., 1995).

Gill infection by Bivagina pagrosomi

Previous research on juvenile snapper held in small cages at FRI, suggested that the mongenean trematode, *B. pagrosomi,* had the potential to adversly affect snapper reared in estauries (Roubal *et al*., 1996). In Japan, *B. tai* a closely related organism, is listed as one of the major causes of disease in the snapper (red sea bream) farming industry (Ikenoue and Kafuku, 1992).

Gill infection by the monogenean trematode, *B. pagrosomi* resulted in a significant group of inappentent, sluggish, dark coloured fish in poor condition which remained in the corners or close to the sides of the seacage. Affected fish had very pale gills due to anaemia. Examination of blood (Canfield *et al*. 1994) from affected fish revealed a profound anaemia and hypoproteinaemia, due most probably to chronic blood loss. Microscopic examination of fresh gills from affected fish showed large numbers of *B. pagrosomi*. The first incidence of bivaginosis occurred in crop 2 snapper in their first winter and followed an outbreak of vibriosis in the same group. Control of bivaginosis was achieved by an *in situ* formalin bath. A treatment bag made of *Tarpol* (Rheem Australia Ltd.) slipped around the netcage was used to contain the formalin. Treatment consisted of 100 ppm of formalin in the seawater contained in the bag for one hour. The treatment was repeated 5-7 days later. During the course of treatment a petrol driven submersible pump aerated and mixed the formalin solution. The formalin solution was also oxygenated and the DO level monitored.

Lymphocystis

Lymphocytsis, is a viral disease which normally does not cause significant mortality. However, it can seriously degrade the appearance of affected fish and lower their value. The virus invades fibroblasts in the skin causing them to greatly enlarge(cytomegaly) and form a thick hyaline capsule. The disease is relatively easy to diagnose. A scraping of the lesions which usually occur on the fins reveals characteristic greatly enlarged cells with a prominent hyaline capsule (Reddacliff and Quartararo, 1992). Because of its viral aetiology there is no known treatment for lymphocystis and normally fish overcome the infection with time. However, lymphocystis may increase the susceptibility of snapper to other pathogens.

Cormorants

The seacages had bird nets which prevented cormorants and other seabirds gaining direct access to the fish. Cormorants did however manage to strike at fish through the sides of the netcage. The wound on fish that were struck was similar to that described by Beveridge (1987). After being struck, fish usually succumbed to an acute peritonitis since in many cases the peritoneal cavity was breached. Although the number of fish lost by cormorant strike was relatively low, the presence of cormorants close to the sides of the netcage probably caused some stress to fish in the netcage. Many of the snapper struck by cormorants appeared to have been either moribund or blind and thus were easy targets since they tended to swim close to the sides of the netcage.

The behaviour of mulloway in a netcage is to swim in a very tight school which tends to remain in one of the bottom corners of the netcage. This behaviour makes mulloway, at least in the early stages, more prone to cormorant strike than snapper. The problem is exacerbated when, as the fish grow the mesh size of the netcage is increased. A solution we developed was to sew in 1x 1 m^2 panels of 3 mm plastic oyster mesh in the bottom corners of the net cage. This gave juvenile mulloway effective protection from cormorant strike and provided extra cover which also appeared to be beneficial.

In contrast to snapper, the incidence of clinical disease appears lower in mulloway. This may reflect their better adaptation to an estaurine environment. The low survival rate of mulloway

found in the present study appears to be mainly attributable to events that occurred soon after the fish were stocked in the sea cage. The relatively low number of mortalities recovered over that period suggests cannabalism. Another possibility is that the dead fish were somehow lost through the floor of the netcage.

FUTURE RESEARCH

The overall aim of future research should be to make production as efficient as possible within the constraints imposed by the environment.

Future research should be aimed at:

1. Decreasing time to market

Two aspects of immediate interest are:

- to further quantify the effect of water temperature on growth of snapper and mulloway; and
- to determine the optimum time to stock juveniles in sea cages.

2. Improving nutrition

The work on snapper nutrition needs to be continued to:

- determine optimum protein level and protein to energy ratio;
- evaluate a wider range of protein sources with potential to replace fishmeal;
- formulate and test finishing diets to improve the colour of farmed snapper.

The immediate priority for mulloway is to develop a reference (control) diet for the species. The feeding behaviour of seacage mulloway needs further elucidation possibly through the use of an interactive feeeding system or underwater surveillance by video camera.

3. Controlling disease

It is likely that vibriosis will be a major production disease for snapper farmed in estuaries. Therefore research on snapper immunology and on the production of fish vaccines and their administration should be undertaken.

4. Improving husbandry

The most pressing need is to develop better techniques for handling fish. This applies particularly to the transfer from hatchery to seacage. The relatively low survival rate of mulloway juveniles soon after stocking needs investigation. The use of biomass estimators/fish counters which do not require handling of the fish should be trialed. Finally, the effect of grading on production should be assessed.

5. Environmental Impacts

Develop methods and a system to assess, monitor and record the impact of fish farms on the environment. Develop husbandry practices that lessen the impacts of fish farms.

CONCLUSIONS and DATA SUMMARY

This project has shown that the farming of snapper and mulloway in estauries is technically feasible and that it could be improved significantly by further applied research. This further research would best be done in collaboration with a commercial partner(s) for example a fish farmer, feed company or equipment manufacturer.

The following key production results were found for snapper and mulloway produced in the hatchery at PSRC and reared in seacages in Botany Bay:

snapper

- time to market (250mm FL, 400g) - 24 months;
- survival rate in seacages - 40% ;
- FCR - 2.4 to 3.1; and
- stocking density at harvest - 10 kg per cubic metre.

mulloway

- time to market (450mm TL, ≈1100g) - 26+ months;
- survival rate in seacages- 26%;
- FCR - 2.2; and
- stocking density at harvest - 15 kg per cubic metre.

The transfer of technology and information to the private sector would be greatly facilitated if sites for fish farms were made available and if a hatchery to supply juvenile fish was established. If juvenile fish were also required for reseeding of wild stocks, the cost of establishing and running a hatchery could be subsidised.

A market for live finfish exists in most capital cities and, at least initially, supply to those markets would bring the highest returns. The cost of transporting live product, especially finfish, implies that sites close to the major capital cities would be more valuable.

REFERENCES

Allan, G. L. & Quartararo N. (1996). Developing diets for snapper. In: N. Quartararo (Editor), *Proceedings of the Marine Finfish Farming Workshop*, 23 June 1995, Cronulla, NSW. NSW Fisheries Research Institute, Cronulla, NSW, pp. 71-94

Austin, B. & Austin, D. A. *Bacterial Fish Pathogens: Disease in Farmed and Wild Fish.* Ellis Horwood Ltd. Chichester UK (1987), 364pp.

Battaglene, S. C. (1996). Seacages and the Environmnet. In: N. Quartararo (Editor), *Proceedings of the Marine Finfish Farming Workshop*, 23 June 1995, Cronulla, NSW. NSW Fisheries Research Institute, Cronulla, NSW, pp. xx-yy

Battaglene, S.C. and Talbot, R.B., 1994. Hormone induction and larval rearing of mulloway *Argyrosomus hololepidotus* (Pisces:Sciaenidae). *Aquaculture*, 126:73-81.

Bell, J. D., Quartararo, N. & Henry, G. W. (1991). Growth of snapper, *Pagrus auratus*, from south-eastern Australia in captivity. *New Zealand Journal of Marine and Freshwater Research*, 25, 117-121.

Beveridge, M., *Cage Aquaculture,* Fishing News Books Ltd. Surrey (1987), 351pp.

Canfield, P.J., Quartararo, N., Griffin, D.L., Tsoukalas, G.N. & Cocaro, S.E. (1994). Haematological and biochemical reference values for captive Australian snapper, *Pagrus auratus*, Bloch & Schneider. *Journal of Fish Biology*, 44, 849-856.

Cleary, J., Battaglene, S. C. & Panhurst N. (1995). The effect of stress on reproduction in snapper. Aquaculture CRC Limited Newsletter December 1995.

Foscarini, R. (1988). A review: intensive farming procedure for red sea bream (*Pagrus major*) in Japan. *Aquaculture*, 72:191-246.

Hepher, B., 1988. *Nutrition of Pond Fishes*. Cambridge University Press, 388 pp.

Ikenoue, H. & Kafuku, T. (Editors). Modern Methods of Aquaculture in Japan (second edition) 1992. Elsevier London. pp 272.

Kadmon, G., Gordin, H. & Yaron, Z. (1988). Breeding related growth of captive *Sparus aurata* (Teleostei, Perciformes). *Aquaculture* 46:299-305.

Langdon, J. S. (1988). Diseases of introduced Australian fish. In: Fish Diseases, *Proceedings 106, Post Graduate Committee in Veterinary Science*, University of Sydney, Australia.

Prescott, J. & Bell, J. D. (1992). Sensory evaluation of Australian snapper (*Pagrus auratus*) raised in captivity. *Asean Food Journal* 7: No. 2:111-2.

Quartararo, N., Allan, G. L. & Bell, J. D. (1992). Fish meal substitution in a diet for snapper, *Pagrus auratus*. In: G. L. Allan & W. Dall (Editors), Aquaculture Nutrition, Proceedings of a Workshop, 15-17 April 1991 at Salamander Bay, NSW, Australia.

Reddacliff, G. L. & Quartararo N. (1992). Lymphocystis in cultured snapper (*Pagrus auratus*) and wild kingfish (*Seriola lalandi*) in Australia. *Australian Veterinary Journal* 69, 116-117.

Reigh, R. C. & Ellis, S. C. (1992). Effects of dietary soybean and fish- protein ratios on growth and body composition of red drum (Sciaeops ocellatus) fed isonitrogenous diets. *Aquaculture* 104:279-292.

Roubal, F.R., Quartararo, N. & West, A. (1996) Ectoparasite infection on young snapper, *Pagrus auratus* (Bloch & Schneider), (Sparidae) from the wild and captivity at Port Hacking, Sydney, Australia. *Australian Journal of Marine and Freshwater Research* (*in press*).

Developing Diets for Snapper

Geoff L Allan

NSW Fisheries, Port Stephens Research Centre, Taylors Beach Road, Taylors Beach, NSW, 2316

Nino Quartararo

NSW Fisheries, Fisheries Research Institute, PO Box 21, Cronulla, NSW, 2230

INTRODUCTION

Since 1986, aquaculture production has increased by more than 40% (Anon., 1990, 1994) to 20.8 million tonnes per year (including aquatic plants). One reason for this increase has been the trend towards more intensive culture practices necessitating a greater reliance on formulated feeds. In the same period, production of aquaculture feeds has risen even faster, and recent estimates predict the Asian aquaculture feed market alone will be about 2.6 million tonnes per annum by the year 2000 (New and Csavas, 1993). As feed and feeding costs can contribute up to 70% of the total operating costs for fish farming (Wee, 1992) the development of nutritionally adequate, economical diets is of crucial importance.

To develop cost-effective aquaculture diets and feeding strategies, nutritionists must know:

- nutritional requirements;
- composition, digestibility and availability of feed ingredients;
- potential to use lower-cost ingredients;
- strategies for effectively and economically feeding fish; and
- potential to improve use of ingredients through processing, and use of additives.

This paper will briefly describe some of the principles of fish nutrition; specific information for marine carnivores, e.g. snapper, will be presented wherever possible. Although nutritional requirements for different life stages (i.e. larvae, juveniles, adults and broodstock) can be very

different, this paper will focus on the development of grower diets (for juveniles and rapidly growing adult fish) as these are by far the most important economically.

NUTRITIONAL REQUIREMENTS

Fish require amino acids, fatty acids, vitamins, minerals and energy from protein, lipid and carbohydrate. To investigate nutritional requirements, most researchers use measures of fish performance to assess response to various manipulated diets. Such measures include survival, growth, food consumption and conversion efficiency, nutrient deposition and gross or histological appearance. Maximum performance is usually considered optimal although this is not always the case. Most rapid growth, for example, does not always correlate with absence of disease or with longevity, and diets which promote the most rapid growth are often not the most economical (Lall, 1991a).

Protein

Protein is comprised of various amino acids; ten of which are essential (NRC, 1993; Lovell, 1989). Essential amino acids are those which cannot be synthesised by the animal or cannot be synthesised in sufficient quantity to support maximum growth (Lovell, 1989). These are: arginine, histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan and valine. Insufficient protein in the diet results in a reduction in growth or a loss of weight as fish withdraw protein from some tissues to support the functions of more vital ones (NRC, 1993). Excess protein will be metabolised for energy. Protein requirements are influenced by a range of variables, including fish size, culture conditions (including stocking density and availability of natural food items), water temperature, feeding strategy (whether fish are fed to satiation or on a restricted regime), composition of the diet (particularly the energy concentration) and the quality of the protein. Gross requirements decrease as fish grow and increase as water temperature increases.

Estimated protein and amino acid requirements for some species of fish are presented in Tables 1 and 2.

Table 1: Estimated Requirements for juvenile fish[1]

Species	Protein source(s)	Estimated requirement (%)
Channel catfish (*Ictalurus punctatus*)	Whole egg protein	32-36
Common carp (*Cyprinus carpio*)	Casein	31-38
Grass carp (*Ctenopharyngodon idella*)	Casein	41-43
Japanese eel (*Anguilla japonica*)	Casein and arginine plus cystine	44.5
Estuary grouper (*Epinephelus striatus*)	Tuna muscle meal	40-50
Milkfish (fry) (*Chanos chanos*)	Casein	40
Snapper (*Pagrus auratus*)	Casein	55
Smallmouth bass (*Micropterus dolomieui*)	Casein and fish protein concentrate	45
Largemouth bass (*Micropterus salmoides*)	Casein and fish protein concentrate	40
Tilapia		
Tilapia aurea (fry)	Casein and egg albumin	56
Tilapia aurea	Casein and egg albumin	34
Oreochromis mossambica	White fishmeal	40
Tilapia zillii	Casein	35
Snakehead (*Channa micropeltes*)	Fishmeal	52
Chinook salmon (*Oncorhynchus tshawytscha*)	Casein, gelatin and amino acids	40
Coho salmon (*Oncorhynchus kisutch*)	Casein	40
Rainbow trout (*Oncorhynchus mykiss*)	Fishmeal	40
	Casein and gelatin	40
	Casein, gelatin and amino acids	45
Sockeye salmon (*Oncorhynchus nerka*)	Casein, gelatin and amino acids	45
Yellowtail (*Seriola quinqueradiata*)	Sand eel and fishmeal	55

[1] Based on NRC (1993) and Wilson (1989)

Lipid

Lipid is a term often used synonymously with fat or oil and includes fats, sterols, waxes, phospholipids and sphingomyelins (New, 1987). Fats are the major vehicle many animals use to store energy. Sterols are components or precursors of hormones, waxes are energy storage compounds, phospholipids are components of cell membranes and sphingomyelins are found in nerve tissue (New, 1987).

Lipids are a concentrated energy source for fish and are important in the palatability of feeds (New, 1987). They are comprised of fatty acids, some of which are essential (New, 1987; Lovell, 1989).The nomenclature describing fatty acids can be confusing. Besides having a common name, fatty acids are also given a numerical designation such as 14:0, 18:3 n-3, 20:5 n-3 or 22:6 n-3. This designation describes the number of carbon atoms present, the number of double bonds and the position of the first double bond (New, 1987). For eicosapentaenoic acid (EPA) or 20:5 n-3, there are 20 carbon atoms and five double bonds, the first of which occurs on the third carbon atom, numbering from the terminal methyl end. Saturated, monounsaturated and polyunsaturated fatty acids (or PUFA's) are those which have 0, 1 or more than 1 double bond respectively. The term HUFA's is used for those PUFA's with four or more double bonds (New, 1987).

Aquatic animals have a greater requirement for n-3 (or omega [Ω]3) series fatty acids than terrestrial animals, which have a greater requirement for n-6 fatty acids (New, 1987; Hepher, 1988). Among fish, cold water species have a greater requirement for n-3 series fatty acids than warmwater species. One hypothesis to explain this is that the n-3 structure permits a greater degree of unsaturation which is necessary in membrane phospholipids to maintain flexibility and permeability of cell membranes at low temperatures (NRC, 1993). Fish can further desaturate and elongate chains of unsaturated fatty acids to form PUFA's, although different speices have different capacities to do so (NRC, 1993; Hepher, 1988). The ability to desaturate and chain elongate fatty acids allows reduction in the dietary content of aquatic animal oils, which can be expensive, and permits substitution with less expensive oils.

NRC (1993) summarised published information on essential fatty acid requirements for warmwater fish and crustaceans. Most fish needing n-3 or n-6 fatty acids require 0.5 - 2.0 % of these fatty acids (NRC, 1993; Lall, 1991a). In commercial rations, lipid contents range from around 5-6% for diets for channel catfish (Robinson, 1989) to 20% for some salmon and trout diets (Lovell, 1989). Elevated lipid contents are used to spare protein. Commercial rations for snapper commonly have lipid contents of 15-16% (Foscarini, 1988) and for tilapias, 5-12% (El-Sayed and Teshima, 1991; Luquet, 1991).

Table 2: Amino acid requirements for juvenile fish (% of protein)

Amino acid	Common[1] carp	Chinook[1] salmon	Gilthead Sea[1] bream	Snapper[2] (*Pagrus auratus*)
Arginine	4.2	6.0	5.0	3.73
Histidine	2.1	1.8		1.73
Isoleucine	2.5	2.2		2.33
Leucine	3.3	3.9		3.46
Lysine	5.7	5.0	5.0	4.27
Methionine	3.1[3]	4.0[3]	4.0[3]	1.07
Phenylalanine	6.5[4]	5.1[4]		2.53[4]
Threonine	3.9	2.2		1.67
Tryptophan	0.8	0.5	0.6	0.6
Valine	3.6	3.2		3.13

1 Based on NRC (1993)

2 Based on Foscarini (1988)

3 Plus cystine

4 Plus tyrosine

Carbohydrate

Carbohydrate includes starches, sugars, cellulose (and other cell wall material) and gums and is usually the cheapest source of energy in fish diets (New, 1987). Fish do not have a specific requirement for carbohydrate (NRC, 1993) and some studies indicate that, like diabetics, fish are incapable of maximum carbohydrate utilisation (Robinson, 1989). Although enzymes necessary for carbohydrate digestion have been detected in fish, some species are clearly better able to digest carbohydrates than others (NRC, 1993). The digestibility of carbohydrates is influenced by the digestive system of fish and herbivorous and omnivorous fish are better equipped to digest carbohydrates than carnivores. Snapper have a poor ability to utilise carbohydrates and growth, food conversion efficiency and protein absorbtion all decrease with increasing carbohydrate content (Foscarini, 1988). Carbohydrate digestibility is also influenced by processing, eg cooking or steam treatment, and by the structural complexity of the carbohydrate (NRC, 1993; Robinson, 1989). Foscarini (1988) recommends carbohydrate content of 10-15% for snapper diets.

In addition to an energy source and to spare protein for growth, carbohydrates may act as precursors for metabolic intermediates necessary for growth, and play a vital role in pellet formulation and binding of commercial fish diets.

Vitamins

Vitamins are organic compounds which are only required in small quantities for growth, health and function (Lovell, 1989). Table 3 lists minimum requirements for channel catfish, carp, and snapper. Different species have different essential vitamins and deficiency signs of these essential vitamins range from poor appetite to severe tissue deformity and death. Deficiency signs for vitamins for a range of species are presented in Table 4. The vitamin contents of the experimental diet used by NSW Fisheries for growth trials are listed in Table 5.

Minerals

Minerals are inorganic compounds some of which are constituents of bone, fins, scales, tissue and blood. Some minerals function as components or activators of hormones and enzymes

Table 3: Minimum requirements (mg/kg) of vitamins to prevent signs of deficiency[1,2]

Vitamin	Channel catfish *Ictalurus punctatus*	Common carp *Cyprinus carpio*	Snapper *Pagrus auratus*
Thiamin	1.0		R
Riboflavin	9.0	7.0	R
Pyridoxine	3.0	5-6	5-6
Pantothenic acid	10-20	30-50	R
Nicotinic acid	14	28	R
Biotin	R	1	N
Folic acid	N	N	N
Vitamin B_{12}	R	N	R
Choline	R	4 000	R
Inositol	N	440	550-900
Ascorbic acid	60	NT	R
Vitamin A	1 000 - 2 000	10 000 IU	NT
Vitamin D	500 - 1 000	N	NT
Vitamin E	30	200-300	NT
Vitamin K	R	N	NT

[1] Based on NRC (1993)

[2] Minimum requirements not allowing for storage or processing losses

R Required

N No dietary requirement demonstrated

NT Not tested

IU International units

(e.g. zinc) (Lovell, 1989). One of the major differences in mineral requirements between fish and other animals is the role minerals play in osmoregulation in fish. For this reason requirements for saltwater and freshwater fish differ. The mineral contents of NSW Fisheries' snapper reference diet are given in Table 5.

The availability of phosphorus depends largely upon the source. Phytate phosphorus from grains is poorly available to fish, phosphorus of fishmeal is about 40-70% available, and inorganic phosphorus, from sodium or monocalcium phosphate, is highly available to all fish (Lovell, 1989).

Energy

Energy is not a nutrient but is required by all animals to sustain life (Smith, 1989). One of the most notable differences between fish diets and diets for homoeothermic land animals is that fish require less energy. This is because:

1. they do not have to maintain a constant body temperature;
2. they use less energy to maintain position and to move about in water than animals do on land, and
3. they lose less energy in protein catabolism and excretion than land animals (Lovell, 1989; Smith, 1989).

One of the manifestations of this lower energy requirement is the much higher crude protein content (and protein to energy ratio) in fish diets than in diets for homoeothermic land animals.

Both an excess and deficiency of energy can reduce growth. Energy needs for maintenance and movement must be satisfied first and if insufficient energy is available in the food, essential nutrients, eg protein, will be used for energy rather than growth. Conversely, if excess energy is supplied, food consumption will be reduced before enough essential nutrients for maximum growth have been consumed. Excess energy:protein ratios can also lead to the deposition of large amounts of body fat which can be undesirable (Lovell, 1989).

