Australian Society for Fish Biology

Workshop Proceedings

Enhancement of Marine and Freshwater Fisheries

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Edited by
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Contents

President's Introduction

The 2000 workshop on Stock Enhancement of Marine and Freshwater Fisheries continued the ASFB series of national workshop on key issues in fisheries science and management. The high quality of these workshops and the associated publication series, and their status in the broader community, ensures that ASFB maintains a preeminent position as the leading professional association for fish and fisheries science and management in the Australasian region.

Stock enhancement is an issue that captures the attention of people outside of the fisheries science and management profession, because it is seen as a quick fix. If there aren't enough fish there, for whatever desired end use, then why not simply add some more? That was the question we set ourselves for the workshop.

Stock enhancement has a long history in Australia - since at least early colonial days. Stocking groups focused their efforts on introducing salmonids into Australian waters, particularly in the southern colonies of Tasmania, Victoria and New South Wales. By the time of Federation, trout hatcheries had been operating for decades, and at least one of these early hatcheries – the Salmon Ponds in Tasmania – remains operational today. Voluntary stocking groups associated with these hatcheries also remain, in one form or another, as active participants in the stock enhancement of salmonid populations for recreational fishing purposes in Australia.

The next significant period of development in the history of stock enhancement in Australia was from the1960's to the1980's when great technical breakthroughs were made in the production of Australian freshwater and estuarine fish species. Much of the impetus for this research was for development of an extensive farm dam aquaculture industry.

While farm dam aquaculture remains a fledgling industry to this day, removal of the technical constraints meant that fish populations in a wide range of new environments could be considered for stock enhancement. This included Murray cod and golden perch into the inland lowland rivers and impoundments of the Murray Darling Basin, and barramundi and Australian bass into the coastal river systems and impoundments from tropical north Queensland to the temperate south eastern States.

The modern era has seen continuing diversification of species used in, and technical approaches to stock enhancement. Marine crustaceans, bivalves and gastropods, and endangered freshwater finfish have all been included into stock enhancement programs. At the same time, concerns about the ecological and genetic interactions between 'wild' and 'enhanced' populations became more prominent. Numerous research programs and management strategies are now in place to gain a greater understanding of these interactions, and to ameliorate the undesirable impacts of stock enhancement programs.

In my introductory presentation to the workshop, I outlined how the workshop would run, and stressed the importance of participation in the workshops that preceded and followed the series of themed sessions. The six key themes were New Methods, Ecological Impacts, Genetic Impacts, Measuring Success in Marine and Estuarine environments, Measuring success in Freshwater Environments, and Management Implications.

The presentations given during the themed sessions were first class, and I thank the presenters for their efforts. I believe we achieved a great level of participation during the workshops. Thanks to Trish Kailola, the session chairs, and other willing helpers did a great job in recording the workshop outputs.

Many other people also worked behind the scenes to make sure the workshop proceeded smoothly. Special mention must go to the organising committee and staff from both the Murray Darling Freshwater Research Centre and NSW Fisheries for their great efforts.

On the social side, the barbecue pit at Lake Hume Resort will remain as a somewhat foggy, very cold, but enjoyable memory for many participants, especially those who partook in a late night fry up of some contraband rifled from the kitchen, washed down with conference muscat.

Finally the support of the sponsors was pivotal in allowing the program to be put together and presented in such a successful manner. NSW Fisheries as the principal sponsor, and co-sponsors the Arthur Rylah Institute for Environment Research, the Cooperative Research Centre for Freshwater Ecology, the City of Albury, and AusIndustry generously donated funds and in-kind support that is greatly appreciated.

Dr Andrew Sanger
President ASFB 2000 – 2001.

Organising Committee
David Crook, Paul Humphries, Alison King, Jarod Lyon, Andrew Sanger, Luciano Serafini, Adrian Toovey

Session 1

NEW METHODS

The Tinaroo Barra Fishery - from Infamy to the Holy Grail

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Abstract

Stock enhancement is much more than releasing fish into a body of water. Success depends on good management and ultimately, the angler catching fish.

Lake Tinaroo is world famous for it's barramundi fishery. It wasn't always that way. Weipa barramundi was the only strain available in 1985/6. We soon learned Weipa fish stopped feeding below 25°C. Tinaroo quickly developed a bad reputation as a difficult fishery.

Several steps were taken to rectify this. Hatchery technology was developed to produce fingerlings from captive local strain barramundi. The closed season and upper size limit were lifted from Tinaroo. A community fish stocking society was set up to raise funds and thus the annual stocking rate. Fish exodus over the spillway was prevented by a $95,000 net.

Increased catches led to a massive publicity campaign, particularly on television. Tinaroo is now the "Holy Grail" of fishermen wishing to catch 40kg and bigger barramundi.

Introduction

Anglers during the 1950's and 60's saw Queensland's impoundments as aquatic deserts. Several attempts were made to introduce rainbow and brown trout, and popular native angling species, without much success (Hogan, 1995; Hamlyn, 1995). The major reason touted for the failure of the native recreational angling species to establish fisheries was the riverine nature of their life cycles and the requirement for running water in which to spawn. Anglers then searched abroad for alternatives that might form self sustaining sport fisheries in impoundments. The African Nile perch, *Lates niloticus*, because of its very close resemblance and size to a barramundi, *Lates calcarifer*, became the favourite (Midgley, 1968). The proposal to import and stock Nile perch became a contentious issue, with lively debate between scientists, anglers and the public at large (Barlow, 1984). The Walkamin Freshwater Fisheries and Aquaculture Centre was established near Lake Tinaroo in 1973 by the Queensland Department of Primary Industries to scientifically evaluate the proposal. Barlow and Lisle (1987) described reasons why the Nile perch project was abandoned. No live Nile perch were ever brought into Australia.

Meanwhile, the technology for producing barramundi fingerlings had been developed in Asia, particularly in Thailand. The Thai technique involved stripping ripe fish on the spawning grounds. The best-defined spawning grounds in Queensland were at Weipa in the Gulf of Carpentaria. Mackinnon and Cooper (1987) successfully used the Thai method to produce Weipa strain barramundi fingerlings, and these were first stocked into Lake Tinaroo in 1985. This is a reasonably large lake, covering 3,500ha at full supply level, holding 440,000ML and with a shoreline length of 209km. While netting surveys indicated the fish were surviving and growing well, anglers were capturing very few fish. A team of 28 of the best known barramundi anglers and fishing media personalities in the nation was assembled in February 1988 for a fishing weekend, in an attempt to publicise the fishery. No barramundi were caught. Lake Tinaroo barramundi thus earned a "bad" reputation as being very difficult to catch. This reputation has been very difficult to shed.