Table 4: Deficiency signs for vitamins[1]

Vitamin	Deficiency signs for salmon, catfish and other species
Thiamin[2]	Poor appetite, muscle atrophy, convulsions, instability and loss of equilibrium, oedema, poor growth
Riboflavin[2]	Corneal vascularisation, cloudy lens, haemorrhagic eyes, photophobia, dim vision, incoordination, abnormal pigmentation of iris, striated constrictions of abdominal wall, dark colouration, poor appetite, anaemia, poor growth
Pyridoxine[2]	Nervous disorders, epileptiform fits, hyperirritability, ataxia, anaemia, loss of appetite, oedema of peritoneal cavity, colourless serous fluid, rapid postmortem rigor mortis, rapid and gasping breathing, flexing of opercles
Pantothenic acid[2]	Clubbed gills, prostration, loss of appetite, necrosis and scarring, cellular atrophy, gill exudate, sluggishness, poor growth
Inositol[2,3]	Poor growth, distended stomach, increased gastric emptying time, skin lesions
Biotin[2]	Loss of appetite, lesions in colon, discolouration, muscle atrophy, spastic convulsions, fragmentation of erythrocytes, skin lesions, poor growth
Folic acid[2]	Poor growth, lethargy, fragility of caudal fin, dark colouration, macrocytic anaemia
Choline[2]	Poor growth, poor food conversion, haemorrhagic kidney and intestine
Niacin[2]	Loss of appetite, lesions in colon, jerky or difficult motion, weakness, oedema of stomach and colon, muscle spasms while resting, poor growth
Vitamin B_{12}[2]	Poor appetite, low haemoglobin, fragmentation of erythrocytes, macrocytic anaemia
C[2]	Scoliosis, lordosis, impaired collagen formation, altered cartilage, eye lesions, haemorrhagic skin, liver, kidney, intestine, and muscle
A[4]	Impaired growth, exophthalmos, eye lens displacement, oedema, ascites, depigmentation, corneal thinning and expansion, degeneration of retina
D[4]	Poor growth, tetany of white skeletal muscle, impaired calcium homeostasis
E[4]	Reduced survival, poor growth, anaemia, ascites, immature erythrocytes, variable-sized erythrocytes, erythrocyte fragility and fragmentation, nutritional muscular dystrophy, elevated body water
K[4]	Prolonged blood clotting, anaemia, lipid peroxidation, reduced hematocrit

[1] Based on Halver (1989)
[2] Water soluble vitamins
[3] No deficiency signs found when channel catfish fed diets without inositol
[4] Fat soluble vitamins

Table 5: Vitamin and mineral contents of NSW Fisheries' snapper reference diet

Thiamin HCl	10 mg
Riboflavin	25.5 mg
Pyridoxine HCl	15 mg
Ca-Pantothenate	54.5 mg
Nicotinamide	200 mg
Biotin	1 mg
Folic acid	4 mg
Cyanobalamin (Vitamin B_{12})	20 μg
Choline chloride	1.5 g
Myo-inositol	600 mg
Ascorbic acid	450 mg
Retinol (Vitamin A)	2.4 mg
Cholecalciferol (Vitamin D_3)	25 mg
α -Tocopherol acetate (Vitamin E)	125 mg
Menadione sodium bisulphate (Vitamin K_3)	16.5 mg
Calcium carbonate ($CaCO_3$)	7.5 g
Manganese sulphate ($MnSO_4$)	0.3 g
Zinc sulphate ($ZnSO_4.7H_2O$)	0.7 g
Iron sulphate ($FeSO_4.7H_2O$)	0.5 g
Copper sulphate ($CuSO_4$)	60 mg
Sodium chloride (NaCl)	7.5 g
Potassium iodate ($KI0_3$)	2 mg

When evaluating feed ingredients or diets it is important to measure or estimate the amount of energy (and essential nutrients) which will be available to the fish. Bioenergetics is the study of energy intake and utilisation. The energy flow is illustrated in Figure 1.

FISHMEAL

Satisfying protein requirements is usually the most expensive task. The protein source of choice for aquaculture diets is fishmeal, and diets can contain as much as 70% (Wee, 1992). Fishmeal is excellent because it has a high total protein content, has a very well balanced amino acid profile and its lipid has a high proportion of desirable unsaturated fatty acids. It is also low in carbohydrate and fibre, is very palatable and, when processed well, is highly digestible with few anti-nutritional factors. Unfortunately, the price and availability of fishmeal will restrict future aquaculture development unless suitable alternatives can be found. In 1991, 31% of the total world fish and shellfish catch (or 26 269 000 t) was reduced into 6 367 000 t of fishmeal (Tacon, 1993). Approximately 14% was used in aquafeeds, and (if current trends continue) this proportion is likely to increase to around 25% by the year 2000. Unfortunately, while world aquaculture production is increasing rapidly, especially in Asia (New and Csavas, 1993), production of fishmeal is expected to remain stable or decline by about 5% by the year 2000 (Barlow, 1989). In Australia, we produce very little high quality fishmeal (<7 000 t), leading to the importation of 65 000 t worth $31 million in 1993/94 (ABARE, 1994). Evaluating suitable alternative protein sources to fishmeal and ways of improving the value of alternative protein sources is an international research priority (Manzi, 1989; New, 1991).

FORMULATING A DIET FOR SNAPPER

An appropriate diet is necessary for experimental culture of any new species and as a reference for on-going nutritional studies. At NSW Fisheries we formulated a 'snapper reference diet' based on published requirements for snapper (red sea bream) (Yone, 1975; Foscarini, 1988) which included high quality imported fishmeal (64%) plus Australian ingredients. The composition and analysis of this diet are listed in Table 7.

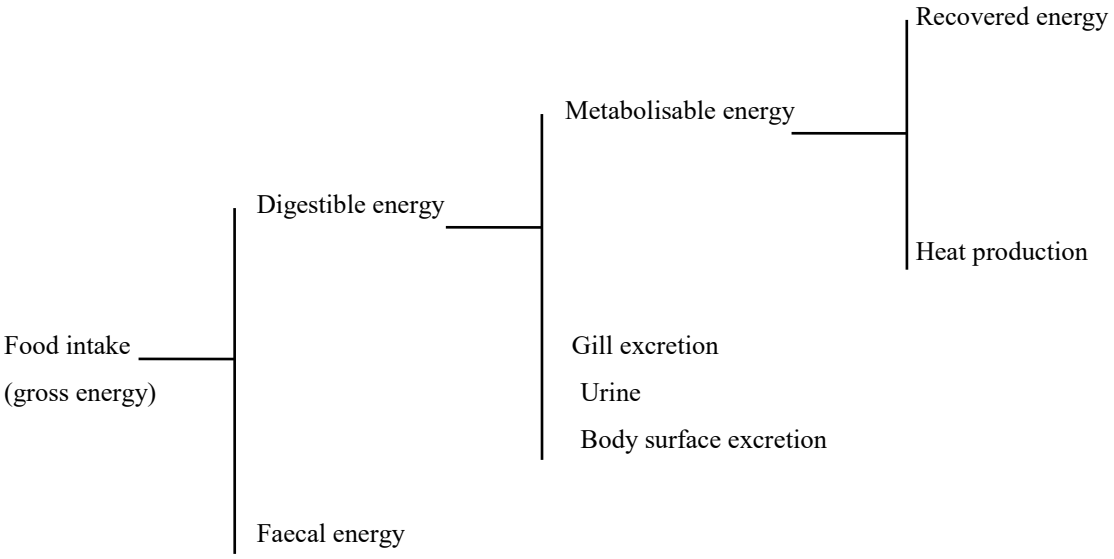


Figure1: Energy flow in fish. Based on Lovell (1989)

To evaluate this diet we compared it with two commercially available marine fish diets; one for barramundi and one for salmon. We also formulated a second diet with a very similar nutritional composition to the 64% fishmeal diet but where we replaced all but 10% of the fishmeal with a mix of soybean meal and poultry offal meal. Results of this experiment are summarised in Table 8 and are more fully reported in Quartararo *et al*. (1992; in press). Results from the experiment summarised in Table 8 indicated that although the 64% fishmeal diet was superior, the 10% fishmeal diet yielded performance similar to two commercial diets. On the basis of these results we used the 64% fishmeal diet for cage culture experiments and as a control diet in nutrition experiments. We also conducted a series of further experiments to determine just how much fishmeal we could replace with high quality Australian protein sources. Results from these experiments are summarised in Tables 9 and 10 (Data from Quartararo, Allan and Bell, unpublished data). This research indicated that more than half the fishmeal could be replaced without significantly reducing growth.

Table 7: Composition of NSW Fisheries reference diet for snapper (96.4% dry matter)

Ingredients	Content (%)
Fishmeal	64.0
Lupins	7.0
Fish oil	3.1
Poultry meal	4.0
Sorghum	10.1
Wheat	7.8
Vitamin premix (see Table 5)	1.0
Mineral premix (see Table 5)	3.0
Composition (dry basis)	
Ash (%)	14.4
Gross energy (MJ/kg)	18.8
Crude protein (N x 6.25) (%)	48.6
Asparagine (%)	4.2
Glutamine (%)	6.7
Serine (%)	2.5
Glycine (%)	3.1
Histidine (%)	1.3
Arginine (%)	3.3
Threonine (%)	2.0
Alanine (%)	2.9
Proline (%)	3.4
Tyrosine (%)	1.4
Valine (%)	2.2
Methionine (%)	1.2
Cystine (%)	0.7
Isoleucine	1.7
Leucine	3.5
Phenylalanine	1.9
Lysine	3.7

Table 8: Weight gain and food conversion ratio of juvenile snapper (8-71 g/fish at stocking) fed one of four diets for 86 days[1]

	Diet			
	1[2]	2[3]	3[4]	4[4]
Weight gain[5] (g/fish)	47[a]	35[b]	37[b]	35[b]
Food conversion efficiency[5,6]	1.6[a]	2.2[b]	2.2[b]	2.2[b]

1 Fish grown in 200 l tanks with seawater at 16-22°C. Fish were fed twice daily to apparent satiation, six days/week

2 See Table 7 for composition

3 Similar nutritional composition to Diet 1 but 10% fishmeal, 22.4% soybean meal, 50.5% poultry offal meal and 3% bloodmeal used to supply most of the protein

4 Commercial diet for barramundi or salmon

5 Values are means of n=8 replicate tanks. Data were analysed using single factor ANOVA. Means compared using Student Newman-Keuls multiple range test. Values with the same superscript are not significantly different (P>0.05)

6 Food conversion efficiency = weight of dry food/weight gain wet fish

Other dietary components

In addition to feed ingredients, vitamins and minerals, diets may contain other materials that can influence fish growth. These include binders, antioxidants, mould inhibitors, pigments, hormones, antibiotics, feeding stimulants and attractants. Common binders include sodium and calcium bentonites, lignosulfonates, hemicellulose, carboxymethylcellulose, alginate, guar gum, gelatinised starch from cereals, wheat gluten, whey and molasses (Lall, 1991a).

Most binders are usually added at about 0.5 - 4.0% of the diet, except for gelatinised starches, which may be added at up to 20% (Lovell, 1989). Commonly used antioxidants and mould inhibitors are listed in Table 11. For a thorough review of pigments, hormones, antibiotics, feeding stimulants and attractants please refer to Lovell (1989), Tacon (1990) and NRC (1993).

Table 9: Weight gain and food conversion efficiency of juvenile snapper (15-77 g/fish at stocking) fed diets with similar nutritional composition but containing different amounts of fishmeal for 115 days[1]

	Diet			
	1	2	3	4
Fishmeal content (%)	64	30	20	10
Soybean meal content (%)	0	20	25	30
Poultry offal meal content (%)	4	21	25	30
Weight gain (g/fish)[2]	40.6^{a}	36.0^{ab}	31.1^{b}	22.0^{c}
Food conversion efficiency[2,3]	2.1^{a}	2.3^{a}	2.6^{a}	3.9^{b}

1 Fish grown in 4 000 l tanks with seawater at 14-19ºC. Fish were fed twice daily, six days/week

2 Values are means for n=3 replicate tanks. Data were analysed with single factor ANOVA and means compared using Student Newman-Keuls multiple range test. Means sharing a letter in the superscript were not significantly different (P>0.05)

3 Food conversion efficiency = weight of dry feed/weight gain wet fish

Table 10: Weight gain of juvenile snapper fed diets with similar nutritional composition but containing either 64 or 30% fishmeal in tanks with either ambient temperature seawater or seawater heated by 3-4ºC for 180 days[1]

	Heated (17-22ºC)		Ambient (14-19ºC)	
	Diet 1 (ref)	Diet 2	Diet 1 (ref)	Diet 2
Fishmeal content (%)	64	30	64	30
Soybean meal content (%)	0	20	0	20
Poultry offal meal content (%)	4	21	4	21
Weight gain (g/fish)[2]	119	105	48	44

[1] Fish were grown in 4 000 l tanks and were fed twice daily for six days/week. Digestible energy, crude protein and essential amino acids were experimentally determined and were similar for both diets

[2] Values are means for n=3 replicate tanks. Data were analysed by two factor ANOVA. Growth was significantly faster at the higher temperature ($P<0.01$) but diet had no affect ($P>0.05$) and there was no interaction between diet and temperature ($P>0.05$)

PROCESSING

Processing includes grinding, classification, sieving, mixing, heating, drying, crumbing, pelleting and extruding. It can affect the digestibility and availability of energy and nutrients in ingredients and the physical and water stability, buoyance, texture, hardness and price ofthe diet. Some diets are fed as moist or semi-moist feeds but most aquaculture feeds are dry feeds and contain about 8-10% moisture.

Fish diets are available as pellets produced either through a pelleting press (with or without steam conditioning) or through an extruder. For the same ingredients, diets processed through a pelleting press should be cheaper as this is a simpler operation requiring less expensive equipment. It relies on the use of moisture, heat and pressure to combine the ingredients into a mash which is then forced through dies of varying size openings and cut to varying lengths (Lall, 1991a). Where a steam conditioner is used, steam is generally added to increase the moisture content to approximately 5-6% and elevate the temperature to 70-90^{o}C (NRC, 1993). This partially gelatinises starch which helps bind the diet and affects digestibility.

Extrusion uses more sophisticated equipment. Here the finely ground feed-mix with a moisture content of around 25% is heated in a conditioning chamber to 104-148^{o}C with dry steam under pressure. The sudden reduction in pressure as the material is forced through the die holes at the end of the barrel allows the water vapour to expand and air is trapped in the feed matrix (Lall, 1991a; NRC, 1993). By modifying this process, buoyancy of the feed can be controlled. The feed then passes through a drying tunnel to reduce moisture content. Extrusion allows almost complete gelatinisation and feeds are more firmly ground resulting in better water stability and less dust than for pelleted feeds (Lovell, 1989). Because some vitamins are destroyed by heat, and for feeds where high contents of lipid are required (eg for some salmonids), feeds are sometimes coated with vitamin mixtures or fat after processing. Cooling prior to bagging and shipment is important for both pelleted and extruded feeds to reduce condensation and restrict the growth of mould.

Nutrition and the environment

It may be argued that the impact on the environment from aquaculture is minor compared with agricultural and industrial pollution. However, in Australia the emerging aquaculture industry will need to minimise pollution from waste and prevent environmental abuse if it is to continue to develop.

Table 11: Commonly used antioxidants and preservatives[1]

Antioxidants
Octyl gallate
Dodecyl gallate
N-propyl gallate
BHA (Mixture of 3- and 2-*tert* butyl 4-hydroxyanisole)[2,3]
BHT (2, 6-di (*tert* butyl) -4-methylphenol)[2,3]
Ethoxyquin (6-ethoxy-1, 2-dihydro-2, 2, 4-trimethyl-quinoline)[2,4]
Preservatives
Propionic acid or Ca, Na or K salt[5]
Sorbic acid or Ca, Na or K salt[5]
Benzoic acid or Na salt
Acetic acid
Formic acid
Citric acid
Ascorbic acid or Ca or Na salt
Gentian violet
Potassium and sodium bisulphite
Potassium and sodium metabisulphite
Propylene glycol
Salt

1 Adapted from Tacon (1990)

2 Major synthetic antioxidants

3 Maximum level permitted in the USA is 0.2% of the total fat content

4 Maximum level permitted in the USA is 150 mg/kg feed

5 Most common. Inclusion level about 0.2 - 1.0% of diet

The issue of aquaculture waste is discussed in detail in Battaglene (1996) but as undigested, unutilised and wasted feed is the major source of aquaculture waste, it is important to note here the major links between nutrition and environment. In general, deficiencies in essential nutrients will reduce growth and food conversion efficiency and therefore increase wastage from feeds. Based on a feed conversion ratio of 1.8:1, a diet with 50% protein (contains about 8%, N) and a fish tissue composition of 30% dry matter and 58% protein (on a dry basis) (contains about 9.3% N), a commercial snapper farm would discharge about 116 kg N per tonne of fish produced.

In fish, ammonia excretion (a major polluting nutrient) is directly linked with protein intake and the current emphasis on diet development is on optimising protein:energy ratios and utilising non-protein energy sources (Kaushik and Cowey, 1991). Increasing the frequency of feeding has also been shown to have beneficial effects in reducing ammonia excretion (Kaushik and Cowey, 1991).

Estimates of the total phosphorus (also a major polluting nutrient) discharged from land based hatcheries and commercial farms ranges from 8-113 kg P per tonne of fish produced (Lall, 1991b). Excretion of phosphorus is related to dietary phosphorus content and bioavailability. Strategies to reduce phosphorus waste include selecting ingredients, particularly phosphorus supplements, with high phosphorus bioavailability and meeting but not exceeding phosphorus requirements. Recently, using exogenous enzymes to improve phosphorus utilisation has shown promise and warrants further investigation for use in aquaculture diets (Lall, 1991b). Selecting highly digestible, fresh ingredients will maximise the utilisation of diets by fish by improving food conversion efficiency (Cho *et al*., 1991).

CONCLUSION

Development of diets for warmwater marine finfish in Australia is still in its infancy. At NSW Fisheries we have formulated and evaluated a successful fishmeal based diet for snapper containing approximately 50% protein. This diet has been used to rear significant quantities of snapper to market size in sea cages and as a control diet in experiments to replace fishmeal

with terrestrial agricultural proteins. Advances have been made using poultry offal meal and soybean meal to replace about half of the fishmeal contained in the snapper reference diet.

Research priorities for snapper nutrition include:

- continued search for and evaluation of high quality protein sources to replace fishmeal;
- determination of requirements for essential nutrients especially amino acids and protein:energy ratios;
- investigation of methods to improve utilisation of nutrients, especially from agricultural ingredients, to reduce feed wastage;
- determination of the most efficient, economical feeding strategies; and
- all nutrition research should proceed with a focus on reducing waste and minimising environmental pollution.

Farmers intending to culture snapper, or any other fish, need to be aware of the importance of nutrition in running an economical operation. Farmers need to ensure that diets are appropriate, stored correctly (to prevent deterioration of essential nutrients and contamination by moulds or bacteria) and used within a reasonable period of time. Records must be kept on types of feed used, physical quality of the diet (amount of dust *etc*.), feeding rates and frequencies, periods when fish do not feed and fish feeding behaviour. Response to feeding is often a good guide to fish health. Changes to feeding strategies, eg changing brands of feed, should be made gradually.

SUMMARY

To successfully develop diets for fish, information is needed on nutritional requirements, the chemical composition, availability, price and value to the fish of potential feed ingredients, and the best way to present and feed diets in culture facilities. Prior to this study, very little research had been done on snapper nutrition. The key results arising from the research described in this paper are:

- formulation of a reference diet for snapper (64% fishmeal) based on locally available ingredients;

- formulation of a series of test diets for snapper containing soybean meal and poultry offal meal in order to reduce the fishmeal content of the diet;
- that the snapper reference diet resulted in significantly faster growth than commercially available diets for two other carnivorous species;
- that snapper diets containing soybean meal and poultry meal should be at least 30% fishmeal;
- that the growth of juvenile snapper in water heated by 3 -5 °C above ambient was approximately doubled;
- that the difference in growth of juvenile snapper in heated water, fed either the reference diet or a test diet which was 30% fishmeal, was not significant; and
- determination of the apparent digestibility coefficients for juvenile snapper of the reference diet and the test diet which was 30% fishmeal.

Acknowledgements

We would like to acknowledge the contribution to research described in this paper by Dr Johann Bell (present address: ICLARM Coastal Aquaculture Centre, Honaria, Solomon Islands) and technical staff from the NSW Fisheries Research Institute at Cronulla and the Port Stephens Research Centre. In particular David Barker, Andrew West and Scott Parkinson were very helpful. Funds for much of the research with snapper was provided by the Fisheries Research and Development Corporation. Ms Jo Pickles expertly typed this manuscript.

REFERENCES

ABARE, (Australian Bureau of Agricultural and Resource Economics), 1994. *Australian Fisheries Statistics* 1994. ABARE, Canberra, ACT, Australia, 49 pp.

Anonymous, 1990. Status of world aquaculture: 1989. *Aquaculture Magazine Buyer's Guide '90*, p.10-20.

Anonymous, 1994. Status of world aquaculture 1993. *Aquaculture Magazine Buyer's Guide '94*, p. 16-27.

Barlow, S., 1989. Fishmeal - world outlook to the year 2000. *Fish Farmer* September/October 1989, p. 40-43.

Battaglene, S. C., 1996. Seacages and the environment. In: N. Quartararo (Editor), *Proceedings of the Marine Finfish Farming Workshop, 23 June 1995, Cronulla, NSW*. NSW Fisheries Research Institute, Cronulla, NSW, pp. 119-152.

Cho, C. Y., Hynes, J. D., Wood, K. R. and Yoshida, H. K., 1991. Quantitation of fish culture wastes by biological (nutritional) and chemical (limnological) methods; the development of high nutrient dense (HND) diets. In: C. B. Cowey and C. Y. Cho (Editors), *Nutritional Strategies and Aquaculture Waste*. Proc. First. Intl. Symp. on Nutritional Strategies in Management of Aquaculture Waste. University of Guelph, Ontario, Canada, 1990. pp. 37-50.

El-Sayed, A. -F. and Teshima, S. -I., 1991. Tilapia nutrition in aquaculture. *Reviews in Aquatic Sciences*, 5(3-4): 247-265.

Foscarini, R., 1988. A review: intensive farming procedure for red sea bream (*Pagrus major*) in Japan. *Aquaculture*, 72: 191-246.

Halver, J. E., 1989. The Vitamins. In: J. E. Halver (Editor), *Fish Nutrition*. Second Edition. Academic Press, San Diego, Ca 798pp.

Hepher, B., 1988. *Nutrition of Pond Fishes*. Cambridge University Press, 388 pp.

Kaushik, S. J. and Cowey, C. B., 1991. Dietary factors affecting nitrogen excretion by fish. In: C. B. Cowey and C. Y. Cho (Editors), Nutritional Strategies and Aquaculture Waste. *Proc. First. Intl. Symp. on Nutritional Strategies in Management of Aquaculture Waste*. University of Guelph, Ontario, Canada, 1990. pp. 3-19.

Lall, S. P., 1991a. Concepts in the formulation and preparation of a complete fish diet. In: S. S. DeSilva (Editor), Fish Nutrition Research in Asia. *Proceedings of the Fourth Asian Fish Nutrition Workshop*. Asian Fish Soc. Spec. Publ. 5, Asian Fisheries Society, Manila, Philippines.

Lall, S. P., 1991b. Digestibility, metabolism and excretion of dietary phosphorus in fish. In: C. B. Cowey and C. Y. Cho (Editors), Nutritional Strategies and Aquaculture Waste. *Proc. First. Intl. Symp. on Nutritional Strategies in Management of Aquaculture Waste*. University of Guelph, Ontario, Canada, 1990. pp. 21-36.