Detailed in the following sections is the combination of science, management, publicity, local commitment and hard work, which reversed this reputation. The Lake Tinaroo barramundi fishery is now regarded by many as the ultimate freshwater fishing experience in Australia.

Strain Selection

The technique of stripping wild ripe fish on the spawning grounds was having some success in producing fingerlings. However it was only at Weipa that the spawning grounds were well enough defined and barramundi numbers large enough to provide a reasonable chance of success in capturing the fish at the right stage of maturity. The major demand for fingerlings for stocking purposes was from impoundments and streams along Queensland's East Coast, where strains of barramundi existed that were different to the Weipa strain. Queensland had a strict policy of not mixing genetic strains, particularly of valuable recreational and commercial species such as barramundi. Thus the fingerlings produced from Weipa were only allowed to be stocked into secure impoundments such as Tinaroo, which was above a substantial waterfall 300m high. There is little chance that a barramundi would survive such a fall, particularly as these falls incorporate cascades.

Commercial and recreational fishermen were concerned the practice of netting spawning aggregations could be disrupting successful spawning and thus recruitment. Because of the limited opportunities to stock Weipa strain fingerlings, along with a number of other problems listed by Garrett *et al* (1987), research was initiated into hormone induction of captive broodstock in a hatchery situation.

Initially, success was sporadic, with just enough fingerlings produced in the hatchery to enable experimental stockings of Cairns strain barramundi to be undertaken. Survival and growth experiments with Cairns and Weipa strains were undertaken in Lake Morris, west of Cairns, by Hogan, Barlow and Graham (in prep.). This lake has a surface area of just 330ha, so is much smaller than Lake Tinaroo. Survival and growth were monitored by a multiple mark/recapture protocol whereby barramundi were caught in gill nets, tagged with dart tags, and released. The first stocking consisted of 599 Cairns strain barramundi, stocked in February, 1987. The second stocking was of 4,000 Cairns strain in April, 1989. This was followed by a release of 2,000 Weipa strain in November 1989. The stocks were sampled at least once per month. Figure 1 shows the growth of these stockings over a year. Note the water temperature was measured at 2m depth, which is where it was believed the barramundi spent most of their time. The line drawn is an average of values over the different years of the experiment.

The major finding was that the Cairns strain continued to grow at all temperatures recorded during the year. The Weipa strain ceased to grow at all once the water temperature was at or below 25°C. Obviously feeding activity and growth would be intimately linked, as would feeding activity and catchability. Thus between April and September, when the water was at or below 25°C, Weipa strain barramundi would be unlikely to be caught. Growth and thus feeding was also much reduced in March and September, so for eight months of the year, Weipa barramundi would be virtually unavailable to anglers. Experience also revealed that a cold snap and falling water temperatures in summer also suppressed the catchability of this strain.

We concluded that Weipa strain barramundi was not a good source of fingerlings to stock Lake Tinaroo with if the aim was to create a reliable recreational fishery. We now have a policy of using only local Cairns strain fingerlings. Barramundi are now caught in Lake Tinaroo by anglers in every month of the year. We also concluded that maximum growth and survival could be obtained if fingerlings were stocked when water temperatures were at their warmest, which was during December and January.

Further pressure was thus generated on fingerling suppliers to produce Cairns strain, and thus hatchery bred barramundi. Garrett and Connell (1991) and other researchers at both the Northern Fisheries Centre in Cairns, and the Freshwater Fisheries and Aquaculture Centre at Walkamin in Queensland, did a lot of good research into broodstock maintenance, spawning induction techniques and fingerling production methods. Production of large numbers of barramundi fingerlings from captive broodstock is now a routine procedure.

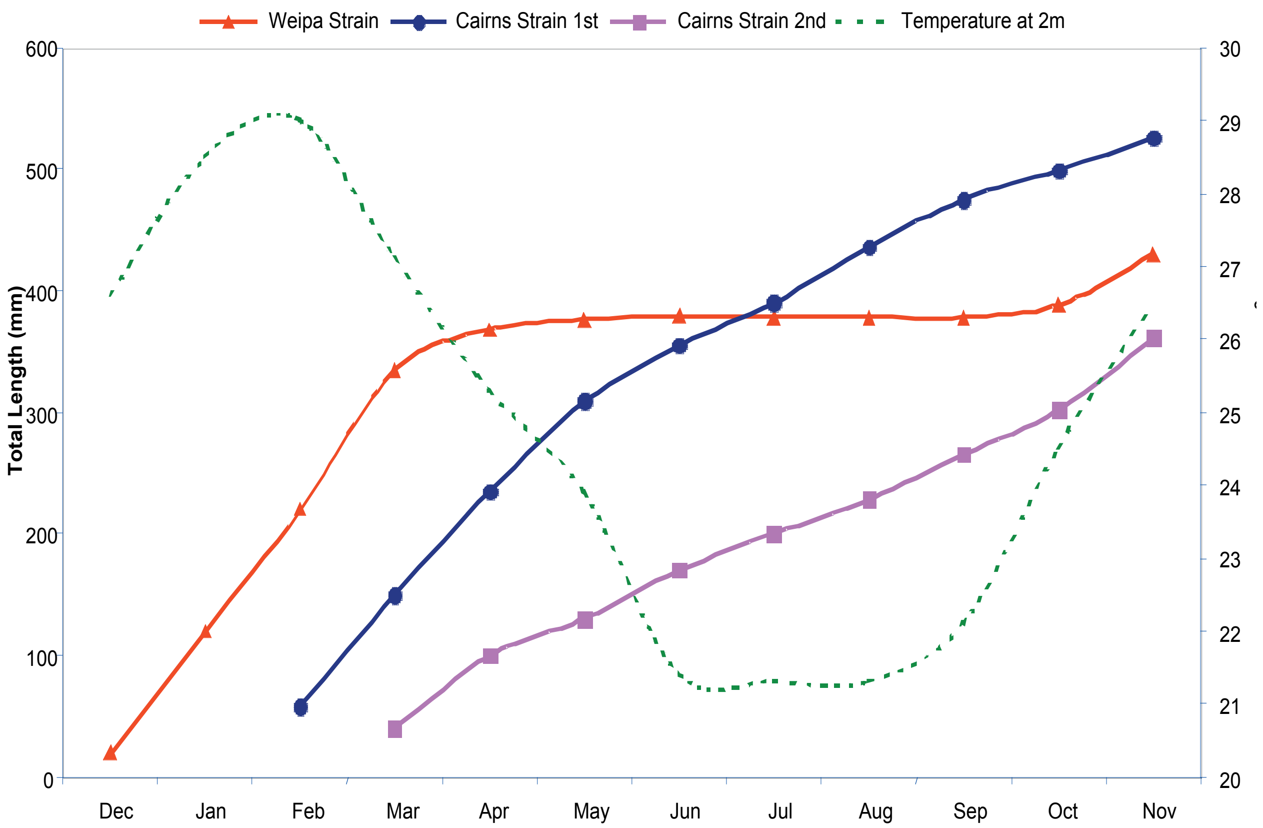

Figure 1. Comparison of growth between strains.

Management Changes

Although Cairns strain barramundi was the only one stocked into Lake Tinaroo from 1991 onwards, angler catches were still regarded as less than desirable. The estimated fishing time required to catch one fish was eleven hours. Our target catch rate was one fish per hour. One perceived problem was that it was technically illegal to fish for barramundi when the fish was most active, and that was during spawning time, when there was a closed season.

The barramundi has a catadromous life cycle, spawning in saltwater along the coastline during summer (Garrett, 1987). Barramundi stocked into the freshwaters of Lake Tinaroo had no chance of ever reaching the coast and contributing to wild barramundi stocks. There was no reason to maintain the closed season on barramundi in Lake Tinaroo, so anglers began lobbying to have the closure lifted.

After four years of debate, the Queensland Fisheries Management Authority changed the fishing regulations to allow the taking of barramundi from Lake Tinaroo during the 1995-6 closed season. In addition, the upper size limit of 120cm, designed to protect the larger spawning females, was also lifted . The bag limit of five and lower size limit of 58cm remained, basically as a public education measure. Thus Lake Tinaroo became the only place in Queensland in which an angler could legally fish for and keep barramundi. It was also the only place from which 120cm or larger barramundi could be taken. This measure virtually guaranteed that all world and national angling records for barramundi would eventually be for fish captured in Tinaroo.

These regulatory changes were very much based on common sense. However, there were conditions. Fish taken outside the ring road encompassing the lake had to be specially tagged and certified as originating from the lake. Three tagging stations were set up at convenient access points. Experience has shown that this system worked well initially. It proved to the regulating authorities that specific recreational fisheries regulations and exemptions for individual areas were practical and feasible. Thus the Tinaroo regulations were the precursor to a number of other site-based regulations. After six years of this system, however, many regular anglers are failing to have their catches specially tagged. Other site-specific regulations, for example for impoundment caught bass, do not include special identifying requirements. It is likely that the special tag requirement for Tinaroo will be dropped in the near future.

Stocking Rates

The initial barramundi stockings in Lake Tinaroo were done by the Queensland Department of Primary Industries (DPI) as a pilot project to determine the suitability of barramundi as an impoundment angling species. Between 1985/6 and 1991/2, the DPI stocked an average of 23,125 fingerlings per year, which equated to 6.6/ha. While such low densities could be sampled effectively with gill nets, fishermen with rod and reel were having great difficulty finding them. As well, the pilot stocking program had gathered enough information to demonstrate the suitability of barramundi as a stocking species, so was finalised. The only way barramundi were going to be stocked into the lake from that point was if the community itself formed a stocking group. Thus the Tableland Fish Stocking Society was formed in 1992 to raise funds, purchase fingerlings and stock them into the lake. The society has managed to raise enough funds to stock, in partnership with the DPI, an average of 69,739 fingerlings per year (20/ha) since 1992/3. The total number of barramundi stocked into the lake to date is 803,500. Most of these were stocked at 25mm, with the sizes ranging from 20 to 300mm. The cost price of these fish would total approximately $200,000.

When anglers present their catches to the tagging stations, details such as time and place of capture, plus the length of time spent fishing, are recorded. From this data, the last 110 fish caught in the lake took an average of 3.4 hours fishing time to catch. This data only includes the successful anglers who kept and presented fish. In a recent weekend fishing competition, just 32 barramundi were weighed in, despite the efforts of 516 anglers This catch rate is still short of our aim to reduce fishing effort to 1 hour per fish for the average angler.

The desired stocking rate for barramundi in Lake Tinaroo is 100 fingerlings/ha/year, and the society has a permit to stock at this level (330,000 fingerlings per year!). The chances of a volunteer community group raising the necessary dollars to stock a large lake at this level annually were slim. The Tableland Fish Stocking Society and other stocking groups in similar positions throughout the state therefore lobbied to introduce a “user pays” system to provide the necessary finance. A Stocked Impoundment Access Fee was eventually introduced in July 2000 on 25 impoundments throughout Queensland to provide some funding to assist the stocking groups to maintain and enhance the fisheries. The success of this scheme is yet to be determined.

Fish Barrier Net

The major concern with stocking a catadromous species such as barramundi is that all mature fish will exit over the spillway at the first opportunity. In 1989, the dam spilled by 52cm, and quite a few fish did swim over the spillway, only to be killed by the 42m fall and impact with the energy dissipaters below. There was no mass exodus, however, even though the spill lasted 106 days. The dam spilled again in 1990, for 124 days, but only to a maximum depth of 24cm. Again, a few fish were lost. These spills occurred between the end of April and August, which was after the spawning season, which