Lovell, T., 1989. *Nutrition and Feeding of Fish*. Van Nostrand Reinhold, New York, pp. 260.

Luquet, P., 1991. Tilapia, *Oreochromis* spp. In: R. P. Wilson (Editor), Handbook of Nutrient Requirements of Finfish. CRC Press, Boca Raton, FL, USA, pp. 169-179.

Manzi, J. J., 1989. Aquaculture research priorities for the 1990's. *World Aquaculture*, 20(2): 29-32.

New, M. B., 1987. *Feed and Feeding of Fish and Shrimp*. FAO Rome, pp. 275.

New, M. B., 1991. Where will feeds be in the year 2000? Fish Farmer May/June, p. 38-41.

New, M. B. and Csavas, I., 1993. Aquafeeds in Asia - a regional overview. In: M. B. New, A. G. J. Tacon and I. Csavas (Editors) *Farm-made aquafeeds*. FAO, Bangkok, Thailand, p. 1-23.

NRC, 1993. *Nutrient Requirements of Fish*. National Academy Press Washington DC, USA, 114pp.

Quartararo, N., Allan, G. L. and Bell, J. D., 1992. Fish meal substitution in a diet for snapper, *Pagrus auratus*. In: G. L. Allan and W. Dall (Editors), *Proc. Aquaculture Nutrition Workshop, Salamander Bay*, 15-17 April 1991. NSW Fisheries, Brackish Water Fish Culture Research Station, Salamander Bay, Australia, pp. 125-126.

Quartararo, N., Allan, G. L. and Bell, J. D., in press. Substitution of fishmeal in a diet for the carnivorous marine fish, *Pagrus auratus* (Bloch and Schneider) for south eastern Australia. *Asian Fisheries Science*.

Robinson, E. H., 1989. Channel catfish nutrition. *Reviews in Aquatic Sciences*, 1(3): 365-391.

Smith, L. S., 1989. Digestive functions in teleost fishes. In: J. E. Halver (Editor), *Fish Nutrition*. Second Edition. Academic Press, San Diego, Ca, pp. 332-421.

Tacon, A. G. J., 1990. *Standard methods for the nutrition and feeding of farmed fish and shrimp, Vol. 1 The essential nutrients*. Argent Laboratories Press. Redmond, Washington, USA.

Tacon, A. G. J., 1993. Feed ingredients for crustaceans. Natural foods and processed feedstuffs. *FAO Fisheries Circular No 866*, Rome, Italy, 67 pp.

Wee, K. L., 1992. Aquaculture nutrition research in Australia. In: G. L. Allan and W. Dall (Editors), *Proc. Aquaculture Nutrition Workshop, Salamander Bay, 15-17 April 1991*. NSW Fisheries, Brackish Water Fish Culture Research Station, Salamander Bay, Australia, p. 243-244.

Wilson, R. P., 1989. Amino acids and proteins. In: J. E. Halver (Editor), *Fish Nutrition*. Second Edition. Academic Press, San Diego, Ca, pp. 112-151.

Yone, Y., 1975. Nutritional studies of red sea bream. In: K. S. Price Jr., N. N. Show and K. S. Doberly (Editors), *Proc. First Intl. Conf. Aquaculture Nutrition*, Univ. Delaware, Newark, D. E., pp. 39-64.

Cost/Benefit Analysis for Marine Farming Of Snapper

John Kable

Northern Rivers Regional Development Board Inc., 50 Victoria Street, Grafton, NSW, 2460

INTRODUCTION

The purpose of this presentation is to examine the business aspects of marine cultivation of snapper (*Pagrus auratus*). It is necessary to compare the likely costs of the operation and the likely returns in order to judge the worth of the commercial risks involved in the venture.

Basically there are three questions to be addressed when assessing the likely commercial viability of any new business proposal:

- Is there market demand for the product or is it likely to be generated?
- Are the necessary technical skills and equipment available to produce the product?

  and the really important question,

- Is there any money in it?

TAKING THESE IN SEQUENCE - MARKET DEMAND

There is a definite and immediate opportunity to sell 500 tonnes per annum because that much snapper is currently being consumed in NSW after being imported from Western Australia or New Zealand (NZ).

There is the possibility of selling up to another 1000 tonnes at a slightly lower price. If production exceeds that quantity then it is likely that the local price will drop and probably by as much as 30%. Local producers would then be forced to compete for export markets.

The export potential is not easy to assess. Europe has adequate supplies from the Mediterranean area. Japan has huge consumption but also huge production capacity, approaching over capacity, and they already receive imports of wild fish from several countries including NZ which are years ahead of Australia in this industry.

This initial evaluation of the snapper industry will therefore concentrate on the local market, assumed to be 500 - 1000 tonnes per annum.

THE SECOND QUESTION - ABILITY TO PRODUCE

The technical papers presented at this conference assure us that it is feasible to produce snapper in sea cages on some parts of the NSW Coast.

ALL THAT IS LEFT TO DECIDE IS THE THIRD QUESTION - IS THERE ANY MONEY IN IT?

Obviously the production of marketable snapper involves two distinct phases:

- production of fingerlings; and
- grow-out to market-size

These should be thought of as two independent businesses because the skills and the equipment needed are quite different. They will also probably be carried on at separate locations, probably under separate ownerships.

In order for the industry as a whole to be successful it is necessary that each of these phases be financially viable as a stand alone business in its own right.

When examining the hatchery operation it is difficult to determine the true value of a fertilized egg and to nominate a fair price for a healthy fingerling.

Most of the discussion in this workshop is centred on the grow out operation, but unless there is an assured supply of quality fingerlings then the rest of the process cannot happen. It is one thing for the Government to make available the initial supply of fingerlings at an artificially low price in order to kick-start a new industry, but if the long term viability of that industry depends on a continuing supply of fingerlings at subsidised prices then it is most unlikely to proceed. This is an important issue which must be resolved before the industry can be established on a firm footing.

For the purpose of this evaluation it will be assumed that an adequate supply of fingerlings will be available at a price comparable to overseas operations and comparable to prices charged for other species produced in commercial Australian hatcheries.

The difficulty in doing a cost/benefit analysis of an industry at such an early stage of development is that many of the costs are just not known. One can only use intelligent estimates and try to give some indication of the likely accuracy of the estimates as they are introduced.

It is also necessary to make some basic assumptions as to the type of business and the size of the operation. Various potential operators of snapper farming ventures will be contemplating quite different scales of operation and investment. The costs involved will vary considerably with the size of the operation but it is only possible, in this exercise, to look at one specific example. Individual operators will need to adjust the figures to suit their own plans.

Other papers have addressed the issues of the technical skills needed to supervise the farm operation and the need to maintain site security. The size of the operation at any site must therefore be big enough to utilize the skills of the technician full time and to absorb the costs of a skilled technician and a 24 hours/day caretaker. These costs could be shared by several small operations in close proximity.

The specific example chosen for detailed examination is a farm producing 50 tonnes per annum by purchasing juveniles and growing them on to market size (500 gram fish size) in 2 years. This farm would be just big enough to absorb the above costs and yet small enough to be financed by a family business structure.

Certain other basic assumptions need to be made about the operation in order to calculate the costs to set up and operate a farm with this output. We need to estimate the survival rate of fingerlings to market size in order to calculate how many fingerlings are needed at start up. We need to know the conversion ratio for converting food into fish flesh as well as the cost per tonne of the food used in order to calculate the cost of feeding a fish to market size.

The full list of basic assumptions is shown in Table 1.

Table 1: Assumptions about snapper farming in NSW

Production capacity	100 tonnes in 2 years	(50 tonnes/year)
Cost of juveniles	$1 each	(50 cents at best)
Survival to market size	60%	
Food conversion ratio	2:1	
Diet costs	$1200/tonne (average)	($1000 at best)
Time to grow to market size	2 years	
Stocking density at harvest	10 Kg/m^3	

Starting with these assumptions it is now necessary to develop a Business Plan for the venture.

In its simplest form a Business Plan is made up of the answers to five questions as shown in Table 2.

Table 2: Questions to be answered to formulate a Business Plan for snapper farming

1. What are you going to do?
2. How are you going to do it?
3. How much will that cost?
4. Where are you going to get the money?
5. How are you going to repay the money?

We will now address these questions in sequence.

1. What are you going to do?

The plan is to buy fingerlings from a hatchery and then grow them out to market size. They will then be taken to a local processor to be gilled and gutted and finally sold as fresh fish at the Sydney fish markets.

2. How are you going to do it?

The intention is to use circular cages, 20 metres in diameter sited in an estuary close to fish processing facilities. Each cage would hold 17 tonnes of fish at harvest.

3. How much will that cost?

This is of course the most important question and also the one most difficult to answer.

It is necessary to examine in detail the individual costs of the many aspects of start up and operation of the business.

The major cost items at start up are shown in Table 3.

By using fish processing facilities that have already been established for trawler operators it is possible to avoid the cash outlay for that equipment. However fees paid to the contract processor must then be added to the operating costs of the business.

When calculating the costs to operate the business one of the costs often ignored by new operators is the annual depreciation in the value of the equipment being used. Although this does not involve an immediate out of pocket expenditure it is a real cost which must be allowed for when assessing the profitability of the proposed business. As can be seen from Table 4 it is also a significant operating cost.

The wages bill must also be allowed for in full even if much of the work is to be performed by the owner and/or his family. It is unrealistic to claim that family members will work for lower wages unless they are prepared to be locked into a lifetime of hard work at low wages.

Table 3: Major startup costs for snapper farming

Snapper Production	
Grow-out 100 tonnes in 2 years	
Start up costs	
Approvals, licences, EIS etc	$40,000
6 circlular cages	$80,000
Moorings	$10,000
3 nets for each cage and predator nets	$140,000
Boat	$15,000
Wharf facilities, feed storage, harvest equipment	$5,000
Fish pump	$80,000
Fish grading system	$20,000
Net cleaner	$60,000
Auto feeder	$10,000
	_____
Total	$460,000
Shore based refrigerator cool rooms	?
Fork lift	?
Gill and gut facilities	?

Some wages could be saved by sharing the costs of the technician and the caretaker with other operators of neighbouring fish farms.

The likely wage costs for our specific example are shown in Table 5.

Table 4: Annual Depreciation Costs

		COST
Cages, boat, wharf equipment		
Fish pump, grading equipment		
Net cleaner, auto feeder	$270,000 at 10%	27,000
Nets of all types		
Mooring	$150,000 at 20%	30,000
Total		$57,000

Table 5: Annual Wages Costs

Manager	45,000
Technician	35,000
Feeder/labourer	25,000
Caretaker/labourer	30,000
	$135,000

The total operating costs to produce 100 tonnes of fish over a 2 year period are summarized in Table 6.

Table 6 : Operating Costs To Produce A Batch Of 100 Tonnes Of Snapper

	COST	
	Probable	***Best***
Purchase 320,000 juveniles	320,000	160,000
Food 200 tonnes	240,000	200,000
Wages (2 years)	270,000	120,000
Maintenance and running costs	14,000	10,000
Depreciation	112,000	112,000
Contract cost to gill and gut	60,000	40,000
Totals	$1,016,000	$642,000

Table 6 shows that it will probably cost more than one million dollars to produce 100 tonnes of fish.

This represents a production cost of $10/Kg of live weight fish.

The likely range of cost fluctuations are shown by the second column in Table 6 which shows the best possible cost estimates for the various items. If all of these could be achieved then the cost of production could be reduced to $6.50/Kg.

As seen from Table 6, the cost of food is a major expense but there is not a lot of potential for cost reductions.

The most significant improvement is likely to come in the reduction of costs for the purchase of fingerlings. This saving could only be achieved by both a reduction in the purchase price per fingerlings and also by an improved survival rate for fingerlings reaching maturity.

The possible reduction in the cost of wages would most likely be achieved by several farms in close proximity sharing the costs of some staff.

It is likely that the cost of production will be approximately $10/Kg in the early years with a gradual improvement towards $6.50/Kg.

Indications are that the likely selling price of fresh fish would probably only be $9.00/Kg. The actual mathematics are worse than that as gilling and gutting reduces the weight of fish to be sold. If production costs are $10/Kg of live fish then it would be necessary to get $11 - $12/Kg at the markets to recover operating costs.

If we refer back to the 5 steps in a Business Plan it is obvious that it will also be necessary to pay interest charges on borrowed funds and then to repay the bank loan.

Obviously it is unlikely that this business would generate sufficient profits to meet all these commitments. It would be necessary to greatly reduce the operating costs and this is not likely to be achieved at the outset. Even if the operation eventually did achieve the best case costs scenario this would only be after years of operating experience.

The risks of financial failure in the early years would be considerable and the venture could not be recommended.

The only other solution to the financial difficulties is to improve the returns from the business ie. get a higher price for the fish.

Exports of processed fish are not likely to be any more financially rewarding, as already discussed. However, high prices are being paid for live fish.

Asian restaurants in Sydney will pay $17 - $18/Kg but that is whilst the fish are in short supply. If snapper became readily available a price of $14.50/Kg is still likely. On this basis the sale of live fish appears to be far more profitable than the sale of processed fresh fish. We will therefore adopt a new business plan to grow the fish to table size, harvest them live and transport them live to Asian style restaurants in Sydney and in other centres of population.

IT IS NOW NECESSARY TO REVISIT TABLE 3 - START UP COSTS.

The new plan still does not involve any gill and gut facilities but there is now a need for handling facilities for live fish

Say +$40,000 → $500,000 total costs for start up.

TAKING A FRESH LOOK AT TABLE 6 - OPERATING COSTS

It is now possible to delete the charge for gilling and gutting (- $60,000) but now add the cost of transport of 100 tonnes of fish and the water that must travel with them

Say +$44,000 → $1,000,000 total or $10/Kg of fish.

The advantage now is that the fish are going to sell for $14.50/Kg and you get to sell the full weight of 100 tonnes of fish to yield $1,450,000 return after 2 years and $1,000,000 in expenses. An apparent annual profit of $225,000.

It would be of benefit to be able to compare these cost predictions with actual operating experience from established fish farms. It is very difficult to get actual cost figures from other countries in a form that allows comparison with what we want to do here in NSW. Considerable confusion is caused by such things as:

- currency fluctuations;
- old data;
- surges in both supply and demand; and,
- different accounting procedures.

The best comparison data available is shown in Table 7.

The cost figures in Table 7 have been recalculated to refer to one single fish.

In Australia the fish will be sold at 500 gram weight whereas in Japan they have been grown out to 1 Kg and that of course introduces another complication.

Table 7: Operating costs ($A) per fish for local sale of live fish

AUSTRALIA 1995			**JAPAN 1990**
500g in 22 months			1kg fish in 27 months
Cost of juvenile	1.60		1.25
food	1.20		10.00
wages	1.35		
depreciation	0.56	1.98	0.63
Maintenance	0.07		
Live transport	0.22		------
Total cost	5.00		11.88
Selling Price	7.25		17.50
Profit per fish	2.25		5.62
Profit/Selling Price	31%		32%

Although Table 7 appears to show good agreement in the total costs, the expected selling price and overall profit margin there are alarming discrepancies in the costs shown for individual items such as food and wages. If we have faith in the set of figures predicted for Australian conditions then it appears as if the growing of snapper in sea cages and then selling them live to local Asian restaurants would be a profitable business.

Instead of producing 100 tonnes every second year it is logical to start with only a half batch and then stagger the operation so that the harvest is 50 tonnes each year.

Can we interpret these figures to mean that this business would cost $500,000 to start up and would show a profit of $225,000 each year after wages? That would imply a period of 3 years to recover the outlay and then a very prosperous lifestyle.

If we think back to the Business Plan, after the question on "What does it cost?"

came "Where will you get the money?"

and "How will you repay the money?"

The obvious answer is through your friendly Bank Manager and he will want to examine both the Business Plan and the Cash Flow Projection. The reason that lending institutions place so much emphasis on cash flow is that only from income can you get the funds to repay interest and loan instalments.

It must be remembered that this business is going to take 2 years after start up before there is anything to sell. This is not like trawling where a fisherman can go out and catch some fish tonight and then sell them tomorrow. With fish farming virtually all of the operating expenses for 2 years have to be paid before there is any income.

This means that although you only need $500,000 for start up equipment, you will outlay another $1,000,000 for operating expenses before any money comes back. During the second year you will owe the bank $1,500,000. A more detailed examination of the cash flow is therefore warranted, as shown in Table 8.

The grossly simplified presentation given in Table 8 shows that the business still represents a good investment but it will be at least 10 years before the business is free of debt. One of the deliberate oversights in this simple treatment is that if the business is earning a profit in excess of $200,000 every year then there should be a provision shown for income tax. Another calculation to treat with caution is the level of interest payments. It has been blandly

Table 8: Cash Flow (in thousands of $A)

Income	**Year 1**	**Year 2**	**Year 3**	**Year 4**
Bank Loan	1000	500	--	--
Sales	--	725	725	725
Total Income	1000	1255	725	725
Expenditure				
Capital Equip	500	--	--	--
Operations	478	500	500	500
Interest	70	105	95	88
Loan Repayment	--	150	100	150
Total Outlay	1048	755	695	738
Final Cash on hand	-48	+452	+482	+469
Bank Debt at year end	1000	1350	1250	1100

stated that in order to borrow $1,500,000 from the bank on a venture of unknown risk then an interest rate of 7% will be offered. The bank may well have other ideas on what represents a suitable interest rate. There has also been no allowance made for such items as:

- administration and office expenses
- power supply to the cages;
- rent for the site;
- licence fees;

- research levies and,
- insurance costs.

Each of these are relatively minor expenses in the overall scale of the project.

I am confident that the major costs shown for set up and for operations are reasonably accurate. I also feel that the expected selling price for the fish is a reasonable estimate.

A figure that does concern me is the assumed yield of 50 tonnes of fish every year, based on the estimate that 60% of fingerlings survive to maturity and they all grow at the expected rate. Actually this venture is like any other type of farming in that there will be good years and there will be bad years. If problems during one year result in a harvest which yields only 20 tonnes of fish to sell then you can ignore the cash flow projection shown in Table 8.

For this reason I am not terribly concerned about the errors and approximations shown in that cash flow.

On the other hand it is quite possible to yield 70 tonnes of fish in one good year and the profit would then increase dramatically.

In brief conclusion, after making allowance for all the estimations and approximations necessary in this analysis I believe that the cultivation of live fish for sale to local restaurants can be made into a viable business.

By the same standards I believe that processing fish for sale here or overseas as fresh gilled and gutted would be a very risky investment.

Barramundi Farming In Australia - Current Status And Future Prospects

Christopher G. Barlow

Freshwater Fisheries and Aquaculture Centre, Queensland Department of Primary Industries, Walkamin, QLD 4872

INTRODUCTION

Developing a new industry is a complex undertaking. If the industry is to succeed it requires a range of critical biological, technical, physical, economic and even social factors to be developed or resolved in a coordinated and directed manner.

In the case of aquaculture, the candidate species needs to possess the biological attributes that make it amenable to intensive, controlled production. Research is required to define husbandry, nutrition and health management procedures and facilities. Investors are required to put up capital in an uncertain environment, and to follow through on the investment in the early years of possible failure and low (or negative) profitability, in the belief that good times are ahead. Support for research and development based on a long-range vision of the potential of the industry to contribute to the nation's economic prosperity is essential, as is a commitment by industry participants to work together to facilitate growth of the industry.

The barramundi farming industry provides an excellent case study of the potential of and problems inherent in aquaculture development in Australia. In this paper I will briefly review the development of the industry to date, and then examine opportunities for further expansion.

HISTORY OF BARRAMUNDI AQUACULTURE

Hatchery production of barramundi or sea bass *Lates calcarifer* fingerlings was achieved for the first time in the early 1970s using eggs stripped from wild spawners in Thailand (Wongsomnuk and Manevonk 1973). By 1975, Thai researchers had successfully produced fry from induced breeding of captive broodstock (Sirikul 1982). The supply of hatchery produced fry facilitated large-scale farming in Thailand, which, coupled with international training programs offered by the Thais, provided the impetus for other countries in the region to investigate hatchery

production of barramundi. Within a decade, hatchery production was achieved in the Philippines (Harvey *et al*. 1985), Taiwan (Lin *et al*. 1985), Singapore (Lim *et al.* 1986) and Malaysia (Ali 1987). Barramundi now forms the basis of well developed farming operations in these countries.

In Australia, detailed work on barramundi culture was instigated in 1983, in two separate projects. The first was a private venture project on development of barramundi hatchery and farming techniques, funded by the Fishing Industry Research Trust Account (FIRTA Project 83/38). This project was conducted in the Cairns-Innisfail region in north Queensland, and led to the formation in 1985 of the publicly listed aquaculture company Sea Hatcheries Ltd. (NL). Concurrently, a second program was conducted by the Queensland Department of Primary Industries (QDPI) at its Cairns and Walkamin laboratories. The initial aims of this work were to investigate controlled breeding and production of fingerlings for stocking freshwater impoundments in north Queensland for recreational fisheries enhancement.

Both the FIRTA and QDPI projects were successful in establishing controlled breeding of barramundi (Heasman *et al*. 1985, MacKinnon 1987a). The resultant supply of fingerlings led to the establishment of grow-out farms in northern Queensland in the late 1980s. About the same time, several private hatcheries commenced operation. The capability of the industry to produce fingerling barramundi was dramatically improved in the early 1990s with the development of larval pond-rearing techniques (Rimmer and Rutledge 1991) and the availability of fertilised eggs from QDPI throughout the year. These advances allowed barramundi farmers to produce their own fingerlings, rather than relying on production by the private hatcheries. In turn, this has resulted in increased output of product for market.

Outside Queensland, the Northern Territory Department of Primary Industry and Fisheries started a program on barramundi aquaculture in 1987. In 1995, six grow-out farms were licensed in the Northern Territory. In South Australia, West Beach Aquaculture Pty Ltd has established a hatchery operation, which provides fingerlings, expertise and facilities to a network of grow-out farms (in 1995, these were located in New South Wales and South Australia). There is also one farm in South Australia producing barramundi in geothermally heated water; it accesses seed stock from farms in north Queensland.

FARMING SYSTEMS

Broodstock Maintenance

Early work on culture techniques for barramundi relied heavily on obtaining fertilised eggs by stripping running-ripe male and female barramundi caught on spawning grounds. This approach is expensive, unreliable, highly seasonal and conflicts with wild stock resource management. It has now been replaced by the development of controlled breeding techniques for captive broodstock. The most reliable and commonly used method is hormone-induced tank spawning, in which the fish spawn naturally following the injection of reproductive hormones (Garrett and Connell 1991). Another, but now outdated, technique is hormonal induction of broodstock followed by manual stripping of semen and ova soon after ovulation. The semen and ova are manually mixed to enable fertilization. This method has been discontinued because of the labour requirement, the difficulties in predicting the time of ovulation, and the fact that fertilization rates are generally not as high as with natural spawning.