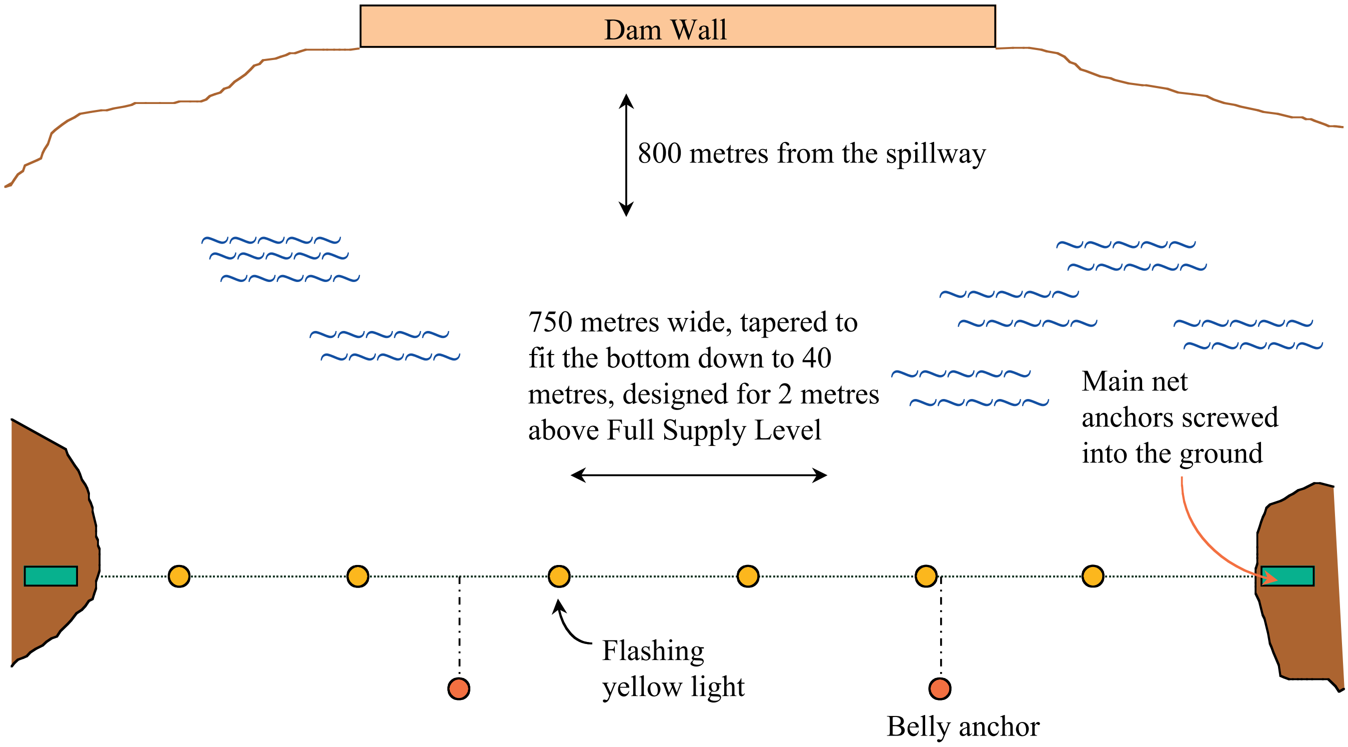

Figure 2. Lake Tinaroo fish barrier net.

normally occurs between November and February.

During Christmas 1990, however, a cyclone crossed the Tinaroo catchment. The dam spilled on 19 January 1991, to a depth of 96cm. This spill lasted for 185 days, during which thousands of dead fish were collected from below the spillway. Most fish went over the spillway during the first few weeks of the spill, yet there didn't appear to be a deliberate migration downstream, despite it being the spawning season. Nevertheless, we estimated half the stocked fish were lost over the spillway. This estimate was based on the losses from Lake Morris.

Mark recapture survival estimates of the three stockings in Lake Morris, depicted in Figure 1, were 82% for the 1st Cairns strain stocking, 37% for the 2nd, and 88% for the Weipa stocking (Hogan, Barlow and Graham, unpublished data). The lake did not spill during the growth to legal size of the 1st stocking. An 85cm spill occurred during the growth period of the 2nd stocking, and a fish barrier net was in place in front of the spillway for the 50cm spill during the growth of the Weipa stocking. The difference of approximately 50% between the high and low estimates was therefore attributed to losses over the spillway during the 2nd stocking.

It was relatively easy to screen off the Lake Morris spillway, as it was just 40m wide by 6.5m deep at FSL. Tinaroo Dam was an entirely different proposition, with the spillway itself being 76m wide and 42m high. The narrowest convenient possible net site was also 750m wide. Alternatives such as bubble curtains, sonic barriers and strobe lights were considered, but the only method with any proven record was a physical barrier such as a net.

Six years of intensive lobbying eventually succeeded in obtaining approval to install the net. The Queensland Government provided the $95,000 required to construct the net, and it was installed for the first time in 1997. The main material is 55mm by 24 gauge knotless prawn mesh. The heavy gauge prevents fish from gill meshing in it. The deployed net is depicted in Figure 2.

\Because of maintenance requirements and variability in the water level, the net is only deployed while the lake is spilling. The net has had to be set every year since 1997, withstanding a record spill of 235cm in 1999. The lake also spilled by 200cm in 2000. Very few fish have been found dead below the spillway since the net has been deployed. There have been fish trapped between the net and dam wall, which have exited over the spillway. Otherwise, the net is believed to be 100% effective.

The advantages of the net are that it prevents the loss of the valuable stocked fish from the lake, prevents a potential health hazard from the possible thousands of tonnes of dead fish, and demonstrates to the general public that the authorities will take all plausible measures to retain and enhance the barramundi fishery in Lake Tinaroo. This positive publicity is very important to the success of the fishery.

Publicity Campaign

The final step in taking the Lake Tinaroo barramundi fishery from having a bad reputation to one of the most desirable fishing destinations in Australia was a positive media campaign. We made a conscious decision to promote the fishery at every opportunity. John Mondora was a founding member of the Tableland Fish Stocking Society, and he wrote in excess of 30 magazine and newspaper articles about the Tinaroo fishery. Other leading writers such as Neil Schultz, Rod Harrison, Mark Williams, Steve Morgan and others also wrote about the Tinaroo fishery. The barramundi fishery was also featured in many TV shows. These included "Wildfish", "Landline", "Rex Hunt's Fishing Adventures", "Hooked on Water", "Creek to Coast", and a number of American and Japanese TV programs. I have also taken every opportunity to appear on radio programs, the local television news and in regional and state newspapers with stories about Tinaroo.

The all tackle world record barramundi capture has been broken twice in Lake Tinaroo, each time with nationwide media coverage. The current world record stands at 37.85kg for a fish caught on a lure in Lake Tinaroo in 1999. This record is unlikely to stand for very long, as the fish are still growing at an average 2.5kg per year. Such captures attract a lot of positive publicity.

Thus Lake Tinaroo now has a thriving fishery. It is unknown how much the Lake Tinaroo barramundi fishery is currently worth to the regional economy, but it is believed to be substantial. Rutledge *et al* have performed the only scientific evaluation of the economics of the Tinaroo fishery, but in 1990. These authors determined a cost benefit ratio for barramundi stockings of 1:31. On this figure, the fishery would currently be worth $6,200,000 annually. However, there have been substantial improvements to the fishery since 1990, as outlined in this paper. The fish are also 10 times heavier on average than the figure used to calculate the value of each individual fish ($153 in 1990). As well, ancillary industries not considered then have developed. As an example, one Cairns taxidermist who specialises in fish mounts, took $15,000 worth of orders in the week following the annual fishing competition. He already had a backlog of work worth $100,000. At least three fishing guides, a boat hire, houseboats, a ships chandlery, two lure makers and a number of fishing lodges also operate on the lake. These too weren't considered in the 1990 estimates.