Purpose built systems are required for broodstock maintenance. The fish are usually held indoors, in either flow-through or recirculating systems. Barramundi broodfish may be kept in either fresh or salt water but must be placed in salt water prior to the breeding season to enable final gonadal maturation to take place. At the Northern Fisheries Centre, Cairns, barramundi has been bred throughout the year using controlled environment systems to manipulate temperature-photoperiod cycles, thus enabling spawning outside the normal spawning season (Garrett and O'Brien 1994).

Larval-fingerling rearing

Barramundi larvae have a physiological requirement for salt water up to about 8-10 days old (approximately 5-6 mm), but thereafter they have the ability to survive in both salt and fresh water (MacKinnon 1987). Consequently, larval production systems can be entirely salt water based, or salt water followed by fresh water after about 10 days.

Production techniques are broadly classified as either ‘intensive’ or ‘extensive’. Intensive larval rearing involves the culture of larvae at high densities in a controlled environment, such as a

hatchery, where the fish larvae are supplied with prey organisms which are also cultured under controlled conditions (Ruangpanit 1987). The intensive system requires dedicated facilities and a high degree of technological skill. In contrast, extensive larval rearing involves the culture of larvae in a largely uncontrolled environment (a pond) and the culturist has relatively little direct control over factors such as water quality, prey organism density and disease (Rimmer and Rutledge 1991; Rutledge and Rimmer 1991). The intensive technique also requires a higher labour input than the extensive technique.

In south-east Asia barramundi larvae are mostly reared intensively, and it was these larval rearing techniques which were introduced to Australia where they are still used in a few hatcheries, usually where environmental control is required because of geographical location. The QDPI barramundi rearing project originally used the intensive technique for early larval production, but modified it to incorporate a freshwater pond rearing phase for larvae older than 15-20 days. In the early 1990s the intensive system was dropped in favour of extensive rearing in brackishwater ponds for all larval and early juvenile stages. The majority of barramundi fry now produced in northern Australia are produced using extensive larval rearing procedures.

More recently, barramundi farmers have begun using the 'green water' nursery culture technique, which entails the phytoplankton, zooplankton and larval fish being grown together in large (5-20 tonne) tanks (Palmer *et al*. 1992). This system has enabled farmers remote from the sea to produce their own fry in artificial sea water, using fertilised eggs purchased from commercial hatcheries.

Grow-out systems

There are three quite different methods currently used in Australia for growing weaned fingerlings to market size. One is cage culture in estuarine waters. Relatively few companies are using this technique. Cage culture in estuarine or marine waters has advantages over other systems where large-scale production (several hundred tonnes or more per annum) is envisaged. There are, however, problems with biofouling and to a lesser extent predators.

The most common grow-out system used in Australia is pond culture, in either brackish or freshwater. Fish are usually maintained in cages, although nowadays cage culture of fish less

than 120-150 mm total length and free-ranging for larger fish are sometimes combined. Pond rearing of free-ranging fish does not require the labour associated with cage culture, and produces fish with a better appearance and colour (silver rather than dark grey to black). The major disadvantages of these methods are difficulties in stock management and harvesting.

The third method of farming barramundi is intensive production in an indoors, controlled environment building, using underground water (i.e. pathogen free) and a high level of recirculation through biological filters. Examples of this technology have been developed and patented by a South Australian company (West Beach Aquaculture Pty Ltd), which has established plants in South Australia and New South Wales. Because of the controlled environment, it allows for year-round production virtually anywhere that underground water is available. It also avoids the environmental concern associated with release of nutrients to open waterways from pond or cage culture operations.

CURRENT STATUS

Barramundi has proven to be an excellent species for farming: its life cycle has been closed; fingerling production is comparatively simple; it can be easily weaned onto artificial food; it is hardy, amenable to crowding and grows fast; it can be farmed in a range of culture systems (indoors, ponds, cages, salt and freshwater); and it is a well-known, marketable product.

Farmers have developed their knowledge and skills, and have formed their own producer association ... the Australian Barramundi Farmers Association (ABFA). The aim of the ABFA is to represent growers' interests to government and to sponsor activities to promote development of the industry. It also provides an information and marketing support network for members. In addition to the joining fee of $450, the ABFA has voluntarily levied 10¢/kg production on its members to raise funds to support research and development activities, initially in the field of marketing. The first industry-sponsored workshop, on Seafood Handling and Marketing, was held at Barramundi Waters Pty Ltd (the largest barramundi producer in Australia) in November 1995.

Production in 1994/95 was approximately 470 tonne, valued at $4.6 M (Figure 1). Most (estimate 90%) was sold as 400-500 g, whole fish, with the remainder being larger fish for the premium fillet market.

FUTURE PROSPECTS

The barramundi farming industry has passed through the initial establishment phase, and is now poised to move into large-scale production. The industry has the potential to become a major contributor (many 1000s' tonnes p.a.) to Australian aquaculture, but only if two major constraints to industry expansion are overcome.

The first of these is marketing. Increasing the production of plate-sized product beyond 500 tonne, without extensive promotion, will result in a drop in price paid by the wholesalers. As a first step in tackling this problem, the ABFA is planning to undertake promotional work in the near future, as well as diversifying its range of products. Expansion of the local market for plate-sized product is seen as necessary to provide a sufficiently large base outlet while the industry moves to production of larger fish. Production of large (2-3 kg) fish at a competitive price, estimated to be $5-6/kg whole fish, will enable producers to supply the very large domestic market for barramundi fillets. In addition, it will pave the way for export, which will almost certainly be based on large fish. One of the bigger companies has already changed its production strategy to large fish, destined for the export market. Apparently Australia has a competitive advantage in this regard, as Asian producers of farmed barramundi generally do not produce fish larger than 500g, and the Australian product is perceived as ‘clean and green’.

The second major constraint is production costs. Estimates of current *on-farm* production costs vary from about $5.00 to $7.50/kg for plate-sized product. The major on-farm variable cost is food, which accounts for 25-50% of *on-farm* costs (the other major components being wages and electricity). Obviously, research to lower production costs needs to focus on feeds (to reduce the cost and increase its quality) and feeding practices (to reduce wastage and thus increase food conversion efficiency). The QDPI is currently conducting work on barramundi nutrition, through funding provided by the Fisheries Research and Development Corporation.

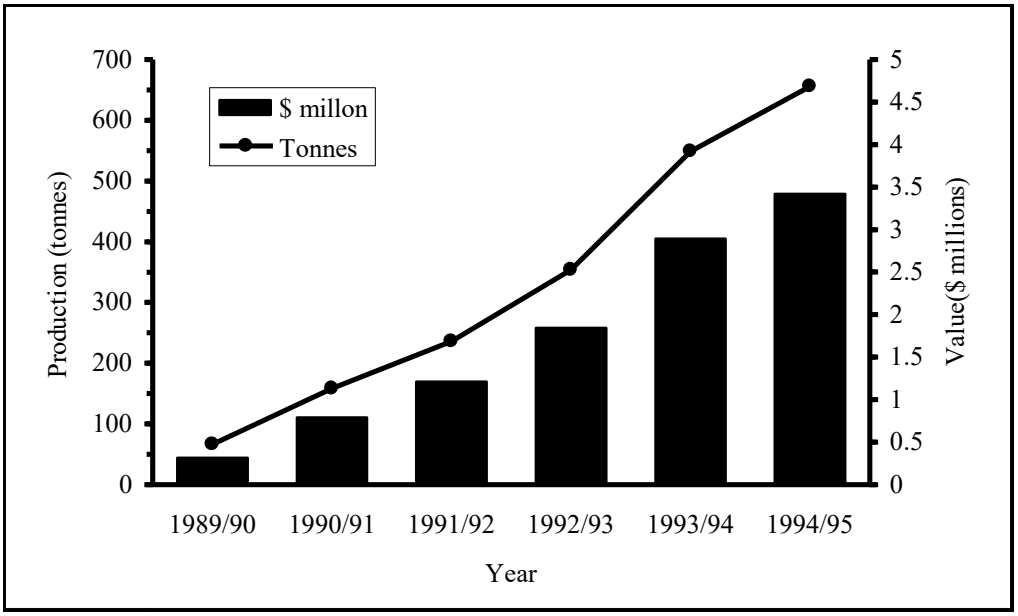


Figure 1: *Production (tonnes) and value ($ millions, farm gate) of farmed barramundi produced in Australia in the period 1989/90 to 1994/95. (The 1994/95 figures are estimates). Information sources for other data are:*

Aquaculture Production Surveys 1989-90, 1990-91, 1991-92. Reports published by Queensland Department of Primary Industries.

Personal communication from:

Dr. C. Shelley, N.T. Department of Primary Industries and Fisheries;

Dr. J. Trendall, West Beach Aquaculture Pty Ltd;

Ms. H. Brayford, W.A. Fisheries Department

Australian Fisheries Statistics 1992; 1994 Aust. Govt. Publishing Service. (The value of Queensland production reported in Australian Fisheries Statistics 1994 was twice the actual value, due to confusion between the value of fillet and the reporting of tonnes live weight).

There are other currently less important constraints which can at times have a significant impact on the development of the industry. One is disruption in the market place arising from an oversupply resulting in a sudden drop in prices. Such disruption can severely impact on profitability, particularly on smaller or highly geared producers. And experience has shown that while prices can drop overnight, it takes many weeks or even months for them to come back to previous levels.

Another longer term problem is the availability of coastal sites for aquaculture. As previously mentioned, barramundi can be farmed in marine, estuarine and fresh water. Most farmed barramundi is currently produced in fresh water, but in accessing export markets in the future we may find that some (e.g., Japan) will take only product reared in salt water. Marine and estuarine sites in Queensland coastal waters suitable for farming barramundi are readily found, but all are subject to multiple and sometimes conflicting uses (e.g., conservation, tourism, commercial and recreational fishing, general public amenity). If the industry is to expand into these areas, it behoves management agencies to plan now so that marine sites are designated for mariculture use.

There is an opportunity for the barramundi farming industry to expand into production of other high value species, using the existing infrastructure on farms. There are several highly esteemed euryhaline species in tropical Australia, for instance mangrove jack *Lutjanus argentimaculatus* and golden snapper *Lutjanus johnii*, which show potential for aquaculture, although researchers first need to define techniques for large scale production of fingerlings. The incorporation of such high value species into the on-farm production portfolio would enable the industry to vary its production strategies in accordance with market requirements, and to decrease its reliance on a single commodity.

SUMMARY

The biology of barramundi is ideally suited to intensive production in salt or fresh water. The barramundi farming industry in Australia has grown rapidly, and in 1994/95 it had a farm gate value of approximately $5 M. Producers have formed their own association, and in conjunction with research agencies have overcome many of the husbandry and health management aspects of barramundi farming. Expansion of the industry is dependant on market development and cost-effective production of larger (2-3 kg) fish for the domestic fillet and export markets.

REFERENCES

Ali, H.M., 1987. Sea bass (*Lates calcarifer*) spawning in tanks in Malaysia. In: J.W. Copland and D.L. Grey (Editors), Management of Wild and Cultured Sea bass/Barramundi (*Lates calcarifer*): *Proceedings of an International Workshop held at Darwin, N.T., Australia*, 24-30 September 1986. *ACIAR Proceedings* No. 20: 129-131.

Garrett, R.N. and Connell, M.R.J. 1991. Induced breeding in barramundi. *Austasia Aquaculture* **5**(8): 10-12.

Garrett, R.N. and O'Brien, J.J. 1994. All-year-round spawning of hatchery barramundi in Australia. *Austasia Aquaculture* **8**(2): 40-42.

Harvey, B., Nacario, J., Crim, L.W., Juario, J.V. and Marte, D.L. 1985. Induced spawning of sea bass, *Lates calcarifer*, and rabbitfish, *Siganus guttatus*, after implantation of pelleted LHRH analogue. *Aquaculture* **47**: 53-59.

Heasman, M.P., Ryall, J.C. and Hockings, I.R. 1985. Development of barramundi (*Lates calcarifer* Bloch) hatchery and farming techniques in Australia, October 1983 - June 1985. *Final Report, FIRTA Project 83/38*.

Lim, L.C., Heng, H.H., and Lee, H.B. 1986 The induced breeding of sea bass *Lates calcarifer* (Bloch) in Singapore. *Singapore Journal of Primary Industries*. **14**: 81-95.

Lin, L.T., Chang, L.C. and Lin, H.H. 1985. On the induced breeding and larval rearing of pond-reared giant perch (*Lates calcarifer* Bloch). *China Fisheries Monthly* **394**: 25-40.

MacKinnon, M.R. 1987. Rearing and growth of larval and juvenile barramundi (*Lates calcarifer*) in Queensland. In: J.W. Copland and D.L. Grey (Editors), Management of Wild and Cultured Sea Bass/Barramundi (*Lates calcarifer*). Proceedings of an International Workshop held at Darwin, N.T., Australia, 24-30, September 1986. *ACIAR Proceedings* No. 20: 148-153.

Palmer, P.J., Burke, J.B., Willett, D.J. and Simpson, R.R. 1992. Development of a low-maintenance technique for rearing barramundi *Lates Calcarifer* (Bloch) larvae. *QDPI Information Series* QI 92036. 19 p.

Rimmer, M. and Rutledge, B. 1991. Extensive rearing of barramundi larvae. *QDPI Information Series* QI91012, 6 p.

Ruangpanit, N. 1987. Developing hatchery techniques for sea bass (*Lates calcarifer*): a review. In: J.W. Copland and D.L. Grey (Editors), Management of Wild and Cultured Sea Bass/Barramundi (*Lates calcarifer*). Proceedings of an International Workshop held at Darwin, N.T., Australia, 24-30 September 1986. *ACIAR Proceedings* No. 20: 132-135.

Rutledge, W.P. and Rimmer, M.A. 1991. Culture of larval sea bass, *Lates calcarifer* (Bloch), in salt water rearing ponds in Queensland, Australia. *Asian Fisheries Science*, **4**: 345-355.

Sirikul, B. 1982. Aquaculture for sea bass in Thailand. FAO/UNDP Training Course on Seabass Spawning and Larval Rearing held at the National Institute for Coastal Aquaculture (NICA), Songkhla, Thailand, 1-20 June 1982. pp 9-10.

Wongsomnuk, S and Manevonk, S., 1973. Results of experiment on artificial breeding and larval rearing of seabass (*Lates calcarifer* Bloch). Songkhla Marine Fisheries Station, Songkhla, Thailand. Contribution No. 5, 20 pp.

Sea Cages and the Environment

Stephen C Battaglene*

NSW Fisheries, Port Stephens Research Centre, Taylors Beach, NSW, 2316

**Present address*: *ICLARM Coastal Aquaculture Centre, PO Box 438, Honiara, Solomon Islands*

INTRODUCTION

Aquaculture has been traditionally considered an environmentally sound practice but increased production, inadequate planning and environmental controls and an increased awareness of the importance of the aquatic environment has resulted in restrictions on the expansion of aquaculture in many countries (Pillay 1992). The culture of fish in sea cages is a form of intensive fish culture in which fish are held at high densities and fed high protein food.

NSW Fisheries has a commitment to the development of a long-term sustainable aquaculture industry and sea cage farming will only be possible if it can be demonstrated that it will have no long-term adverse effect on the environment. There are three main reasons why potential NSW fish farmers need to consider the impact of their operations on the environment. These are:

1 The NSW Fisheries requirement for environmentally responsible aquaculture and ecologically sustainable development.
2 The planning legislation and an approval process which requires an Environmental Impact Statement (EIS).
3 The detrimental effect that environmental degradation may have on the proposed farm's own fish production.

Useful reviews of the environmental impact of sea cages have been undertaken by Woodward (1989), Pillay (1992) and Purser (1992). It is worth noting that to date most studies on the environmental effects of sea cages have been conducted on coldwater salmonid farms. Studies on the impact of marine sea cage farms operating

under conditions similar to those in New South Wales are rare (but see Wu *et al*. 1994).

The negative impacts of cage culture appear to be comparatively small and highly localised (Gowen *et al*. 1991; Pillay 1992). Woodward (1989) points out that fish farming is a self-regulating system and poor husbandry will usually reduce the viability of the farm well before any substantial off-farm effects become evident. Overseas, environmental problems stemming from sea cage farms are usually the result of a cumulative effect of many farms, often located in inappropriate areas and operated with inadequate controls.

In any assessment of the impacts of sea cage culture, one must also point out some of the benefits derived from the activity to the wider community. These are: efficient food production; their use as biological monitors of the estuaries health; the reduced pressure on wild fish stocks; the increased recreational angling opportunity; the education and tourism potential; and employment.

The following paper briefly reviews the potential environmental impacts of sea cages with particular reference to the culture of snapper *Pagrus auratus* in NSW estuaries. NSW Fisheries has identified snapper and mulloway *Argyrosomus hololepidotus* as suitable cage culture candidates in NSW (Battaglene and Bell 1991). Snapper is the same species as the widely cultivated red sea bream in Japan and the environmental conditions suitable for culturing red sea bream are given in Tables 1 and 2.

ENVIRONMENTAL IMPACT OF SEA CAGES

The major environmental impacts associated with sea cage culture are on water quality and bottom sediments. Water quality is affected by increased nutrients (ammonia, phosphorus, nitrogen and total carbon), turbidity and lowered oxygen (Pillay 1992; Seymour and Bergheim 1991). Sediments and benthic fauna are impacted on by solid wastes from fish and uneaten food. Three specific types of environmental impact are of particular interest because they can be used to model the effects of farms they are: hypernutrification, benthic enrichment, and biochemical oxygen demand (Pillay 1992; Gowen *et al.* 1990; Silvert 1992) .

Table 1

Desirable environmental conditions for red sea bream culture in Japan according to Fukusho (1991).

1	suitable water depths (2 times the depth of the cage)
2	moderate tidal current and high water exchange
3	water temperature 12 to 18 ^{0}C
4	locations away from river mouths that supply fresh water and contaminants
5	protected bays and inlets
6	convenient locations for supplies of feeds, harvesting, and markets
7	no red tides

Environmental impacts from sea cages vary with space and time, ranging from between cage effects through farm sites to, in the case of very large developments, regional impacts (Pearson and Rosenberg 1978; Silvert 1992). Impacts also vary with tidal cycles, seasonally and during the grow-out cycle of the fish (Pillay 1992).

Hypernutrification and eutrophication

The productivity of many aquatic systems is limited by the amount of nutrients (particularly nitrogen and phosphorus) available. In marine waters nitrogen is considered to be the most important nutrient limiting marine phytoplankton growth (Dugdale 1967; Howarth 1988). Most nutrients entering our coastal waters result from natural runoff. The amount of nutrients entering estuaries has been increased by agricultural farming, urban development and industry. Fish farms can also contribute significant quantities of both nitrogen and phosphorus (Figure 1). For example, around 15 kg of phosphorus and 85 kg of nitrogen are discharged for each ton of salmon produced in Sweden (Enell and Lof 1983).

Table 2

Physicochemical water quality parameters required for the culture of red sea bream (after Foscarini 1988)

Parameter	
Minimum culture temperature ^{0}C	4
Mean culture temperature	16-17.5
Light (lux)	8000-30 000
Minimum specific gravity	1.023
Optimal specific gravity range	1.025-1.027
Minimum aeration	0.1-0.2
Maximum aeration	2.5-11
pH	7.6-8.6
Chloride (%)	17-18
Minimum dissolved oxygen (DO, ml/l)	1.5
DO in small tanks (ml/l)	4-8
DO in large tanks (ml/l)	4-6
Maximum NO-N (ppm)	0.5

Potentially the greatest environmental impact of sea cage culture comes from the increased nutrients added to the system in the form of fish food. Two major pollution processes can result from the addition of too much food: hypernutrification and eutrophication. Hypernutrification is any increase in the concentration of dissolved

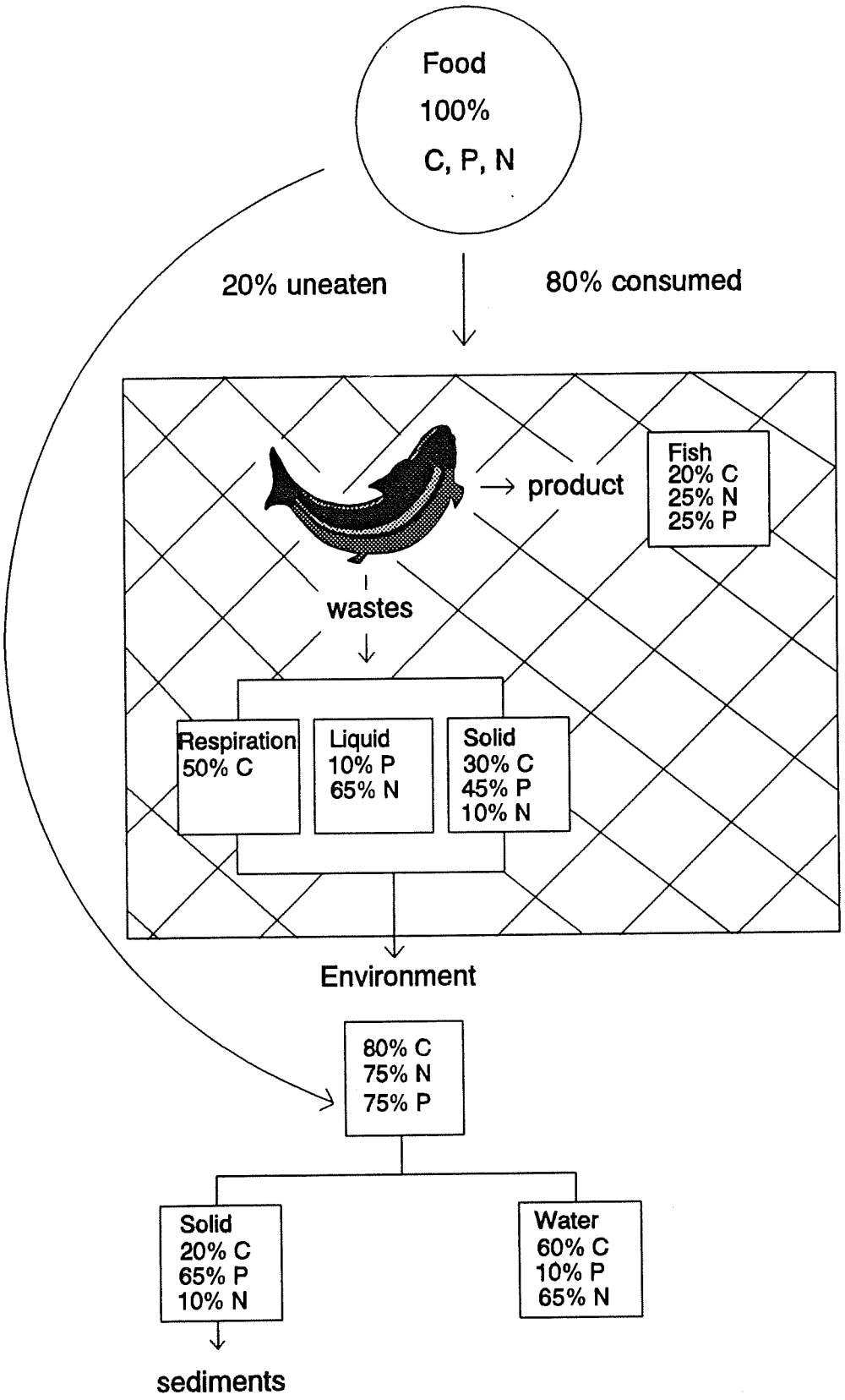


Figure 1 Diagramatic illustration of the approximate flow of carbon (C) phosphorus (P) and nitrogen (N) through a salmonid sea cage. (based on data in Philips and Beveridge 1986, Bergheim et al 1991, Gowen et al 1991)

nutrients in the water and under certain conditions can lead to an increase in phytoplankton growth and productivity termed eutrophication (Pillay 1992).

Eutrophication occurs when the nutrient supply increases to an amount beyond that useable by the normal photosynthetic community in the system (Brodie 1995). The effects of eutrophication can be severe, ultimately leading to massive fish kills and changes in benthic communities (Figure 2). Hypernutrification does not necessarily lead to eutrophication and eutrophication is very dependent on the degree of turbulence and turbidity (Woodward 1989). Phytoplankton growth is influenced by turbulence and turbidity via their effects on light and nutrient availability.

The incidence of 'red tides' and other algal blooms is increasing around the world (Anderson 1994). Aquaculture has been suggested as possibly contributing to the occurrence of algal blooms, however it is difficult to determine the precise influence of fish farming on their occurrence (Takahashi and Fukazawa 1982; Kato *et al.* 1985; Wu *et al.* 1994). The most common causes of eutrophication worldwide are not aquaculture but agriculture, sewage and industry (Brodie 1995).

Massive algal blooms occur naturally in Australia and have been found in areas like Jervis Bay in NSW, which is suitable for sea cage culture. For example, a bloom of a golden-brown non-toxic coccolithophorid algae occurred in December 1992 and was suggested to have resulted from an intrusion of continental-slope water rich in nutrients (Blackburn and Cresswell 1993).

Hypernutrification and eutrophication are therefore potential negative impacts of large scale aquaculture, although much more commonly the result of other environmental degradation. Correct siting of cages, sound husbandry practises and regulations to control the size and number of farms will reduce any possible risk of eutrophication.

Anoxia

Anoxic conditions can sometimes arise below sea cages (both in the water and the sediments) when oxygen is used up faster than it can be provided by diffusion from the atmosphere and/or photosynthetic activity. The usual causes of anoxia are overloading of the aquatic system with oxygen demanding substances such as organic

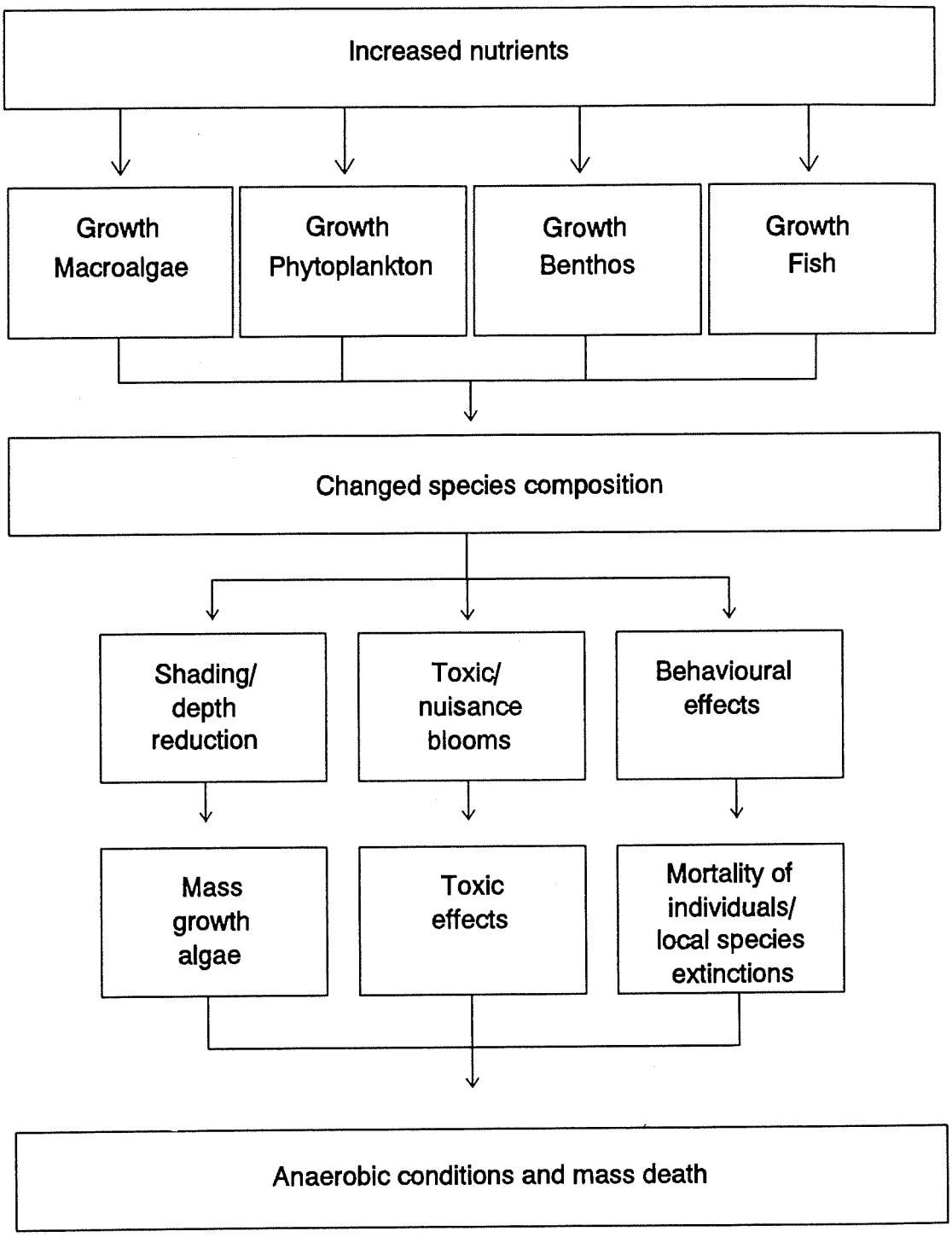


Figure 2 Effects of eutrophication (modified from Grey 1992 & Brodie 1994)

material often combined with stratification of the water column which slows oxygen transport from the atmosphere to the bottom of the water column (Brodie 1995). The biochemical oxygen demand (BOD) of waste material is a useful parameter for evaluating the pollutive strength of wastes and is a measure of the oxygen required by micro-organisms to decompose organic matter (Pillay 1992).

Anoxic/hypoxic conditions can be prevented through correct siting of farms in well flushed locations, by limiting the number of cages and by not overstocking or overfeeding fish. Anoxia/hypoxia, if it occurs, is generally more of a problem for the fish farmer than the environment at large as it reduces fish growth and survival well before it impacts on the wider environment.

Increased sedimentation

Sea cages located in estuaries can cause a build up of sediments by reducing current flow (Frid and Mercer 1989). The current speed within a cage may be half that outside it (Edward and Edelsten 1976). The resulting accumulation of sediment combined with the addition of uneaten food and faeces can result in anoxic conditions, hydrogen sulphide production and reduction in the diversity of benthic fauna (Brown *et al.* 1987; Pillay 1992). The degree to which sedimentation is a problem is related to the: flow dynamics of the estuary; water depth; tidal flow; silt load; location of cages; number and type of cages; and nets used. In general, it is recommended that cages be placed perpendicular to a current (Loland 1993). Where this is not possible the cages should be spread over the whole lease area, the density of fish should be kept as low as is economically possible and the sea cages regularly rotated within the site.

The loading of the sediment beneath a fish farm is therefore dependent on many factors but studies have shown it is likely to significantly affect relatively small areas usually less than 1 sq km of sea bed around the farm (Gowen and Bradbury 1987). For example, organic pollution effects of salmon farming are confined to a small area of seabed directly around the sea cages (Brown *et al.* 1987). It is recommended that farms only be sited over fine sediment if rotation of leases is possible (Lumb 1989).

The sea cages in Botany Bay where experimental research is being conducted by NSW Fisheries were located over predominantly sand substrate (Quartararo 1996).

Changes in bottom flora and fauna

Changes in the chemical conditions of the substrate occur with increased sedimentation and decomposition of organic matter. Sulphate reduction can under very high organic enrichment lead to the release of hydrogen sulphide gas. Changes in the biota below sea cages also occurs over time with the accumulation of sediment, faeces and uneaten food. Aerobic microbes become less prevalent as the oxygen demand increases and conditions become hypoxic and then anoxic. Degradation of organic matter follows a sequential pathway starting with aerobic oxidation, followed by nitrogen reduction, sulphate reduction, fermentation and production of methane (Figure 3)(Morris 1983). A useful overview of the chemical process involved and the effects of organic loading below sea cages is given by Woodward (1989) and Bergheim *et al.* (1991). Although once again it must be stressed that most studies are of salmonid farms in cold-temperate waters.

The first sign of ecological changes in the benthic communities below sea cages is the appearance of opportunistic species like polychaete worms (Bergheim *et al.* 1991). Constant deposition of large amounts of waste can create azoic zones below sea cages which are devoid of macrobenthic organisms (Pillay 1992). Species like capitellid polychaetes and "cobweb-like" bacteria then tend to proliferate under cages (Brown *et al.* 1987; Tsutsumi *et al.* 1991; Purser 1992).

The amount of organic matter that settles below a sea cage is usually significantly greater directly below the cage than a few metres away (Brown *et al.* 1987; Bergheim *et al.*. 1991). In Norway this can result in a series of zones extending out from the farm. The inner area is the azoic zone (0-0.5 m deposition) usually confined to < 5m from the cage, followed by the opportunistic species zone and then a biostimulated zone rich in macrofauna and species diversity (Bergheim *et al.* 1991). Depending on the location of the farm and farming practises the organic enrichment is usually confined to 60-80 m around the farm (Bergheim *et al.* 1991). While the process of

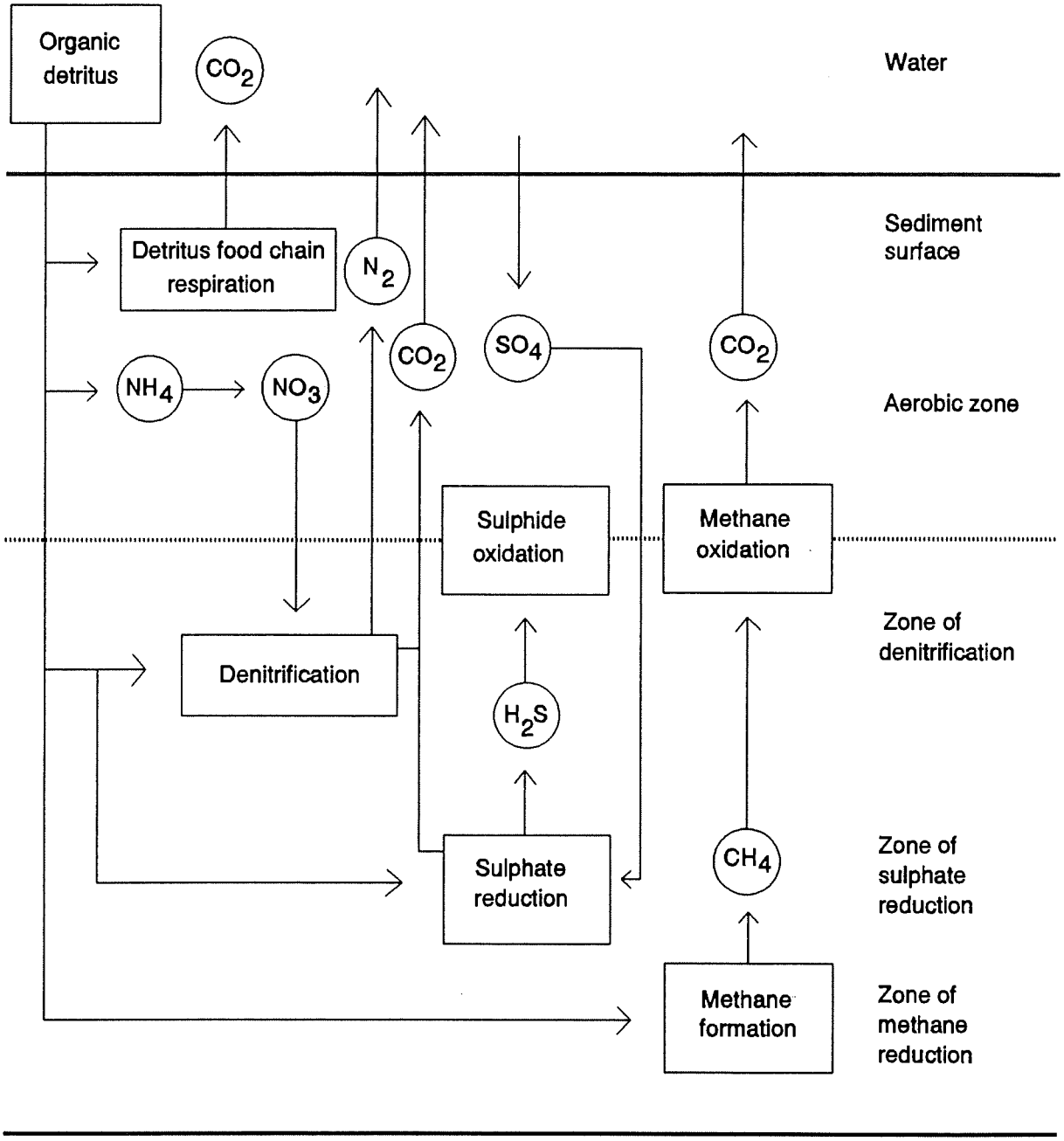


Figure 3 A flow diagram showing the fate of organic detritus in an aquatic sediment (after Gowen et al., 1991)

organic enrichment can be rapid it appears to take anything up to several years for sites to return to "normal" following the cessation of farming (Gowen *et al.* 1991).

The rotation of cage culture sites is one way in which the negative impacts of sedimentation and organic matter deposition can be controlled. How often and for how long a site needs to be 'rested' is dependent primarily on the amount and type of food being used and the physical characteristics of the site. There are very few scientific studies examining the desirability and optimisation of site rotation (Purser 1992). Clearly, having alternative culture sites is an advantage but further research is required to determine how best to minimise the long-term environmental impact of sea cages through cage and site rotation.

A pilot-scale monitoring of the sea cages in Botany Bay by the NSW Environmental Protection Authority (EPA) showed that they were not generating high nutrient loads and levels of all nutrients were always below levels recommended by ANZECC (1992). The study suggested that the cages were having 'a small localised effect' on nutrients in the water column and some species of algae and fauna (EPA 1995). In addition, although the cages are only 1 m off the bottom at mean low water, sedimentation and benthic fauna did not appear to be significantly different at the cages compared to control sites. These results are encouraging for potential farms but it must be remembered that the scale of environmental impact is dependent primarily on the size of a farm and that localised eutrophication and sedimentation would be expected only in large farms in poorly flushed locations (Gowen *et al.* 1991; EPA 1995).

Pathogenic bacteria and parasites

Sediment bacteria and bacteria pathogenic to fish have the ability to rapidly become resistant to antibiotics (Husevag *et al.* 1991; Nygaard *et al.* 1992). Antibacterial agents are known to persist in the sediment below sea cages for long periods of time eventually leading to the selection of drug-resistant strains (Jacobsen and Berglind 1988; Samuelsen 1989; Nygaard *et al.* 1992; Coyne *et al.* 1994; Hektoen *et al.* 1995). In addition, some antibacterial agents e.g. oxytetracycline have been shown to enhance development of anaerobic conditions and are relatively stable in anoxic environments

(Jacobsen and Berglind 1988). Poorly sited farms compound the problem by producing anoxic sediments which produce methane gas bubbles that transport the drug resistant bacteria back to the fish and re-infection can occur as soon as three weeks after treatment (Nygaard *et al.* 1992).

Alternatively, some studies have suggested that at well sited farms the long-term build-up of resistant bacteria does not occur below cages and that the majority of antibiotics do not necessarily reach the sediment (Coyne *et al.* 1994; Kerry *et al.* 1994).

The development of antibiotic resistant pathogens represents a major threat to some aquaculture industries e.g. the pollution from ponds and oxytetracycline resistant bacteria in south-east Asia has seriously reduced shrimp production (Macintosh and Phillips 1992). Ultimately, the use of antibiotics does not solve disease problems and the underlying causes need to be addressed (e.g. stocking density, inappropriate cage site selection etc.). Vaccines have been developed for some diseases and are routinely used in the production of hatchery fish in Japan and some parts of Europe (Matsuyama *et al.* 1992; Newman 1993; Magarinos *et al.* 1994 ; Tozarzo *et al.* 1995). The use of vaccines will probably increase when they can be delivered in the diets of fish (Raison 1995).

Translocation and transfer of fish

Cultured fish may escape during predator attacks, storms, floods, grading, harvesting and vandalism (Purser 1992). The escape of cultured fish to the wild is likely and for cage cultured salmonids in Britain has been estimated to be as high as 15% of all farmed fish (Mills 1989). Some 5 000 juvenile snapper were lost to vandalism from the sea cages at Botany Bay during the first three years of operation (Quartararo 1996).

Cage cultured fish can be very different to those occurring in the wild, both in their genetic material and their behaviour. It is therefore important to consider the impact that the cultured fish may have when they escape and how these impacts can be lessened. The ability of cultured fish to compete with, replace, or interbred and have a genetic impact on the gene pool of a local population, needs to be considered as does

the possibility of disease transmission (Iwama 1991; Sako 1995). In Japan, red sea bream juveniles are imported from Hong Kong, China and Taiwan and new diseases have been introduced with these fish (Sako 1995).

Obviously the use of native species derived from local stocks is a wise precaution and overcomes many of the potential difficulties. However, with successive generations of hatchery produced fish the genetic differences between wild and cultured fish increase (Pillay 1992). This is particularly the case if a selective breeding program is conducted or if fish are genetically engineered e.g. polyploid fish or transgenic fish.

Some stock discrimination of snapper (MacDonald 1982) and mulloway (Black and Dixon 1992) indicates that significant genetic differences exist between stocks, particularly those from eastern and western Australia. In addition, there already appears to be inadvertent selection for stress resistance in the first generation of hatchery produced snapper by NSW Fisheries (Cleary 1995).

There is presently insufficient information to assess the risks of release of genetic material on snapper and mulloway stocks and of disease transmission. However, it is worth noting that snapper in Japan have been cultured and released into the wild for over thirty years (Foscarini 1988), without any apparent ill effects. As Pillay (1992) points out "even though the possibility of transmission of pathogenic infections from diseased farmed fish to wild fish has been suggested, there appears to be no evidence of it having occurred".

Sea cages also attract native fish by offering cover, natural food (fouling on nets etc.) and artificial food (pellets). Studies have shown increases in the distribution and abundance of fish around sea cages (Iwama 1991). At Botany Bay the sea cages attracted large numbers of apparently resident species such as yellow finned bream *Acanthopagrus australis* which could be seen feeding on food washed out of the cages. These fish were consequently targeted by recreational anglers who often moored in the near vicinity of the cages.

Effects on other animals

According to Pillay (1992) the impact of aquaculture on birds and aquatic animals has not been adequately studied. There are the obvious problems with predators such as seals, sharks and cormorants feeding on caged fish or birds stealing food intended for fish and how to control them. However, there may also be more subtle effects e.g. on breeding populations of birds, particularly endangered species. Cages should not be placed in areas containing endangered species if there is significant potential for impacts.

The combined effect of holding fish at high densities and the external addition of food, and the mortality of caged fish attracts predators. Cage nets can be protected by predator exclusion nets often constructed from steel. These protector nets can contribute to current reduction and make net changing more difficult. Seals in Tasmania have been discouraged using air bombs, pressure guns and by trapping (Van Drunen, pers. comm. 1995).

In NSW sharks are more prevalent than seals which makes them potentially more of a problem. Fish farms should not be sited near swimming beaches for obvious reasons. Daily removal of dead fish from sea cages is a necessary management tool to reduce the risks of the smaller bottom dwelling sharks, rays and other predatory fish damaging cages. No fish losses have been recorded from the sea cages in Botany Bay due to fish predators, although cormorant strikes have caused fish losses particularly of mulloway (Quartararo 1996).

Bird nets are used to stop cormorants and other birds gaining access to the fish. However, the aggregation of gulls and other sea birds can be undesirable because of the loss of food, increased noise, smell, and disease risks. Cages and associated mooring systems have also been suggested as a potential navigation problem for migrating whales and dugongs, although the siting of cages in protected bays and estuaries vastly diminishes the potential hazard.

Chemicals

There are currently very few chemicals registered for aquaculture use. However, antibiotics, biocides, antifoulants, disinfectants, hormones and anaesthetics are all used to varying degrees in sea cage culture. The direct application of chemicals on fish in sea cages is not often used because of the problems with containment. It is far more common for treatments to be fed to the fish in specially formulated therapeutic diets. However, even when incorporated in the food much of the chemicals can still end up in the environment. For example, only 20 to 30 % of antibiotics administered in food is taken up by the fish because of reduced feeding by sick fish and the unpalatability of medicated food (Hustvedt *et al.* 1991). The remaining 70-80% ends up in the environment (Samuelsen 1989).

Bath treatments of formalin or freshwater can be used in some cases to treat parasitic diseases. In larger cages (e.g. salmonid cages in Tasmania) treatment is effected by using fish pumps to transfer fish into treatment baths. In smaller cages such as those we have in Botany Bay it is practical to enclose the netcage in a bag made of *Tarpol* for the duration of the treatment (Quartararo 1996). These techniques can be used with pesticides such as dichlorvos based Neguvon but the release of contaminated waters into the environment creates a more serious problem than that with freshwater or formalin (which is rapidly degraded). Pesticides are highly toxic to many invertebrates at very low levels (Pillay 1992).

Antibiotics are often used to treat bacterial diseases and are available in some commercial diets. They can be very important in getting the first few fish crops through to market. Historically, the use of antibiotics is common place during the development phase of a new industry and becomes less frequently used as improvements are made to vaccines, fish handling and husbandry techniques. For example, in Norway in their huge salmon farming industry the use of antibacterial agents reached a peak in 1987 of 47 000 kg, dropping to 8000 kg in 1993 (Hektoen *et al.* 1995) and almost zero in 1995 despite increasing production.