Future Plans

The highly prized mangrove jack (*Lutjanus argentimaculatus*) is currently being evaluated as a stocking species. This evaluation project is nearly finalised. The mangrove jack too shows great promise. It is a species that will appeal to anglers of all levels and ages, and if stocked in sufficient numbers, will make Lake Tinaroo one of the world's most desirable fishing destinations.

References

Barlow, C.G. (1984). The Nile perch project: progress and plans. *Search* **15**(3-4), 88-91.

Barlow, C.G. and A. Lisle (1987). Biology of the Nile perch *Lates niloticus* (Pisces: Centropomidae) with reference to its proposed role as a sport fish in Australia. *Biological Conservation* **39**, 269-289.

Garrett, R.N. (1987).Reproduction in Queensland barramundi (*Lates calcarifer*) pp. 38-43 in Copland, J.W. and D.L. Grey (eds.). *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, 210p.

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

Garrett, R.N., M.R. MacKinnon and D.J. Russell (1987). Wild barramundi breeding and its implications for culture. *Australian Fisheries* **46**(7), 4-6.

Hamlyn, A. (1995). A history of fish stocking in Southern Queensland - where are we at? In 'Fish Stocking in Queensland, Getting it Right'. Proceedings of the symposium held in Townsville, Queensland, 11 November 1995. (Eds. P. Cadwallader and B. Kerby) pp 25-33. (Queensland Fisheries Management Authority, Brisbane).

Hogan, A.E. (1995). A history of fish stocking in North Queensland - where are we at? In 'Fish Stocking in Queensland, Getting it Right'. Proceedings of the symposium held in Townsville, Queensland, 11 November 1995. (Eds. P. Cadwallader and B. Kerby) pp 8-24. (Queensland Fisheries Management Authority, Brisbane).

MacKinnon, M.R. and P.R. Cooper (1987). Reservoir stocking of barramundi for enhancement of the recreational fishery. *Australian Fisheries* **46**(7), 34-37.

Midgley, S.H. (1968). A study of the Nile perch in Africa (and consideration as to its suitability for Australian tropical inland waters), *Winston Churchill Memorial Trust Fellowship Report* No. 3.

Rutledge, W., M. Rimmer, J. Russell, R. Garrett and C. Barlow. (1990). Cost benefit of hatchery-reared barramundi, *Lates calcarifer* (Bloch), in Queensland. *Aquaculture and Fisheries Management* **21**, 443-448.

Artificial Spawning Substrate: Sex Aids for Desperate Handfish

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Abstract

The rare spotted handfish (Brachionichthys hirsutus) has a life cycle characterised by low fecundity and restricted dispersal. Successful reproduction of this species appears to be limited by the availability of vertical structures on the sea floor suitable for the attachment of an egg mass. Seagrass, types of algae (Caulerpa spp) and stalked ascidians (Sycozoa spp) have been utilised by handfish for this purpose. A low and decreasing abundance of these organisms within the spotted handfish's small range was of concern. To counter this threatening process, the provision of Artificial Spawning Substrate (ASS) was considered a management option with merit. Two similar ASS designs, modelled on the most common natural spawning substrate, were constructed from PVC and deployed at two locations in the Derwent estuary. Severe sand scouring at one experimental site removed sufficient ASS to make analysis of the data impractical. At the second experimental site, fifty-four handfish egg masses were located within the experimental zone, the majority (90%) attached to ASS. There was no significant difference between the utilisation of either type of ASS (P = 0.26). The results of this trial suggest that the deployment of ASS at strategic locations to enhance handfish reproduction should form part of an ameliorative strategy for this species.

Why enhance spotted handfish stocks?

The spotted handfish, *Brachionichthys hirsutus* was once commonly observed in its restricted historic range within the Derwent Estuary and adjoining bays and channels. Few observations during surveys in 1989/90, 1994 and 1996 suggested that *B. hirsutus* had suffered a dramatic decline in both range and abundance since the mid - 1980's. Spotted handfish were subsequently classified as Endangered (ASFB in 1994) and Critically Endangered (IUCN in 1996). It became the first marine fish to be listed as Endangered under the Commonwealth Environment Protection and Biodiversity Conservation Act (1999).

Brief background on handfish biology

All handfish species have limited movement and dispersal capabilities. Juveniles and adults have a benthic habit, preferring to walk on modified pectoral and pelvic fins rather than swim. Typically, resighted spotted handfish have moved less than 100 metres between observations. One spotted handfish was relocated less than 100 metres from its original position after an intervening period of 21 months. A few individual fish have been relocated around 200 metres from the position of first sighting after periods of 6 to 12 months.

Handfish do not have pelagic eggs or a pelagic larval stage for dispersal. Eggs are attached to the benthos where hatchlings emerge fully formed and settle directly onto the sediments.

Handfish have a low fecundity, with egg masses typically between 80 and 150 ova. The female usually stays with the eggs for the 7 to 8 weeks prior to hatching. Spotted handfish mature at the end of the second or third year, around 70 mm in length.

Successful spawning is dependent on the availability of vertical objects on the sea floor suitable for egg attachment. Spotted handfish have been observed using vertical blades of seagrass (*Heterozostera* spp.), fronds of small macrophytes (*Caulerpa* spp.) and the stalk of the Holozoan ascidian (*Sycozoa* spp.). In the Derwent Estuary ascidians are the predominant spawning substrate; other suitable structure are uncommon.

Observations of spotted handfish populations in the field suggest that there is marked inter-annual variability in recruitment. The local availability of suitable structures, the effects of weather (ie, storm surge) and irregular ecological events (such as heavy settlement of the native paper oyster, *Electroma georgiana*) are likely to affect the success of recruitment in any breeding season. Natural spawning substrates are subject to fouling and environmental degradation (particularly detachment), which may reduce spawning success and increase egg and early juvenile mortality.

Our field observations indicated that the ascidian density was in decline at one of the regularly surveyed locations in the Derwent Estuary (figure 1). As no other type of natural spawning substrate was available at this site we thought it would be a sound strategy to provide artificial structures for handfish egg attachment.

Concept development

We had evidence that handfish had utilised artificial structures for spawning in the past. An archived photograph of a Ziebell's handfish in an aquarium with eggs wrapped around the uplift tube was incentive to place vertical plastic rods in aquaria during captive rearing trials in 1996 and 1997. These were successfully used by captive spotted handfish for egg mass attachment.