Commonly used antibiotics to control bacterial diseases in farmed fish include oxytetracycline and the quinolones, oxolinic acid and flumequine (Hektoen *et al.* 1995). The use of antibiotics to treat snapper in the seacages at Botany Bay is

described by Quartararo (1996). However, the use of antibiotics is becoming highly controversial and continued reliance on their long-term use should be discouraged.

For some chemicals there is a withdrawal period after administration in which the fish can not be marketed. There is an increasing awareness by consumers of the residual levels of chemicals in aquaculture products and strict limits are being enforced in the export markets to many countries (O'Sullivan 1995). The siting of cages in areas subjected to large amounts of agricultural runoff and/or industrial or mining areas are therefore a potential hazard because of the risk of increased chemical levels e.g. heavy metal contamination.

The fouling of nets is a major consideration in the management of most cage farms. The natural accumulation of fouling organisms reduces current flow through the cage and can affect fish health by reducing water quality (Hodson 1995). Antifouling can be applied to cages or the fouling physically removed *in situ* or by net rotation (Hodson and Lewis 1995). Nets can be washed in net machines as is practised in Tasmania or allowed to dry and then the fouling physically removed. Care must be exercised to ensure the waste water from washing machines is disposed of in an environmentally favourable manner. Antifouling agents containing tributyl tin (TBT) are banned in NSW because they are highly toxic to shellfish and other animals. Research is currently being undertaken within the Aquaculture CRC to develop new and more environmentally acceptable antifouling strategies including the use of foul-inhibiting polymers (Christov *et al.* 1995; de Nys 1995).

Hormones and anaesthetics are routinely used in hatcheries particularly with broodstock but not on sea cage cultured fish. There does not appear to be any risk with the use of these products as a human health hazard (Pillay 1992). The use of steroids, transgenic fish and growth hormones is not commercially practised in Australian fish aquaculture.

Conflicts with recreation, navigation, scenic beauty

Sea cages impact on humans when they are sited in estuaries that are heavily used for human habitation and recreation. Many suitable cage culture sites are already used for

other purposes and by other users. For example, as navigation channels, safe boat moorings, sailing courses, wharves and by recreational and commercial fishermen. Conflicts in these areas can generally be avoided by careful planning and site selection. For example, we overcame many of these concerns by siting the snapper grow-out cages next to the Ampol (formerly Caltex) refinery wharf in Botany Bay. The need for a shore based facility and the 24 h nature of sea cage operations generally make them incompatible with most residential areas. Most planning authorities stipulate minimum distances from farms (see Liszka 1996 for NSW Fisheries requirements).

Conflicts of a human nature are often not environmentally damaging as for example the other factors discussed above but they are as important to successfully obtaining permission to operate a farm. Guidelines assisting in the correct siting and operation of farms in Tasmania, Scotland and New Zealand are given by Woodward (1989).

DETERMINING FACTORS FOR FARM EFFLUENT

Fish do not pollute, feed and feeding pollute (Cho *et al.* 1991). Three key factors influence the impact of nutrients on the environment through the addition of food. They are: the type of food used; the method of feeding; and most importantly the amount of food used.

Feed composition and type

The development of diets for snapper is discussed in Allan and Quartararo (1996) but briefly, the main types of feed used in sea cage farms are trash fish, semi-moist feeds and dry feeds. In the more advanced countries most farms now operate using dry feeds which are pelletised (compressed or extruded) and generally less polluting than trash fish (Wu *et al.* 1994). For example, in Norway 95% of the food used to farm salmon is pelletised (Bergheim *et al.* 1991) and cultured red sea bream in Japan which were traditionally fed on raw fish are now increasingly being fed on dry pelleted diets (Foscarini 1988; Murai 1991). In Japan this change in the type of food used has resulted from diminished supplies of raw fish, and a realisation that earlier feeding

practises were polluting and nutritionally inadequate (Foscarini 1988; Fukusho 1991; Murai 1991).

One of the advantages of using highly processed feeds, which have been subjected to high temperatures, is the reduced likelihood of introducing diseases. The farming industry in South Australia, for example, has used frozen pilchards to feed tuna , but the possibility of a link (as yet unproved) between imported pilchards and the recent large-scale pilchard kills, combined with the high costs, poor FCR and polluting nature of feeding pilchards is seeing the introduction of artificial diets (van Barneveld *et al.* 1995; Carter 1995).

It is therefore highly likely that any new sea cage farm in NSW will use an extruded dry diet (Allan and Quartararo 1996). Extruded diets have environmental as well as commercial advantages over compressed diets in having lower dust levels, greater stability and slower sinking speeds. Extruded diets can also have a higher energy concentration through increased fat content (Bergheim *et al.* 1991).

Research efforts to reduce pollution from fish feed have focused on improving food conversion, reducing protein levels, optimising protein:energy ratios and using non-protein energy sources (Alsted 1991; Kaushik and Cowey 1991). In the salmonid industry high energy diets have been used to improve feed conversion usually in association with lower content but higher quality protein (Johnsen and Wandsvik 1991). The use of these diets can result in a decrease in organic matter pollution and phosphorous and nitrogen discharge (Johnsen and Wandsvik 1991). The discharge of dissolved phosphorus can also be reduced by selecting fish meal with a low content of water soluble phosphorus, using ingredients with high phosphorus bioavailability, and using exogenous enzymes to improve the uptake of phosphorus (Alsted 1991, Lall 1991).

Farmers also need to take care in the storage and handling of feeds, for no matter how good the diet it is irrelevant if the feed is allowed to go mouldy, lose essential vitamins and nutrients or disintegrate. Poor food and feeding practises can lead to

increased pollution through increased waste, poor FCR and ill-health of fish leading to the use of chemicals.

Feeding

One of the main ways in which food can pollute the environment is when it passes through the sea cage uneaten. Food can remain uneaten either because it is unavailable to the fish (e.g. because of strong currents, rapidly sinking diets, floating diets blown away, incorrect size *etc*.), unpalatable (e.g. lacking attractants, rancid, too hard) or overfed. Studies have shown that between 5 and 40 % of salmonid food is uneaten (Philips and Beveridge 1986), and 25 to 30 % is excreted as faeces (Butz and vens-Cappell 1982; Beveridge 1984). Studies also suggest that 50% of the pollution loading from Norwegian salmonid farms is caused by uneaten food (Bergheim *et al.* 1991).

Optimal feeding strategies are very important in reducing food wastage. Frequent feeding is often recommended both as a way to improve food conversion efficiency but also because it reduces ammonia excretion (Kaushik and Cowey 1991). Hand feeding gives farmers instant information on fish behaviour, reduces food loss and helps in the early detection of diseases. However, it can be impractical on large farms and limits the number of times fish are fed. Automatic feeders are becoming more common, particularly during the early rearing of juveniles like snapper which need to be fed regularly to reduce aggression.

Some new systems are also being developed that detect the amount of uneaten food and control the rate of feeding. In addition, there have also been systems designed to catch uneaten food and faeces and pump the waste to holding tanks (Bergheim *et al.* 1991). Some automatic systems decrease the frequency of feeding when uneaten food is detected beneath the cage and increase feeding when food is not detected.

Stocking density

The degree to which sea cage farms will impact on the environment is very much related to the number of farms that will be licensed to operate in any location and the

amount of fish cultivated at each farm which will depend on the number of cages, and the density of fish cultivated in each cage. The number of farms is not an issue in NSW at this stage as there are no farms operating but will eventually be determined from monitoring the impact of pilot scale projects and the first licensed farms.

From overseas studies it appears that the final stocking density in sea cages should not exceed 10 kg/m^3, at most sites, to avoid environmental problems. However, the final determination of the carrying capacity of any individual farm will be closely linked to the choice of site, particularly the amount of current and flushing, the size of individual cages and the distance between cages. For example, red sea bream grow best at culture densities of 3 kg/m^3, the Japanese authorities recommend 7 kg/m^3 but most farms operate at densities of over 10 kg/m^3 and some as high as 30 kg/m^3 (Foscarini 1988; Fukusho 1991). A total production limit of 40 to 50 tonnes per ha is applied in some areas of Japan and open areas to sea cage ratios are typically set at 10-15 open to 1 sea cage (Foscarini 1988; Woodward 1989; Battaglene, unpublished 1992).

In Japan, the government encourages small scale farm developments. It is unlikely that small farms will be economically viable in NSW because of security and economies of scale. The Japanese have also had difficulties managing the large number of small farms both to control pollution and quality of fish produced (Murai 1991).

In Norway maximum cage volume was 4 000 m^3 and this could be doubled when farming skill was demonstrated (Woodward 1989). Staged developments are more likely to be approved in NSW particularly when associated with monitoring programs. In Scotland farms are limited to a maximum biomass at any one time of 70 tonnes per farm (Stanley, pers. comm. 1995). No biomass limits are currently being considered in NSW.

ASSESSMENT OF IMPACTS

Studies on the environmental impact of sea cage farms in Australia are very limited (Ritz *et al.* 1989; Woodward *et al.* 1992). However, the salmonid industry in Tasmania is now recognising the importance of environmental assessment and is developing techniques for monitoring the environment, particularly marine benthos (Macleod 1995). Similarly a number of studies investigating the environmental impact of tuna cages in South Australia are currently underway or in the process of being published (Purser, pers. comm. 1995).

Before any farm begins to operate in NSW it will be required to make an environmental assessment of the potential impact it may have on the environment. This is the process of providing an Environmental Impact Statement (EIS) and the requirements for EIS's, licensing and operating sea cage farms in NSW are outlined by Liszka (1996). The environmental impact of any individual farm will largely be determined by its location and the factors that need to be considered in site selection are outlined in Ogburn (1996).

According to Environmental Protection Authority guidelines a full description of the environment is needed and identification of the range and nature of likely environmental interactions, and analysis of the scale and significance of interactions (Staveley 1985). However, assessment of environmental impact can be ambiguous and the approach needed depends on the questions asked and the power of the analysis to detect impacts (Fairweather 1991; Lincoln Smith 1991). This is an area of science that is changing rapidly and requires considerable skill and expertise. Readers interested in this area are referred to Constable (1991), Lincoln Smith (1991) and Underwood (1991).

Some of the general principles are simple. It is important to assess the biological characteristics of a site before a farm is operational. This baseline information can then be used to assess future changes in the environment. There will also be a requirement for continued monitoring of control sites and areas within the farm during its operational life to assess its impact on the environment and other changes

occurring independently of the fish farm. The choice of control sites and sampling frequency is particularly critical (Underwood 1991).

The regulation of aquaculture and coastal zone management in Australia is generally the responsibility of the State and Local Governments (Anutha and O'Sullivan 1994). ANZECC (1992) makes recommendations on maximum levels of Australian water quality parameters. However, there are currently no detailed guidelines for prospective fish farmers to follow when assessing the impact of sea cage culture in NSW. The type of environmental data that needs to be collected to assess a potential sea cage site for salmonid culture in Scotland is given in Table 3.

As a guide to the types of monitoring required in NSW the EPA (1994) has provided a proposed draft monitoring program to document the impact of sea cage farms on the environment. EPA (1994) has suggested three main areas of study: water quality, sediment analysis and ecological impacts (Table 4). Each area to be monitored at two spatial scales (small: pollution gradient and large: the farm and control sites) and two temporal scales (seasonal and daily). The sampling design involves a four factor design (nested) (estuaries, sites (nested within estuaries), pollution gradient, time (seasonal and daily) analysed with an asymmetrical ANOVA (EPA 1994).

The above assessment method is the traditional chemical and limnological approach and is complicated and expensive for potential fish farmers. It will, however, remain the bench mark for all EIS's evaluating farm impacts. An alternative ' biological method of predicting aquacultural waste output' (BMPAWO) has been suggested as simple, economic and accurate (Cho *et al.* 1991) and may have a role to play when the industry becomes more established.

The BMPAWO model is based on using estimates of feed composition and consumption, fish production and water outflow (Cho *et al.* 1991). Its major advantage over the more traditional approach is that it focuses on the source of the pollution and does not promote "dilution as the solution" (Cho *et al.* 1991). Therefore instead of setting limits on the allowable levels of pollutants in the environment

Table 3

The following table lists environmental data that needs to be collected for farming applications in Scotland. The information is taken from the Clyde River Purification Board guidelines and was kindly provided by Dr Simon Stanley of the Marine Environment Branch, Department of Primary Industry and Fisheries in Tasmania. It provides a indication of the type of information required to assess a farming site from the environmental perspective.

Hydrography

water depth

contour map of site bottom

tidal current measurement (surface, mid-water and bottom)

wind speed and direction

wave height

Sediment and biological data

sediment samples within and outside proposed farm

(minimum sediment sample 0.025 m^2 using Craib or Millbrink corers)

redox potential (Eh)

organic carbon

colour, size and texture of sediment

fauna samples taken using a van Veen or Day grab

identification of animals in major taxonomic groups

Water samples (monthly)

dissolved oxygen

temperature

salinity

ammonia

pH

turbidity

(ANZECC 1992) it provides specifications for food (e.g. DE 20MJ/kg, DP 22 g/MJ DE, total P 8 g/kg, expected feed efficiency 1.2) and estimated wastes per kg of fish produced (e.g. total solids< 190g, N solid <6g, N soluble <33g, P solid<3g, P soluble <1.5g, fines <1%) (Cho *et al.* 1991).

MANAGEMENT OF IMPACTS

Throughout this paper there have been suggestions of ways to minimise the environmental impacts of sea cages. The following list summarises (but does not prioritise) the main ways that the impacts of sea cages can be lessened:

- Correct siting of farms particularly in relation to depth and current (see Ogburn 1996)
- Use of isolated areas (few available in NSW)
- Using offshore cages. In Japan they are now experimenting with offshore cages in Kumamoto and Ehime prefectures (Murai 1991)
- Intelligent feeding (hand or automatic)
- Using dry pellets not trash fish
- Not overstocking (<10 kg/m^3 at harvest)
- Using high energy pellets low in phosphorus (or with high P bio-availability)
- Waste removal (still essentially experimental)
- Polyculture (growing algae near cages can reduce levels of nutrients, (Murai 1991))
- Use of non-persistent chemicals e.g. formalin or freshwater rather than pesticides
- Use of vaccines instead of antibiotics (Sako 1995)
- Improved husbandry practises
- Regulation (Government and self-regulation through farming associations, (Lizska 1996)
- Monitoring of impacts (assist in knowing when to rotate sites, lower densities etc.)
- Rotation of sea cage sites

Table 4

Proposed environmental monitoring parameters for sea cage assessment (after EPA draft Aquaculture monitoring 1994)

Water Quality
The following measurements would be made in the water column at farm and control sites.

Water circulation/currents
Nutrients (TKN, NOx, NH3, TP)
DO
SS/Turbidity
Fluorometry
Temperature
Salinity
Conductivity
pH
Chlorophyll a

Sediments
The following measurements would be made in bottom sediments at farm and control sites.

Nutrients (as above plus TOC)
SOD
Chemicals/drugs
Redox potentials
Sedimentation
Mass sediments
Grain size

Ecological impacts
The distribution and abundance of the following organisms and habitats would be assessed at farm and control sites.

Distribution and abundance of benthic organisms
Type and cover of macroalgae, sea grass, macroinvertebrates and epiphytes
Algal blooms
Fish species associated with cages
Assessment of antibiotic and copper concentrations in fish

SUMMARY

This paper provides only a brief summary of the ways in which sea cage culture can impact on the environment. On researching the paper I was surprised by the lack of relevant information pertaining to snapper culture, particularly given the large-scale production in Japan. It will therefore be important that all proposals for sea cages in NSW make the point that we are in many cases making educated guesses about the environmental impacts.

Overseas studies have shown environmental impacts of sea cages to include: increased sedimentation; changes in bottom flora and fauna; possible nutrification and eutrophication of surrounding waters; increased levels of chemicals; translocation of fish; and effects on birds and aquatic animals. The degree to which these factors can be mitigated against is dependent on the physical characteristics of the site and husbandry practices. The small number of farm sites and the relatively small size of proposed farms by international standards should ensure that the impact of cage culture in NSW is minimal.

Prospective farms should be aware that they will have to: 1) commission EIS's to obtain permits; 2) monitor the environment carefully during the life of the farm; 3) take a precautionary approach to the establishment of large farms and increase the carrying capacity gradually over a number of years; and 4) have a number of sites available for rotating the cages.

Finally, the evidence to date strongly indicates that sea cage farming does not have to be environmentally damaging. Indeed, good planning, siting and operation of sea cages is feasible in NSW without prohibitive environmental damage or monitoring costs.

REFERENCES

Allan, G. L. and Quartararo N., 1996. Developing diets for snapper. In: N. Quartararo (Editor), *Proceedings of the Marine Finfish Farming Workshop, 23 June 1995, Cronulla, NSW*. NSW Fisheries Research Institute, Cronulla, NSW, pp.71-94.

Alsted, N. S., 1991. Studies on the reduction of discharges from fish farms by modification of the diet. p. 77-89. In: C. B. Cowey and C. Y. Cho (eds.). Nutritional Strategies and Aquaculture Waste. *Proceedings of the First International Symposium on Nutritional Strategies in Management of Aquaculture Waste*. University of Guelph, Guelph, Ontario, Canada, 1990. 275 p.

Anderson, D. W., 1994. Red Tides, *Scientific American*, August, pp. 52-58.

ANZECC, 1992. Australian Water Quality Guidelines for Fresh and Marine Waters. Australia.

Anutha, K. and O'Sullivan, D., 1994. Aquaculture and Coastal Zone Management in Australia and New Zealand. *An Aquaculture Sourcebook publication*; Turtle Press, Australia. 82 pp.

Battaglene, S. C. and Bell, J. D., 1991. Aquaculture prospects for marine fish in New South Wales, *Fishnote DF/6 NSW Agriculture & Fisheries*, Sydney.

Beveridge, M. C. M., 1984. Cage and pen fish farming. Carrying capacity models and environmental impact. *FAO Fish. Tech. Paper 255*, 131 pp.

Bergheim, A., Aabel, J. P. and Seymour, E. A., 1991. Past and present approaches to aquaculture waste management in Norway net pen operations. p. 117-136. In: C. B. Cowey and C. Y. Cho (eds.). Nutritional Strategies and Aquaculture Waste. *Proceedings of the First International Symposium on Nutritional Strategies in Management of Aquaculture Waste*. University of Guelph, Guelph, Ontario, Canada, 1990. 275 p.

Black, M. and Dixon, P. I., 1992. Stock identification of mulloway in Australian waters. *Final report to FIRTA, Centre for Marine Science, University of NSW*. pp. 38.

Blackburn, S. I. and Cresswell, G., 1993. A coccolithophorid bloom in Jervis Bay, *Australia. Australian Journal of Marine and Freshwater Research*, 44(2): 253-260.

Brodie, J., 1995. Water quality and pollution control. Coastal management in the Asia-Pacific regions: Issues and approaches. K. Hotta and I. M. Duton (eds.). *Japan International Marine Science and Technology Federation*, Tokyo, pp. 39-56.

Brown, J. R., Gowen, R. J. and McLusky, D. S., 1987. The effect of salmon farming on the benthos of a Scottish sea loch. *Journal of Experimental Marine Biology and Ecology*, 109(1): 39-51.

Butz, I. and vens-Cappell, B., 1982. Organic load from the metabolic products of rainbow trout fed with dry food. In Report of the EIFAC Workshop on Fish Farm Effluents (Ed. by J. S. Alabaster). *EIFAC Tech. Pap., 41*: 73-82.

Carter, C., 1995. Correlates of growth and condition in Southern Bluefin tuna (*Thunnus maccoyii*). *Proceedings of CRC Scientific Conference Bribie Island, 27-29 September 1995* (Abstract).

Cho, C. Y., Hynes, J. D., Wood, K. R. and Yoshida, H. K., 1991. Quantitation of fish culture wastes by biological (nutritional) and chemical (limnological) methods; the development of high nutrient dense (HND) diets. p. 37-50. In: C. B. Cowey and C. Y. Cho (eds). Nutritional Strategies and Aquaculture Waste. *Proceedings of the First International Symposium on Nutritional Strategies in Management of Aquaculture Waste*. University of Guelph, Guelph, Ontario, Canada, 1990. 275 p.

Christov, V., Sturman, M. and Christie, G., 1995. Controlled release antifouling polymners for aquaculture netting. *Proceedings of CRC Scientific Conference, Bribie Island, 27-29 September 1995* (Abstract).

Cleary, J. J., 1995. The effect of capture and handling stress on plasma levels of gonadal steroids in Australian snapper, *Pagrus auratus*. *Proceedings of CRC for Aquaculture Scientific Conference*, *Bribie Island, 27-29 September 1995* (Abstract).

Constable, A. J., 1991. The role of science in environmental protection. *Australian Journal of Marine and Freshwater Research*, 42(5): 527-538.

Coyne, R., Hiney, M., O'Connor, B., Kerry, J., Cazabon, D. and Smith, P., 1994. Concentration and persistence of oxytetracycline in sediments under a marine salmon farm. Aquaculture, 123: 31-42.

de Nys, R., 1995. Natural antifoulants from marine algae and their application in aquaculture. Proceedings of CRC Aquaculture Scientific Conference, Bribie Island, 27-29 September 1995 (Abstract).

Dugdale, R. C., 1967. Nutrient limitation in the sea: dynamics, identification and significance. *Limnology and Oceanography*, 12: 685-695.

Edwards, A. and Edelsten, D. J., 1976. Marine fish cages - the physical environment. *Proc. Roy. Soc. Edinburgh (B),* 75: 207-221.

Enell, M. and Lof, J., 1983. Environmental impact of aquaculture - sedimentation and nutrient loadings from fish cage culture. *Vatten*, 39(4): 364-375 (in Swedish).

EPA, 1994. Monitoring the effects of aquaculture on the environment. *EPA Draft report*.

Fairweather, P. G., 1991. Statistical power and design requirements for environmental monitoring. *Australian Journal of Marine and Freshwater Research,* 42(5): 555-567.

Foscarini, R., 1988. A review: intensive farming procedure for red sea bream (*Pagrus major*) in Japan. *Aquaculture*, 72: 191-246.

Frid, C. L. J. and Mercer, T. S., 1989. Environmental monitoring of caged fish farming in macrotidal environments. *Marine Pollution Bulletin*, 20(8): 379-383.

Fukusho, K., 1991. Red sea bream culture in Japan. In: R. McVey (Ed); *Handbook of Mariculture. Vol. II, Finfish aquaculture*, Roca Baton, CRC Press, 73-87 pp.

Gowen, R. J. and Bradbury, N. B., 1987. The ecological impact of salmonid farming in coastal waters: A review. In Oceanography and Marine Biology: An Annual Review (Ed. by M. Barnes). *Oceanography and Marine Biology Annual Rev*iews, 25: 563-575.

Gowen, R. J., Weston, D. P. and Ervik, A., 1991. Aquaculture and the benthic environment: a review. p. 187-205. In: C. B. Cowey and C. Y. Cho (eds.). Nutritional Strategies and Aquaculture Waste. *Proceedings of the First International Symposium on Nutritional Strategies in Management of Aquaculture Waste*. University of Guelph, Guelph, Ontario, Canada, 1990. 275p.