Two types of Artificial Spawning Substrate (ASS) were prepared for field trials. One was made using 6 mm diameter PVC rod as the vertical component and was the more expensive to produce. The second model used 3 mm PVC welding rod as the vertical component. The vertical rod in both models was 200 mm in length. A 50 mm diameter disc of 3 mm PVC sheet was attached 50 mm along the length of the vertical. The function of the disc, once buried into the sediments, was to anchor the structure firmly on the sea floor. A small rubber band was positioned onto the vertical rod to help stop any egg mass from slipping off.

Experimental aims and design

The principle aims of the experiment were (1) to test whether spotted handfish would use ASS in the wild, and (2) establish if the ASS design was stable in the natural environment. A secondary aim was to determine if there was any difference in the use of thick or thin ASS by spawning handfish.

Two sites, approximately 4 km apart, were selected to trial the ASS in the Derwent estuary. Both sites had populations of adult handfish and spawning on ascidians had been observed at both locations in previous years. For the purposes of this text these sites will be referred to as Site 1 and Site 2.

Experimental areas were marked out on the sea floor at each site using a grid-work of alpha-numerically coded steel pegs. An area 100 metres long by 15 metres wide (running parallel with the shore in 8 metres of water) was divided into sixty 5 x 5 metre quadrats. At Site 1 twelve quadrats were selected at random for treatment. At Site 2 thirteen quadrats were similarly selected. Each treatment consisted of 10 thick ASS and 10 thin ASS embedded into the sediments within the quadrat in a random manner. ASS were deployed in mid - August 1998.

Results

Initial observations of ASS in late August were very encouraging. Adult spotted handfish were located in the vicinity of ASS. Occasionally small groups of 2 or 3 fish were located within treatment quadrats. The first spotted handfish egg masses were observed on ASS in late September.

Site 1

Quadrats were checked at this site on 4 occasions. Only 3 egg masses were observed on ASS. Heavy water movement through the area had scoured the sediments, dislodging many of the ASS. In some cases only 1 or 2 ASS remained within a treatment. Consequently it was impractical to make any analysis of this site.

Site 2

This site was given its final check during two days of diving in early October. Fifty-five of the quadrats were searched, including 12 of the 13 treatments.

A total of 54 spotted handfish egg masses were located within the experimental area. Within the 12 treatment quadrats checked, 50 egg masses were attached to ASS (2 on a single ASS) and 3 were attached to ascidians. Within the 43 control quadrats checked only one egg mass was located (attached to an ascidian).

There was no significant difference in the number of egg masses around thick and thin ASS (ANOVA, $P = 0.26$), see figure 2.

The amount of spawning activity within the quadrat area appeared to be greater than that of the surrounding area. The mean density of egg masses was calculated for the entire surrounding area (500 x 100 m = 50,000 m^2) and compared to that of the (checked) experimental area (55 x 25 m^2 = 1,375 m^2). The mean egg mass densities were 1/1000 m^2 and 39/1000 m^2 respectively.

Conclusions

Artificial Spawning Substrate can be used to enhance the reproductive potential of spotted handfish in the wild. A deployment of around 400 ASS near the experimental quadrats at Site 1 prior to the 1999 breeding season (Spring) was attributed to a subsequent high recruitment of juvenile handfish observed in early 2000 (figure 3). The recruitment index for this year class is the greatest we have observed so far at Site 1. The coinciding low abundance of natural spawning substrate during this period also suggests the ASS have been successful in enhancing the recruitment of spotted handfish. Note also from figure 3 that even in a year when (the relatively close) Site 2 had high recruitment, Site 1 did not. This suggests that spawning substrate may have been limiting at Site 1 on this occasion.

As there was no significant difference in utilisation of the thick or thin ASS, the cheaper (thin) ASS can be used for enhancement purposes.

The aggregation of handfish in areas of high spawning substrate density during the breeding season may also increased the chance of encountering a mate. Small scale aggregation of handfish has been observed around high densities of natural spawning substrate at another site, indicating this is not an unnatural behaviour.

Artificial Spawning Substrate was susceptible to loss from sand scouring. Embedding the anchoring disc deeper into the sediments or deploying the units in areas not subject to sand scouring reduces dislodgment.

Acknowledgments

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Using population Models to ameliorate the decision making process in the stocking and reintroduction of trout cod

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A bstract

The decision about where to place hatchery produced fish as part of a stocking or reintroduction program may not be a simple task. The decision making process can be simplified if the different decisions available could be ranked based upon some criteria of success. A population model describing the ecology of trout cod in terms of both deterministic and stochastic processes was written to analyse three different stockingreintroduction strategies. These strategies relate to the plascement of a one off extra allocation of 20,000 trout cod fingerlimgs. These fingerlings could be added to: (i) the Ovens River allotment of 2,000 one year old fish and 20,000 fingerlings; (ii) the Golburn River reintroduction of 1994-96; or (iii) a placement at a new location identified as being part of the former range and providing suitable habitat. Based upon predictions of the model it was concluded that the extra allocation of fingerlings would be best used to enhance the Ovens River stocking. The methods implemented in this study can be broadly applied to aid the decision making process for other native species for both stocking and reintroductions.

Prospects for stock enhancement in the Tasmanian rock lobster fishery

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Introduction

The southern rock lobster, *Jasus edwardsii*, is distributed across southern Australian and New Zealand waters and is fished commercially across its range. Within Tasmania, the southern rock lobster fishery constitutes the backbone of the fishing fleet with over 240 vessels and directly employs over 600 people. The fishing fleet is decentralized and is a major contributor to the socio-economic wellbeing of the communities associated with regional ports. In the 1998/99 fishing season the catch was about 1480 tonnes with a value in excess of $45 million (Gardner, 1999).

The economic importance of the fishery, and the high value of the product, mean that small improvements in catch can have significant economic benefits. Although current management strategies aim at rebuilding the stock, there are a number of options for enhancement of catches. These include: direct addition of hatchery reared juveniles, short-term culture of wild caught post-larvae to overcome high mortality periods in the wild prior to re-seeding, addition of artificial reefs and translocating lobsters from low productivity to high productivity regions.

Several research projects directed at the enhancement of rock lobster stocks have been undertaken at the Tasmanian Aquaculture and Fisheries Institute. Three of these are outlined in this paper. Support for research in this field has increased due to recent initiatives into rock lobster aquaculture. Aims are to increase yield, to increase egg production in certain regions, and to compensate for the harvest of pueruli (juveniles) for ongrowing in aquaculture.

Enhanced Settlement

Settlement of southern rock lobster pueruli has been monitored since 1991 at several locations around Tasmania (Gardner *et al.*, 1998). This long-term project was established to provide an index of rock lobster recruitment, to be used for predicting future catch rates. This has recently proved successful in Tasmania (Gardner *et al.*, in press).

Crevice collectors developed in New Zealand (Booth and Tarring, 1986), are used to monitor settlement. The crevice collectors consist of seven wedge shaped crevices formed by eight 400 x 400 mm, plywood sheets (Figure 1a.; Booth and Tarring, 1986). The collector head is secured within a galvanised steel frame, which is attached to a mooring stand. These collectors are currently serviced by divers, which is both time consuming and expensive. Improving the efficiency of the collectors so that trends could be detected with fewer collectors became a priority.

Research on puerulus settlement in Japan has demonstrated that higher settlement occurs on collectors with floating seaweed attached (Chris Norman, Tokyo University of Fisheries, Pers. Comm.). The enhanced settlement did not appear to be due to any chemical stimulus of the seaweed, rather, seaweed simply increased the settlement area for the puerulus. Consequently, we examined the effect of mesh attached to collectors (to simulate macroalgal cover) to test if settlement was enhanced in *J. edwardsii*.

Methods and Results

To represent algal cover over a rocky reef, standard crevice collectors (Booth and Tarring, 1986) were modified by attaching 50 mm trawl mesh, wrapped around a buoyed line - termed “mesh collector” (Figure 1b). These “modified collectors” (Figure 1c), were deployed with standard crevice collectors to compare catch rates. In addition to the modified crevice collectors and control standard crevice collectors, mesh collectors were also deployed alone (i.e. not attached to a crevice collector) to provide additional information on the effect of mesh on catches. Catches of puerulus were monitored monthly for 9 months.

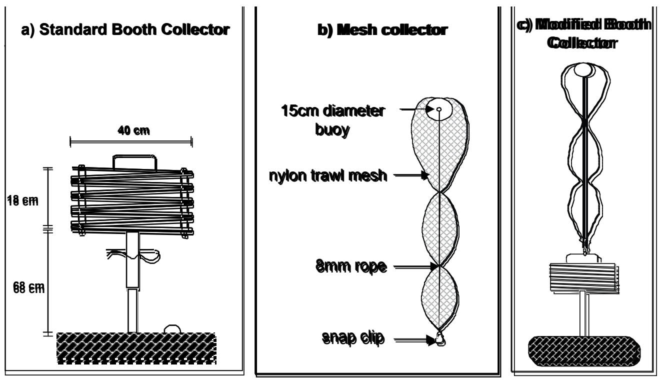


Figure 1. Puerulus collector designs. a) Standard crevice collector (Booth and Tarring, 1986). b) Mesh collector consisting of a buoyed line with 15cm trawl mesh attached. Brass snap clip used for attaching mesh collector to the top of the standard Booth collector. c) Modified crevice collector consists of a standard Booth collector with a mesh collector attached.

The standard crevice collectors and the modified collectors had similar trends in monthly catches (Figure 2). Modified crevice collectors however caught significantly more puerulus than standard crevice collectors, while few puerulus were found on the attached mesh. Catches on mesh collectors were not included in analyses, as most caught no puerulus. To test if enhanced catches recorded on modified collectors were at the expense of neighbouring collectors we compared catch rates on the standard collectors (controls), interspersed with the modified collectors and with standard collectors at adjacent sites. Trends in catch rates of both groups of crevice collectors, recorded prior to the experiment, remained the same after the addition of the modified collectors, confirming that catches on the modified collectors reflected enhanced settlement in the region.

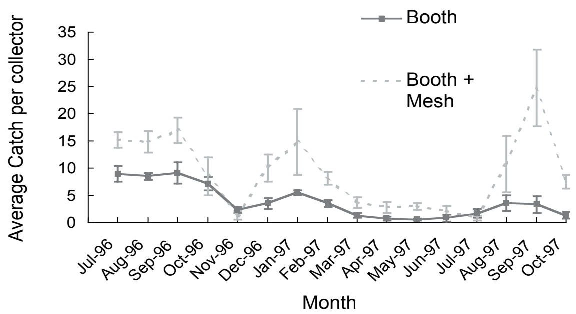


Figure 2. Trends in puerulus catches on standard Booth collectors and modified Booth collectors (with mesh collector attached). Sampling was conducted from July 1996 to March 1997 with 6 collectors of each type. The number of puerulus is all puerulus and post-puerulus stages combined with juveniles excluded

Assessment of survival of ongrown juveniles

While hatchery methods of producing puerulus are still being investigated, wild grown pueruli must be viewed as a finite and valuable component of the rock lobster fishery resource. The efficiency of the wild fishery lies in the fact that there is no investment in individual lobsters prior to harvest, although survival from puerulus through to harvest is low. Methods of increasing survival to a marketable product have the potential to significantly improve the yield.

Survival through the first year of life in the wild is low with survival estimates for the spiny lobster *Panulirus argus* as low as 3% (Herrnkind and Butler, 1994). In contrast, *J. edwardsii* puerulus removed from the wild and on-grown in culture for a year have a 93-99% survival rate (Crear *et al*., 1998). Following culture through this period of high mortality, there are two options for producing a marketable product; ongrowing in culture, or reseeding wild populations for future harvest.

If lobsters are retained for culture, there is a net loss to the fishery. Releasing, after a year of culture, the equivalent number of juveniles that would have survived in the wild, could offset this loss. Any additional juveniles released above this would act to enhance the fishery, so that it becomes possible to both enhance the fishery and retain animals for ongrowing in culture.

The potential for this enhancement benefit is dependant on the ability of on-grown juveniles to survive following release. Survival of reseeded juveniles may differ from that of wild juveniles as they may be more vulnerable to predation or have less ability to locate and compete for food and shelter resources after 12 months in culture.

Little is known about movement, behaviour or survival of the early juvenile stages of southern rock lobster in the wild. Difficulties in capturing this early life stage have limited research opportunities. Accordingly, this preliminary project did not aim to quantify survival of reseeded juveniles, but rather develop methods for accurately assessing survival of reseeded lobsters relative to wild lobsters in the field over short periods of up to 1 month.

Methods and Results

Although movement of juvenile lobsters was not the primary interest of this study, it was anticipated that it would be critical in establishing robust methods for estimating survival. Movement patterns were assessed by attaching miniature acoustic transmitters (IBT96-1 tag, Sonotronics, 1130 E. Pennsylvania St., Suite 505 Tucson, AZ85714) to lobsters on-grown from puerulus and equivalent sized lobsters caught from the wild. The aim of this was to assess the appropriate size of area to be searched by divers in a large-scale reseeding exercise.