Gowen, R. J., Rosenthal, H., Makinen, T., Ezzi, I., 1990. Environmental impact of aquaculture activities. In Aquaculture Europe '89 - Business joins Science. N. De Pauw and R. Billard (eds). *Special Publication No. 12, Bredene, Belgium*.

Grey, J. S., 1992. Eutrophication in the sea, Columbo, G. (Ed.*), Marine Entrophication and Population Dynamics*, Olson & Olson, Denmark, 3-15.

Hektoen, H., Berge, J. A., Hormazabal, V., Yndestad, M., 1995. Persistence of antibacterial agents in marine sediments. *Aquaculture*, 133: 175-184.

Hodson, S., 1995. Field testing of antifoulants for salmon-cage netting. *Proceedings of CRC Aquaculture Scientific Conference, Bribie Island, 27-29 September 1995* (Abstract).

Hodson, S. and Lewis, T., 1995. Development and evaluation of a prototype *in situ* net cleaner and novel antifoulants for netting. *SALTAS research and development programme, 17th October 1995*. pp. 171-192.

Howarth, R. W., 1988. Nutrient limitation of net primary production in marine ecosystems. *Annual Reviews of Ecology*, 19: 89-110.

Husevag, B., Lunestad, B. T., Johannessen, P. J., Enger, q. and Samuelsen, O. B., 1991. Simaltaneous occurrence of *Vibrio salmonicida* and antibiotic resistant bacteria in sediments at abandoned aquaculture sites. *Journal of Fish Diseases*, 14: 631-640.

Hustvedt, S. O., Storebakken, T. and Salte, R., 1991. Does oral administration of oxolinic acid or oxytetracycline effect feed intake of rainbow trout? *Aquaculture*, 92: 109-113.

Iwama, G. K., 1991. Interactions between aquaculture and the environment. Critical *Reviews in Environmental Control*, 21: 177-216.

Jacobsen, P. and Berglind, L., 1988. Persistence of oxytetracycline in sediments from fish farms. *Aquaculture*, 70: 365-370.

Johnsen, F. and Wandsvik, A., 1991. The impact of high energy diets on pollution control in the fish farming industry. 51-64pp. In: C. B. Cowey and C. Y. Cho (eds.). Nutritional Strategies and Aquaculture Waste. *Proceedings of the First International Symposium on Nutritional Strategies in Management of Aquaculture Waste*. University of Guelph, Guelph, Ontario, Canada, 1990. 275p.

Kato, S., Hirobe, H. and Maegawo, T., 1985. On the essential sea water parameters to discriminate between red tide and non-red tide by discriminant analysis. *Bulletin of. Japanese Society of Fisheries*, 51: 7-12.

Kaushik, S. J. and Cowey, C. B., 1991. Dietary factors affecting nitrogen excretion by fish. pp. 3-19. In: C. B. Cowey and C. Y. Cho (Editors), Nutritional Strategies and Aquaculture Waste. Proc. *First International Symposium on Nutritional Strategies in Management of Aquaculture Waste*. University of Guelph, Ontario, Canada, 1990. 275p.

Kerry, J., Hiney, M., Coyne, R., Cazabon, D., Nicgabhainn, S. and Smith, P., 1994. Frequency and distribution of resistance to oxytetracycline in micro-organisms isolated from marine fish farm sediments following therapeutic use of oxytetracycline. *Aquaculture*, 123: 43-54.

Lall, S. P., 1991. Digestibility, metabolism and excretion of dietary phosphorus in fish. p. 21-36. In: C. B. Cowey and C. Y. Cho (eds.). Nutritional Strategies and Aquaculture Waste. *Proceedings of the First International Symposium on Nutritional Strategies in Management of Aquaculture Waste*. University of Guelph, Guelph, Ontario, Canada, 1990. 275p.

Lincoln Smith, M. P., 1991. Environmental impact assessment: the roles of predicting and monitoring the extent of impacts. *Australian Journal of Marine and Freshwater Research*, 42(5): 603-614.

Lizska, D., 1996. Aquaculture leases and permits for marine finfish farming in NSW. In: N. Quartararo (Editor), *Proceedings of the Marine Finfish Farming Workshop, 23 June 1995, Cronulla, NSW*. NSW Fisheries Research Institute, Cronulla, NSW, pp. 165-170.

Loland, G., 1993. Current forces on, and water flow through and around, floating fish farms. *Aquaculture International*, 1: 72-89.

Lumb, C. M., 1989. Self-pollution by Scottish salmon farms? *Marine Pollution Bulletin*, 20(8): 375-379.

MacDonald, C. M., 1982. Life history characteristics of snapper *Chrysophrys auratus* (Bloch and Schneider, 1801) in Australian waters. Victorian Department of Conservation and Lands, Fisheries and Wildlife Division, *Fisheries and Wildlife Paper 29*. 16pp.

Macintosh, D. J. and Phillips, M. J., 1992. Environmental issues in shrimp farming, Saram, H. and Singh, T. (Eds*). Proceedings from the third global conference on the shrimp industry, Hong Kong*, 118-137 pp.

Macleod, C., 1995. Environmental monitoring - Marine Benthos. *SALTAS research and development programme 17th October 1995*. 193-224 pp.

Magarinnos, B., Romalde, J. L., Santos, Y., Casal, J. F., Barja, J. L. and Toranzo, A. E., 1994. Vaccination trials on gilthead seabream (*Sparus aurata*) against *Pasteurella piscicida*. *Aquaculture*, 120: 201-208.

Matsuyama, H., Mangindaan, R. E. P. and Yone, Y., 1992. Protective effect of schizophyllan and scleroglucan against *Streptococcus* sp. infection in yellowtail (*Seriola quinqueradiata*). *Aquaculture*, 101: 197-203.

Mills, S., 1989. Salmon farming's unsavoury side. *New Scientist*, 29 April, 40-42.

Morris, A. W., 1983. Practical Procedures for Estuarine Studies. *Handbook prepared by the Estuarine Ecology Group of the Institute for Marine Environmental Research, National Environmental Research Council.*

Murai, T., 1991. Various measures undertaken in Japan to prevent environmental pollution by fish farming. In: C. B. Cowey and C. Y. Cho (Eds.). Nutritional strategies and aquaculture waste. *Proceedings of the first International Symposium on Nutritional Strategies in Management of Aquaculture Waste*. University of Guelph, Guelph, Ontario, Canada, 1990. 275p.

Newman, S. G., 1983. Bacterial vaccines for fish. *Annual Reviews of Fish Diseases*, 3: 145-185.

Nygaard, K., Lunestad, B. T., Hektoen, H., Berge, J. A. and Hormazabol, V., 1992. Resistance to oxytetracycline, oxolinic acid and furazolidone in bacteria from marine sediments. *Aquaculture*, 104: 31-36.

Ogburn, D., 1996. Site selection for marine finfish farming. In: N. Quartararo (Editor), *Proceedings of the Marine Finfish Farming Workshop, 23 June 1995, Cronulla,NSW*. NSW Fisheries Research Institute, Cronulla, NSW, pp. 153-163.

O'Sullivan, D., 1995. Last chance for chemical registration. *Austasia Aquaculture*, 9(4): 3.

Pearson, T. H. and Rosenberg, R., 1978. Macrobenthic succession in relation to organic enrichment and pollution of the marine environment. *Oceanography and Marine Biology Ann. Rev*., 16: 229-311.

Philips, M. and Beveridge, M., 1986. Cages and the effect on water condition. *Fish Farmer*, May/June, 17-19.

Pillay, T. V. R., 1992. *Aquaculture and the environment*. Fishing Industry News, England.

Purser, J., 1992. Environmental Impacts of Aquaculture. *Multi-skilling in aquaculture a hands on training workshop.* National Key Centre for Teaching and Research in Aquaculture. June 28 - July 2, University of Tasmania at Launceston, 66 pp.

Quartararo, N., 1996. Grow-out of snapper and mulloway in sea cages. In: N. Quartararo (Editor), *Proceedings of the Marine Finfish Farming Workshop, 23 June 1995, Cronulla, NSW*. NSW Fisheries Research Institute, Cronulla, NSW, pp. 37-70.

Raison, R. L. Development of oral vaccines for fish. *Proceedings of CRC for Aquaculture Scientific Conference. Bribie Island, 27-29 September 1995* (Abstract).

Ritz, D. A., Lewis, M. E. and Ma Shen, 1989. Response to organic enrichment of infaunal macrobenthic communities under salmonid seacages. *Marine Biology*, 103: 211-214.

Sako, H., 1995. Recent trends in fish diseases in Japan. *Proceedings of the Seminar on Aquaculture development in Southeast Asia*. T. U. Bagarinao and E. E. C. Flores (Eds). Iloilo City, Philippines, 26-28 July 1994. pp. 63-72.

Samuelsen, O. B., 1989. Degradation of oxytetracline in seawater at two different temperatures and light intensities and the persistence of oxytetracycline in the sediment from a fish farm. *Aquaculture*, 83: 7-16.

Seymour, E. A. and Bergheim, A., 1991. Towards a reduction of pollution from intensive aquaculture with reference to the farming of salmonids in Norway. *Aquaculture Engineering*, 10: 73-88.

Silvert, W., 1992. Assessing environmental impacts of finfish aquaculture in marine waters. *Aquaculture*, 107: 67-79.

Staveley, P., 1985. 'Manual for Environmental Impact Assessment'. NSW Department of Environment and Planning: Sydney.

Takahashi, M., and Fukazawa, N., 1982. Effects of selective nutrient simulation on the growth of different phytoplankton species in natural waters. *Marine Biology*, 70: 267-273.

Tozarzo, A. E., Devesa, S., Romalde, J. L., Lamas, J., Riaza, A., Leiro, J. and Barja, J. L., 1995. Efficacy of intraperitoneal and immersion vaccination against *Enterococcus* sp. infection in turbot. *Aquaculture*, 134: 17-27.

Tsutsumi, H., Kikuchi, T., Tanaka, M., Higashi, T., Imasaka, K., Miyazaki, M., 1991. Benthic faunal succession in a cove organically polluted by fish farming. *Marine Pollution Bulletin*, 23: 233-238.

Underwood, A. J., 1991. Beyond BACI: Experimental designs for detecting human environmental impacts on temporal variations in natural populations. *Australian Journal of Marine and Freshwater Research*, 42(5): 569-587.

van Barneveld, R., Smart, A. and Clarke, S., 1995. Growth performance of caged Southern Bluefin tuna fed manufactured diets. *Proceedings of CRC Scientific Conference, Bribie Island, 27-29 September 1995* (Abstract).

Woodward, I., 1989. Finfish Farming and the Environment - A Review. *Technical Report 35, Division of Sea Fisheries, Tasmanian Marine Laboratories.*

Woodward, I. O., Gallagher, J. B., Rushoton, M. J., Machin, P. J., Mihalenko, S., 1992. Salmon farming and the environment of the Huon Estuary, Tasmania. *Technical Report 45, Division of Sea Fisheries, Tasmanian Marine Laboratories.*

Wu, R. S. S., Lam, K. S., Mackay, D. W., Lau, T. C. and Lam, V., 1994. Impact of marine fish farming on water quality and bottom sediment: A case study in the sub-tropical environment. *Marine Environmental Research*, 38: 115-145.

Site Selection For Cage Culture Of Marine Fish In NSW

Damian M. Ogburn

NSW Fisheries, Locked Bag 9, Pyrmont, NSW, 2009

INTRODUCTION

Aquaculture investment for marine finfish farming world-wide has increasingly focused on cage culture. This has lead to a rapid increase in production during the last decade in Europe, Japan and South East Asia. Japan, in particular, has one of the longest histories of marine finfish farming, following the development of cage culture after the Second World War (Davy, 1990). Globally, there has been a rapid rise in the technology for farming marine fish in cage systems, particularly during the last ten years. More species are coming into commercial husbandry; new techniques and designs developed; and areas that were previously considered not suitable for the establishment of cages are now being utilised. Chamberlain (1993) predicts that by the end of this decade annual world marine finfish production will double to approximately 350,000 tonnes.

However, as could be expected in new industries, there have been problems during the development of this technology and the outcomes have not always been a viable and sustainable industry.

This paper deals with one important aspect of cage culture of marine fish, that of site selection. A correct evaluation of a site helps to ensure that the business will indeed be viable and ecologically sustainable.

GENERAL FEATURES

For the purposes of this discussion, cages (sometimes called pens) refer to net enclosures where the floor panel (bottom) of the cage is not in contact with the seabed. These cages are fixed horizontally, usually by means of flotation devices at the top of the cage and ropes or cables attached to anchoring devices on the seafloor. They vary widely in design, size and

shape as well as (construction) material. Cages may be floating at the surface of the sea or in some cases actually submerged. The cultured fish species are confined within the cage where most of the ongrowing husbandry practices, such as feeding and grading, are undertaken. Given the diversity of techniques and species available in marine finfish farming, I will limit this discussion to the culture of table grade, temperate water marine finfish, in particular snapper (*Pagrus auratus*).

The first question to be asked in establishing a marine finfish farm, once the technical and market feasibility issues have been canvassed, is where to look for a suitable site for establishing cages. Experience around the world has shown that commercial cage culture of marine finfish normally requires minimum water depths of at least 6 metres for practical farming purposes. The NSW Fisheries experimental cage site at Botany Bay is in 5-6 metres of water at low tide which could potentially present management problems in the longer term. The minimum depth requirement immediately excludes any significant cage culture from areas within most of the 133 estuaries/embayments along the NSW coast. Exceptions to this include Twofold Bay, Jervis Bay, Botany Bay, Port Jackson, Broken Bay and Port Stephens.

Because of the engineering requirements and cost in establishing cages in areas exposed to major ocean swells, marine finfish farming industries have traditionally developed in relatively sheltered areas. Examples include the salmon farms situated in deep estuaries in Norway and Canada, salmon farms in the D'Entrecasteaux Channel in Tasmania and the tuna cages in Port Lincoln, South Australia. As experience and confidence in these industries has developed, the technology for so called 'offshore' or 'midwater' farming at more exposed coastal sites has developed. For example, in Norway polyethylene cages with volumes up to 30,000 m^3; systems capable of withstanding wave heights of 7 metres and currents greater than 1m/sec have been developed (Norwegian Trade Council, 1992).

Given these qualifiers, what factors are to be used in selecting or evaluating a site for cage culture of marine finfish in NSW. The two broad questions to be asked are firstly whether the site is **available** and secondly whether the site is **suitable.**

AVAILABILITY

The NSW coastline is the fifth longest in Australia and has the greatest density of coastal human habitation. Over 80 % of the NSW's population (6 million) live in the coastal zone (Anon, 1994). This has been exacerbated in recent decades by the establishment of holiday homes/resorts that service the nearby major cities and retirees escaping urban life. This, in turn, creates heavier demands on coastal resources and places further constraints on any proposed development such as fish farms.

This background of coastal development introduces further potential conflicts and impacts and has required increased Government intervention to regulate coastal development and activities. One of these mechanisms is the implementation of coastal planning controls that are holistic and ensure community consultation in a process which aims to achieve orderly and sustainable development. An excellent example of this is the development of Marine Farming Plans by the Tasmanian Department of Primary Industries and Sea Fisheries, Marine Farming Branch. These plans identify available areas of State waters for purposes of marine farming in a fairly detailed way (e.g. Draft Plan for the D'Entrecasteaux Channel, 1995). Currently, approximately 400 hectares of inshore waters are leased for salmon farming in Tasmania.

However, it seems unlikely that NSW will experience development of fish farms to this extent, in the short term, given the shortage of suitable areas similar to those developed so far in Tasmania for the salmon industry. Pursuant to this, recent amendments to environmental planning legislation, i.e. the *Environmental Planning and Assessment Act, 1979*, now requires that an Environmental Impact Statement (EIS) be prepared prior to granting of development approval for intensive aquaculture, such as cage culture of finfish, in NSW State waters. Any form of aquaculture which requires supplemental feeding is considered intensive.

For the purposes of cage culture of fish, the establishment of structures within the sea requires the granting of a lease from the Minister for Fisheries (NSW), as well as other Government agency approvals (Liszka 1996).

Currently, there are over 3,500 leases for traditional oyster farms in NSW covering an area of approximately 5,000 hectares. As yet, there have been no leases of public water land granted for other types of aquaculture, including cage culture of fish in NSW.

In assessing applications for leasing of public water land, NSW Fisheries and the Inter Departmental Committee - Mariculture, which NSW Fisheries convenes, request applicants to consider the availability of an area for the proposed development of a marine finfish farm in terms of the following:

1. To what extent would other user groups be adversely affected or excluded such as:

    - fishers, whether commercial and/or recreational. Generally, adverse effects would be confined to trawlers and purse seiners;
    - navigation obstacle to commercial and Government shipping and recreational boating. Jervis Bay is an obvious example in respect to the Navy operations in those waters;
    - other aquaculturists, such as oyster and mussel farms, competing for the same or nearby areas; and
    - recreational use, whether passive (e.g. sight seers) or active (e.g. divers).

2. Potential aspects of environmental concern include:

    - fragility of the area;
    - uniqueness of the area;
    - biodiversity; and
    - sustainability.

3. Legislation: For instance there is currently a closure on Port Jackson for leasing for aquaculture. Consideration of local and/or regional environmental plans and their relevance, if any, to the proposed site should be made. Information can be sought via local Government or from the Department of Urban Affairs and Planning (DUAP).

4. The likelihood of resident opposition, whether perceived or factual in relation to:

- visual impact of the development and its proximity to land and or residential/inhabited areas;
- land owners who are concerned that their real estate may be devalued;
- residents or preservationists who argue for no change; and
- effects on tourism.

SUITABILITY

Wild fish populations have the ability to migrate away from water bodies in which the water quality is changing. Not so with fish in fish farms. Hence, there is a need to carefully consider factors which may vary in time (both short and long term) and space. Marine fish aquaculture in cages has a number of physical/environmental site requirements that need to be considered in assessing a site's suitability. The requirements can be separated into primary, secondary and tertiary factors. Primary factors are immutable and essential for the implementation of the venture. Secondary factors play a determining role in the project feasibility over the short term. Tertiary factors affect the long term economic performance of the project. The recommended values for these suitability factors are listed in Table 1.

1. The primary factors to be considered are:

- Shelter of the site from wave, current and wind action. This influences the engineering and structural requirements for cage design and operational logistics including intervals between servicing during inclement weather. Relatively protected areas enable the use of less rugged (and therefore less expensive) cage design, anchoring and boating equipment. In more exposed areas there are significant increases in equipment requirement for cage design (e.g. anchoring devices/steel alloy stanchions/triple ring polar circles/ submersible cages); service boats; feeding, general stock handling and husbandry practices.

- Depth of the site should be greater than six metres. For offshore systems envisaged in this discussion, sites less than 50 metres in depth are recommended. Deeper offshore

sites are restricted by the difficulty and expense in installing and servicing anchoring systems. A good rule of thumb for commercial operations is that the depth of the site be twice the depth of the cages.

- The rate at which the waterbody undergoes exchange around and through the site and the ambient 'water quality' act as a control on the level of stock within an area. Exchange rate and water quality may vary spatially and temporally. Generally, well flushed areas in open embayments with unrestricted deepwater flows are recommended.

- Marine fish farming does not require large areas of water in order to obtain considerable levels of production (NOFARIC, 1995). For example, the entire commercial snapper catch for NSW in 1991/1992 (500 tonnes) could be farmed in less than 2 hectares of cage area. On the other hand, the area available for the farming operation should incorporate areas available for periodic cage transfer (1 - 2 years) to allow fallowing of sites for a similar period. Generally, one cage unit should have three sites in which to operate. In the highly developed Norwegian salmon farming industry, the volume of cages (which, in turn, controls the amount of stock) in a given surface area is strictly regulated. This planning control is based on carefully monitored, modelled and calculated parameters for ecologically sustainable marine farming development.

2. Secondary factors to be considered are:

- Seasonal changes in the temperature of the waterbody at the site can affect the operation. Since fish are cold blooded their growth and feeding rates are strongly controlled by temperature. Health of the fish may also be affected. Consequently fish have optimal ambient water temperature for good growth. In the case of snapper, optimal seawater temperatures are in the range 18 - 26^{o} C. Siting cages in areas where the growing season is longest would reduce the time in which the fish could be brought to harvest. Mean monthly seawater temperatures and an estimate of the corresponding number of growing months (18 - 26^{o}C) in a year, for 5 regions of the

NSW coast is shown in Figure 1. This was compiled from seawater surface temperature data collected during the last 20 years (Wolf & Collins, 1979). The data has been averaged and therefore, within a region, significant temporal and spatial variation from these average figures could occur.

- Salinity of the waterbody on a temporal and spatial (water column) basis may also be a decisive factor in site suitability. Snapper are essentially a marine fish and tend to live in waters with a salinity greater than 30ppt. Ocean seawater has a salinity of 35ppt. The potential for large and extended fluctuations in salinity, such as may occur near major river mouths, should be assessed. Areas where large fluctuations in salinity occur regularly should be avoided.

- Turbidity and pollution at the site should also be considered. High levels of suspended silt; excessive eutrophication; plankton upwellings; land runoff containing pesticides, industrial pollutants or other harmful agents can all significantly affect the water quality and overall health of the fish.

3. Tertiary factors to be considered as having a potential affect on the long term viability of the farm are:

- Substratum in the proposed fish farm area, especially in shallower sites, can affect the capacity of the area immediately below the cages to deal with solid waste such as faeces and uneaten pellets. Generally, more coarse sediments (sandy) tend to facilitate maintenance of aerobic conditions at the sediment/water interface. This reduces the production of hydrogen sulfide which can impact on the health and performance of the fish in the cages above.

- Mechanisms for around the clock security from both animal predators, whether aerial or aquatic, and human interference, should be considered in the initial assessment of the site.
- Shore facilities required for the project operation and the proximity to the cage site play a role in the management and methodology used in day to day running of the

farm. This includes wharf facilities, net cleaning and storage areas, waste (liquid and solid) treatment and disposal, feed and other farm equipment storage, on shore electricity, office and communications systems, road access and staff housing.

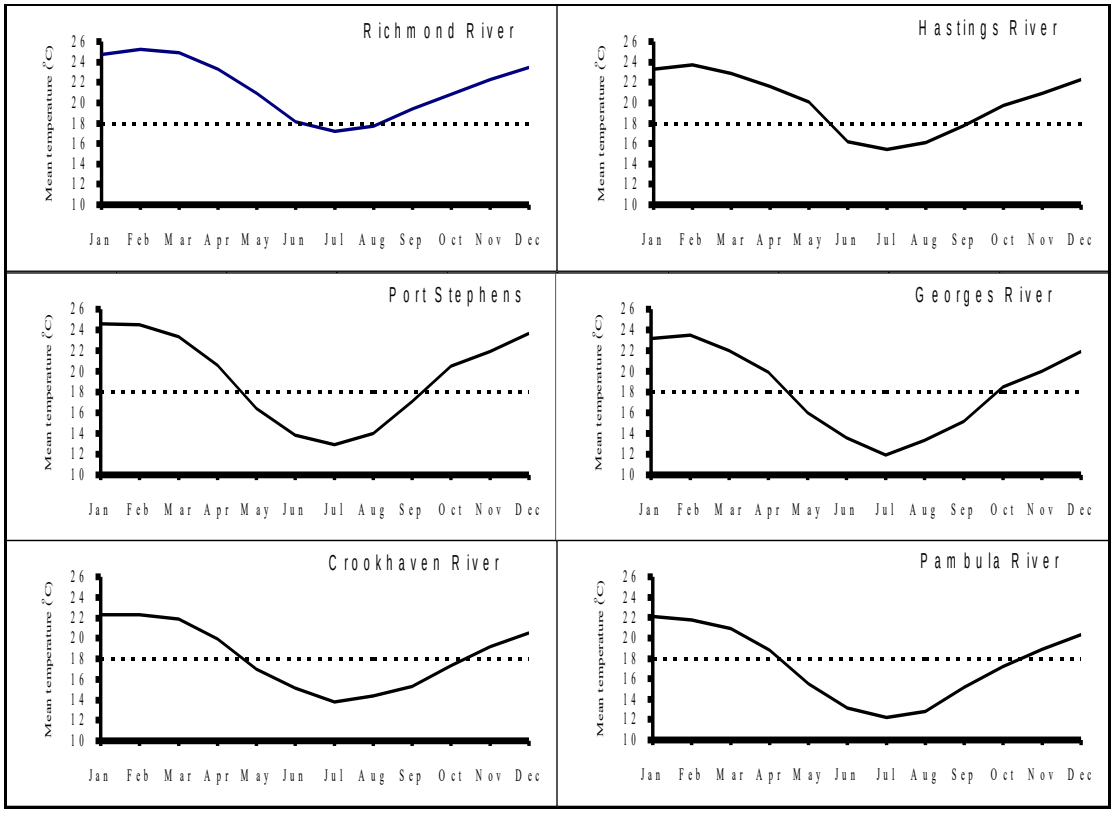


Figure 1: Water temperature data for various estuaries along the NSW Coast

- The proximity of the market and supply of inputs (e.g. fingerlings/feeds/ice, to name a few) requires evaluation. Access to feed and fuel supplies and general farm inputs, particularly in an emergency, can be important. Sydney is the largest market for seafood in Australia and it is this proximity to any proposed fish farm in NSW that gives transportation advantages relative to other states as well as flexibility and scope to the manner in which the fish can be sold.

SUMMARY AND CONCLUSION

The development of marine finfish farms is an inevitable consequence of stagnant or declining wild fishery resources coupled with the increasing demand for seafood products. Coastal protected areas suitable for establishing marine fish farms in NSW are limited by a number of constraints. However, the technology involved in this activity does not require large areas to achieve production levels in the order of 200 - 300 tonnes/annum. Central to Northern NSW appears to be the most promising for the production of snapper. In the short term it is likely that any developments would be in more protected coastal areas, such as open embayments.

NSW Fisheries and other Government agencies need to assist industry in obtaining, operating and monitoring select sites in open embayments to foster an embryonic marine finfish farming industry. NSW is an Eastern seaboard State that, arguably, has the greatest potential in Australia for developing a viable and environmentally sustainable industry involving the cage culture of marine finfish such as snapper, during the next few decades.

Over the next decade, the NSW marine fish farming industry needs to develop and mature. Following this development, significant increases in production in midwater areas off the coast where there are fewer constraints, could occur.

Table 1: Summary Of Site Selection Criteria And Recommended Values

FEATURE	CRITERIA	RECOMMENDED
Site exposure	Wave height	< 2 metres maximum
	Storm protection	NE to SE
	Current speed	5 - 15 cm/second
Depth	Mean Low tide	> 8 metres
	Offshore	< 60 metres
Water exchange	Residence time	Minimal
	Circulation	No dead zones
	Open embayments	Unrestricted opening
Substrate	Type	Sandy
Available area	Carrying capacity	e.g. 12000m^3/km^2 - Norway
	Fallowing	12 - 18 month turnover
	Expansion	e.g. 300T/Ha @ 5m cage depth
Temperature	Ideal	18 - 26° C
Salinity	Median	> 30 ppt
Turbidity	Median	< 10 mg NFR
Secchi Depth	Median	> 2 metres
Oxygen		> 6 mg/Litre
BOD_5	Median	< 3 mg/Litre

REFERENCES

Anon. 1994. Draft revised coastal policy for NSW. *Coastal Committee of NSW*: pp106.

Chamberlain, G.W. 1993. Aquaculture trends and feed projections. *World Aquaculture* 24(1): 19 - 29.

Davy, F.B. 1990. Mariculture in Japan, 1. Development of an industry. *World Aquaculture* 21: 36 - 47.

Lizska, D., 1996. Aquaculture leases and permits for marine finfish farming in NSW. In: N. Quartararo (Editor), *Proceedings of the Marine Finfish Farming Workshop, 23 June 1995, Cronulla, NSW*. NSW Fisheries Research Institute, Cronulla, NSW, pp. 165-170.

NOFARIC. 1995. Potential for commercial marine fish farming in NSW. Prepared by Pacific Seafood Management Consulting Group P/L. NOFARIC. Sydney: Australia.

Norwegian Trade Council. 1992. Norway Exports. Aquaculture Technology and Equipment: 24pp.

Wolf, P.H. & A.J. 1979. Summary of daily temperature and salinity records for major oyster bearing estuaries of New South Wales 1966 - 1973. *Miscellaneous Bulletin 2. Division of Fisheries, NSW Agriculture*.

Aquaculture Leases And Permits For Marine Finfish Farming In NSW

Dan Liszka

NSW Fisheries, Locked Bag 9, Pyrmont, NSW, 2009

INTRODUCTION

The construction and operation of a marine finfish farm requires licences, permits and approvals from several state agencies and local government. The central pieces of legislation that regulate the development of marine finfish farms in NSW are the *Environmental Planning and Assessment Act* (1979) (EP&A Act), the *Clean Waters Act* (1970), the *Coastal Protection Act* (1979) and the *NSW Fisheries Management Act* (1994).

The process required to obtain the necessary approvals to establish and operate a marine finfish farm is complicated and time consuming. This is due to the large number of organisations that are involved in regulating development in coastal NSW. Despite this, current regulations and application processes are comprehensive and beneficial. They are designed so that all aspects and possible impacts are taken into consideration and they enable participation of other user groups. This procedure ensures that all environmental, resource usage and management implications are considered and that only well researched and planned developments are permitted. However, potential investors need to note that this results in a situation where there is potential for long delays in achieving a final decision.

The objective of this paper is to outline a general application sequence and to discuss the specific areas of concern of relevant government agencies; the timeframe and costs involved, and the factors that need to be considered in an application to establish and operate a marine finfish farm. There are two stages to obtaining the necessary approvals to establish and operate a marine finfish farm: an advisory stage and an application stage.

ADVISORY STAGE

The proponent commences by contacting NSW Fisheries and briefly outlining the proposal. NSW Fisheries will then provide the proponent with the advisory information that is available, an Interdepartmental Committee - Mariculture (IDC) information package and the necessary lease application forms.

The local council is contacted in the area of the proposed site and requested to make a decision as to whether development consent is required. This amounts to council identifying whether the proposed fish farm lies within the boundaries of that council as specified in a Local Environment Plan (LEP). This information is used to determine whether the proposal will be assessed under part 4 of the EP&A Act (the proposed fish farm lies within the boundaries of a local council and that council is the consenting authority) or the proposal is assessed under part 5 of the EP&A Act (the proposed fish farm is situated outside the boundaries of any council and the determining authority is nominated by the Department of Urban Affairs and Planning).

The proponent then completes the NSW Fisheries lease application forms and submits the proposal including the application fee to NSW Fisheries who will then convene the IDC to assess the proposal.

The IDC is an advisory committee formed in 1992 to ensure a planned approach is taken for the development of aquaculture over public water land in NSW. The committee is made up of representatives from the following departments:

NSW Fisheries (Convenor),
Department of Urban Affairs and Planning (DUAP),
Department of Land and Water Conservation (DLWC),
Environment Protection Authority (EPA),
Department of Business and Regional Development (BRD),
Waterways Authority (WA) and,
National Parks and Wildlife Service (NPWS).

In respect to finfish farms, the Department of Urban Affairs and Planning is responsible for administering the EP & A Act and issuing guidelines for the preparation of Environmental Impact Statements (EISs). The Department of Land and Water Conservation is responsible for managing submerged crown land. The Environment Protection Authority is responsible for any inputs into waterways which may be considered as polluting. The Department of Business and Regional Development is concerned with promoting activities which generate employment. The Waterways Authority is responsible for any structures which may affect safe navigation in our waterways. The NSW National Parks and Wildlife Service is concerned with the safety of marine mammals and any possible impacts on marine birds. NSW fisheries, as well as promoting the development of sustainable and environmentally responsible aquaculture industries, is also responsible for preserving important fish habitats and promoting efficient commercial fisheries.

The IDC jointly assesses applications for mariculture developments and provides advice regarding location of the development, the determining authorities are identified and any technical limitations of the project are considered. The IDC has no statutory powers so it cannot directly approve or reject an application but it is a forum to: evaluate a proposal; provide advice that can be used to ensure that the proponent receives a coordinated interagency response; streamlines regulatory processes and allows for the development to be undertaken in an environmentally responsible manner.

APPLICATION PROCEDURE

Depending on the determination given by local council there are two separate application procedures. If the site is within council boundaries then under part 4 of the EP&A Act, council is the consenting authority and the applicant needs to prepare a Development Application (DA). Finfish farms are considered designated developments because they require artificial inputs of food. Therefore, as part of the development application an Environmental Impact Statement (EIS) will also need to be prepared. The proponent will need to contact the DUAP to obtain advice on preparing the EIS. If the proposal threatens any endangered species or their habitat a Fauna Impact Statement (FIS) will also need to be prepared. The list of NSW endangered fauna can be found in Schedule 12 of the National Parks and Wildlife Act (1974) and includes all marine mammals. Land owners consent to

lodge the DA is then obtained from the Department of Land and Water Conservation. With land owners consent, the DA including an EIS is then lodged with council.

The Council then exhibits the DA and EIS for public comment. The FIS, if required, can be incorporated into the EIS and exhibited concurrently. Submissions from the public are considered and forwarded to the DUAP. Council also consults other Government Departments as required. After consideration of the EIS, public submissions and information provided by other Government Departments, the council then approves or rejects the DA.

If the DA is approved, the applicant then obtains the necessary permits from the other Government Departments as identified by the IDC. A marine finfish farm would normally require a licence from the EPA, approval from the Department of Land and Water Conservation and a commercial mooring licence from the Waterways Authority.

The applicant finalises the application procedure by submitting the approved DA, the approvals from the other government departments identified by the IDC, and a completed permit application including a commercial farm development plan to NSW Fisheries. NSW Fisheries would then process the application and approve it subject to certain permit and lease conditions. NSW Fisheries reserves the right to reject an application even at this late stage but if an application were not to be supported by NSW Fisheries the proponent would be informed through the IDC at the advisory phase.

Under part 5 of the EP&A Act the determining authority is nominated by DUAP. In the case of aquaculture activities this is usually NSW Fisheries. The proponent commences the application procedure by lodging a revised lease application form with NSW Fisheries incorporating the recommendations of the IDC. The proponent then approaches the DUAP for guidelines on preparing an EIS. The EIS (incorporating an FIS if required) is then prepared and lodged with the nominated determining authority.

The nominated determining authority will then exhibit the EIS for public comment. Submissions received from the public will be considered and forwarded to DUAP. Approvals from the other determining authorities identified by the IDC need to be obtained at

this stage and they are the same as indicated under part 4 of the EP&A Act. At this stage a permit application including a commercial farm development plan needs to be lodged with NSW Fisheries.

After consideration of the EIS, public submissions and the necessary approvals from other determining authorities NSW Fisheries will then approve the application subject to conditions or reject it.

COSTS

Relative to the costs of construction and operation, the administrative costs involved in the application process are low and include the following charges levied by NSW Fisheries:

- A Class 3 Lease (Intensive aquaculture in areas deeper than 6 metres) application fee $1100.
- A Class B permit (Intensive aquaculture on public water) application fee $300.
- A Security Deposit of $1000 per hectare or part thereof. The security deposit is kept in a trust account earning interest until control of the lease is relinquished by the lessee. If necessary, the security deposit is used to correct any form of environmental mismanagement of the site e.g. the collection and disposal of any abandoned structures.
- A research levy of $20 per hectare or part thereof, which is kept in a trust account and used to fund industry focused research.
- A lease rental of a value to be determined.

Probably the greatest cost involves the preparation of an EIS and FIS. This cost will be determined by the nature of the proposal and its location.

TIME FRAME

Assuming that the proposal is well thought out and well prepared the advisory phase will take approximately 3 months. To date the main problem experienced at this stage is the lack of technical expertise of proponents. This is understandable given that the marine finfish aquaculture industry is in its infancy in NSW. However, the assessment of proposals will be

delayed if applications do not contain the necessary information. The application phase, assuming a 3 month period for the preparation of an EIS and that there are no significant objectors from either government or specific interest groups, will normally take 10 to 12 months. It is likely that this timeframe will be reduced as models for such activities become established in NSW.

Appendix 1 - List of Attendees

Dr Geoff Allan
NSW Fisheries
Port Stephens Research Centre
TAYLORS BEACH NSW 2316

Mr J. Arcus
2 Euroka Street,
NORTHBRIDGE NSW 2063

Ms T. Ball
23 Torrens Street,
RICHMOND TAS 7025

Chris Barlow
Queensland Dept. of Primary Industries
Freshwater Fisheries & Aquaculture Centre
WALKAMIN QLD 4872

Dr Steve Battaglene
ICLARM Coastal Aquaculture Centre
PO Box 438 HONIARA,
SOLOMON ISLANDS

Mrs W. Bell
17 Adelaide Street,
GREENWELL POINT NSW 2540

Mr P. Bell
17 Adelaide Street,
GREENWELL POINT NSW 2540

Mr A. Bradley
PO Box 759,
WERRIBEE VIC 3030

Mr G. Brown
1 Sabugal Road,
ENGADINE NSW 2233

Mr I. Cameron
RMB 503,
MURDUNNA TAS 7178

Mr S. Carr
8 Verdon St,
DROMANA VIC 3936

Mr W Christensen
PO Box 5171,
MANLY QLD 4179

Mr C. Denton
PO Box 18,
TUNCURRY NSW 2428

Mr D. Doyle
PO Box 20,
WATSONS BAY NSW 2030

Mr S. Doyle
PO Box 20,
WATSONS BAY NSW 2030

Mr C. Dunn
69 Church St,
ULLADULLA NSW 2539

Mr R. Evans
PO Box 409,
NAMBUCCA HEADS NSW 2448

Mr M. Farthing
PO Box 92,
TEA GARDENS NSW 2324

Mr R. Fidden
PO Box 92,
TEA GARDENS NSW 2324

Mr J. Fisher
PO Box 392,
CLAYFIELD QLD 4011

Dr Kunihiko Fukusho
Japan International Research Centre for
Agricultural Sciences (JIRCAS),
Japan 305, Ibarakii, Tsukuba, Ohwashi1-2

Dr Alan Fridley
TAFE, 327 Lords Place,
ORANGE NSW 2800

Mr M. Gage
153 Holland Street,
FREMANTLE WA 6160

Mr P. Gale
362 Ninth Ave,
LLANDILO NSW 2747

Mr R. Gibbons
2/17 Waratah Way,
GOONELLABAH NSW 2480

Mr T. Gorman
PO Box 340,
NEWPORT NSW 2106

Mr P. Graham
P.O. Box 5171,
MANLY QLD 4179

Mr B. Greenhill
PO Box 392,
CLAYFIELD QLD 4011

Appendix 1 - List of Attendees

Mr S. Hall
57 Squire St,
FINGAL BAY NSW 2315

Mr D. Harris
PO Box 9,
MENTONE VIC 3194

Mr J. Hassall
5th Floor, 131 Clarence St,
SYDNEY NSW 2000

Mr P. Hassall
5th Floor, 131 Clarence St,
SYDNEY NSW 2000

Mr A. Hassall
5th Floor, 131 Clarence St
SYDNEY NSW 2000

Mr M. Haseloff
PO Box 325,
WICKAM WA 6720

Mr A. Hawley
325 Willarong Rd,
CARINGBAH NSW 2229

Mr Ian Henderson
PO Box 2066
Bribie Island QLD 4507

Mr C. Holbert
160 Salamander Way,
SALAMANDER NSW 2317

Mr G. Holbert
160 Salamander Way,
SALAMANDER NSW 2317

Mr T. Holbert
160 Salamander Way,
SALAMANDER NSW 2317

Mr J. Ireland
17 St Albans Road,
WISEMANS FERRY NSW 2775

Mr T. Ireland
17 St Albans Road,
WISEMANS FERRY NSW 2775

Mr M. Johns
1/456 George Street,
SOUTH WINDSOR NSW 2756

Mr C. Judd
66 Kalaroo Road,
BENSVILLE NSW 2251

Mrs. R. Judd
66 Kalaroo Road,
BENSVILLE NSW 2251

John Kable
Northern Rivers Regional Development Board
50 Victoria Street, GRAFTON NSW 2460

Dr Robert Kearney
School of Natural Resources
University of Canberra
PO Box 1, BELCONNEN, ACT 2616

Mr A. Kent
20 Harwood Close,
MANNERING PARK NSW 2259

Mr W. Kent
20 Harwood Close,
MANNERING PARK NSW 2259

Mr A. Kopoulos
PO Box 584,
WATERLOO NSW 2017

Mr P. Krogh
PO Box 187,
DECEPTION BAY QLD 4508

Mr N. Lambert
PO Box 696,
GRAFTON NSW 2460

Mr R. Lauder
PO Box 87,
OLD BAR NSW 2430

Mr P. Lewis
PO Box 2064,
TAREN POINT NSW 2229

Dan Liszka
NSW Fisheries
Locked Bag 9, PYRMONT NSW 2009

Mr J. Lonergan
PO Box 1,
LORD HOWE ISLAND NSW 2898

Dr D. MacLennan
15 Bundabah Ave,
ST IVES NSW 2075

Mr D. Mahoney
National Seafood Centre,
19 Hercules Street, Hamilton, 4007 QLD

Appendix 1 - List of Attendees

Mr S. McCann
PO Box 643,
SEVEN HILLS NSW 2147

Mr B. McKinley
2 Taree Street,
NELSON BAY NSW 2315

Mr D. Micallef
127 Griffith Street,
MANNERING PARK NSW 2259

Mr V. McDonall
CFAC, PO Box 253
PYRMONT NSW 2009

Dr P. Montague
PO Box 123,
BROADWAY NSW 2007

Mr A. Mozqueira
6/250 Victoria Pde,
EAST MELBOURNE VIC 3002

Mr T. Newman
4 Higherdale Ave,
MIRANDA NSW 2228

Damian Ogburn
NSW Fisheries
Port Stephens Research Centre
TAYLORS BEACH NSW 2316

Mrs N. Ogburn
c/- NOFARIC, P.O. Box 247
PYRMONT NSW 2009

Mr N. Orfanidis
24 Sunnyside Road,
MT. WAVERLEY VIC 3149

Mr D. O'Sullivan
PO Box 243,
MOWBRAY TAS 7428

Mr N. O'Sullivan
19 Ocean View Terrace,
TATHRA NSW 2550

Dr D. Overend
Level 3, 230 Victoria Road,
GLADESVILLE NSW 2111

Mrs A. Perry
PO Box 6104,
BUNDABERG QLD 4671

Mr P. Perry
PO Box 6104,
BUNDABERG QLD 4671

Dr Nino Quartararo
NSW Fisheries
Fisheries Research Institute
PO Box 21, CRONULLA NSW 2230

Mr S. Raines
PO Box 107,
PORT ARLINGTON VIC 3223

Mr N. Rabjohns
PO Box 5171,
MANLY QLD 4179

Mr P. Rankin
PO Box 165,
NORTH SHORE VIC 3214

Mr N. Reid
399 Darling Street,
BALMAIN NSW 2041

Mr A. Relf
c/- 32 Park Street,
SWANSEA NSW 2281

Mr N. Ruello
4 Sherwin Street,
HENLEY NSW 2111

Mr I. Ryan
16 Hilary Ave,
McCRAE VIC 3938

Mr G. Searle
Middle Road,
Palmers Island NSW 2460

Mr L. Searle
PO Box 123,
BROADWAY NSW 2000

Mr M. Shannessy
C/- 264 Attunga Road,
YOWIE BAY NSW 2229

Mr N. Sinclair
PO Box 189,
Hunter Region Mail Centre
NEWCASTLE NSW 2310

Mr J. Sjostrom
Lot 114,
PEBBLY BEACH NSW 2536

Appendix 1 - List of Attendees

Mr D. Smith
6 Willowbrook Place,
SYLVANIA NSW 2224

Mr J. Smith
24 Torrens Street,
RICHMOND TAS 7025

Mr C. Stannard
399 Darling Street,
BALMAIN NSW 2041

Mr B. Tooth
9 Kindlebark Drive,
MEDOWIE NSW 2318

Mr P. Tsolidis
c/- MMI Insurance Ltd
2 Market St, SYDNEY NSW 2000

Mr W. Turner
c/- MMI Insurance Ltd
2 Market St, SYDNEY NSW 2000

Mr S. Von Stanke
C/- Post Office
CARPENTER ROCKS, SA 5291

Mr I. Von Stanke
C/- Post Office
CARPENTER ROCKS, SA 5291

Mr K. Walker
C/- 264 Attunga Road,
YOWIE BAY NSW 2228

Mr M. Watson
109 Denham Street,
HAWTHORN VIC 3122

Mr B. Webster
C/- Post Office,
DUNALLEY TAS 7177

Mr N. Wendt
28 Montrose St,
MANNERING PARK NSW 2259

Dr R. Whittington
E.M.A.I.
PMB 8, CAMDEN NSW 2570

Mr B. Wilshire
15 Lily St,
ALLAWAH NSW 2220

Mrs P. Wraight
PO Box 38,
TEA GARDENS NSW 2324

Mr R. Wraight
PO Box 38,
TEA GARDENS NSW 2324

Mr R. Wong
4 Higherdale Ave,
MIRANDA NSW 2228

Mr K. Wynn
28 Montrose St,
MANNERING PARK NSW 2259

Mr C. Young
Fisheries Division QDPI
GPO Box 2454, BRISBANE QLD 4001

Mr G. Zippel
Box 182,
CEDUNA SA 5690