Three lobsters from each of three treatments were released on an area of patch reef on two occasions. On-grown lobsters were released with two control groups: lobsters captured on the release reef; and lobsters captured on neighbouring reef. The second group was included to assess whether lobsters captured at neighbouring reef sites exhibited any 'homing' behaviour when released in a different location. These were tracked for a period of 11 days. Most movement was confined to a small area centred on the release site (Figure 3). However, one lobster from each treatment moved in excess of 50m from the release site during the experiment.

On-grown lobsters were observed by divers to immediately move into appropriate shelters or dens, often cohabiting with wild lobsters. Avoidance behaviour towards divers and thus potentially large predators appeared well developed. All lobsters were recaptured after 11 days and their stomachs removed. Similar stomach fullness and gut contents were observed from wild and on-grown lobsters.

Our ability to estimate the survival of reseeded juveniles was assessed by mark/recapture surveys of 427 individually antennal-tagged juvenile lobsters ongrown for a year since capture as pueruli, and 153 similar sized wild caught controls.

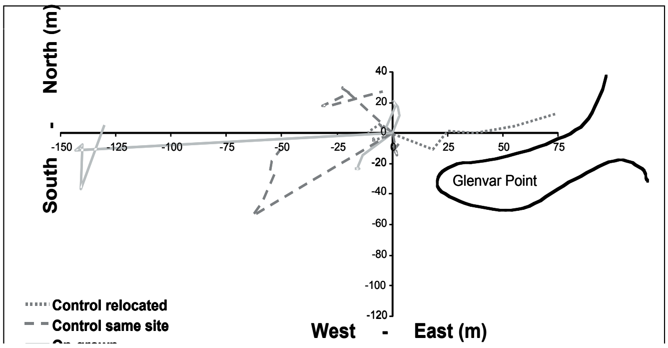


Figure 3. Daily movement tracks for nine acoustic tagged lobsters from 3 treatments groups: reseeded on-grown, relocated wild caught control and same site wild caught control lobsters.

To overcome the problem of movement-biased survival estimates, two approaches were used, involving different search methods. The first, the Jackson Square technique (Manly 1985), uses movement between grid squares within the search area to estimate movement away from the search area. An optimal search area of 32m x 32m was determined from our acoustic tracking study. This area was divided into a grid of 4m x 4m squares, and searched intensively on 9 occasions over 1 month. Position and tag code of lobsters within the grid, and on reef immediately adjacent to the grid were recorded.

The second approach involved wider area searches, using transects up to 800m from the release reef performed on 3 occasions. Data on movement between the release reef and adjacent areas were included in a multi-strata mark/recapture model to derive survival estimates. This approach accounted for animals emigrating beyond the search area, but potentially increased the risk of missing animals that were present. Analysis in the second approach used a multi-strata Cormack Jolly Seber model, which permits estimation of parameters for different spatial areas (termed "strata"). Analysis was performed using program MARK (Cooch and White, 1999). We attempted to survey such a broad area that emigration out of the search site was minimal. This was tested by searching at increasing distances from the release site until the proportion of tagged lobsters decreased to zero.

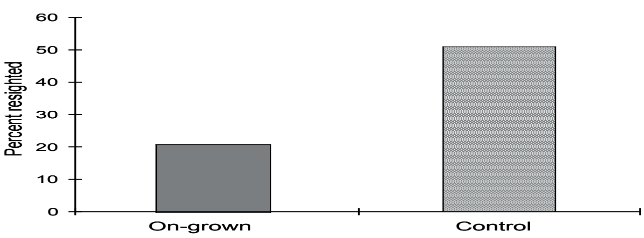


Figure 4. The percentage of on-grown and control lobsters resighted within the Jackson Square search area during the survey period.

During surveys within the Jackson Square, a significantly higher percentage of control than on-grown lobsters were resighted (Figure 4). Possible conclusions from these surveys were that mortality amongst on-grown lobsters was high, or that movement beyond the Jackson Square grid was greater for on-grown lobsters than controls. Transects performed for multi-strata modelling confirmed the second possibility to be true. Lobsters from both groups moved considerably further than anticipated from acoustic tracking results, and on-grown lobsters moved further than controls. As distance from the release site increased, the proportion of on-grown lobsters resighted by divers increased (Figure 5). In transects 400 and 800m from the release site, the proportion of on-grown lobsters sighted was higher than initially released.

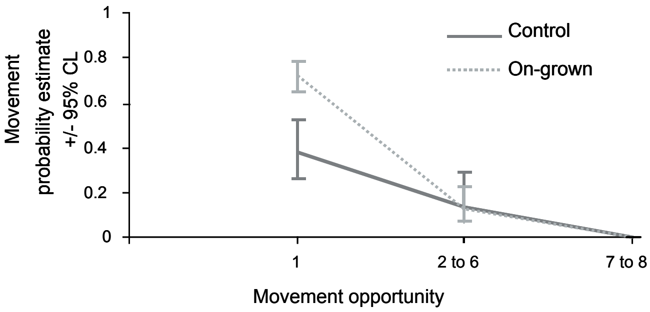


Figure 5. Comparison of movement of control and on-grown rock lobsters. Counts of on-grown rock lobsters from transects were conducted on the last resighting opportunity (sample 9) at a range of distances from the release site. The proportion of on-grown animals is lowest near the release site but increases with distance. This demonstrates that on-grown animals tended to move further from the release site than controls.

Multi-strata modelling was more robust than the Jackson Square technique for measuring survival of juvenile rock lobsters as it allowed some flexibility in extending the sampling area to cover all habitat being used by the reseeded juveniles. Divers could follow natural reef contours to optimise their chances of resighting juveniles, rather than be constrained by the geometric grid of the Jackson Square. Estimates from the model confirmed higher rates of movement by on-grown lobsters, but only in the first two days following release (Figure 6). Surveys after this period revealed little or no movement suggesting lobsters had redistributed away from the areas of highest density and settled into dens.

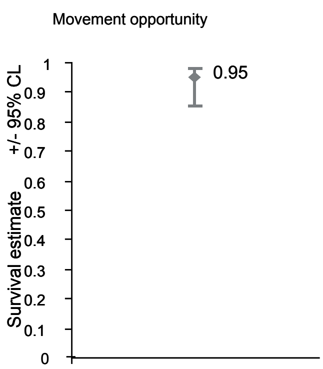
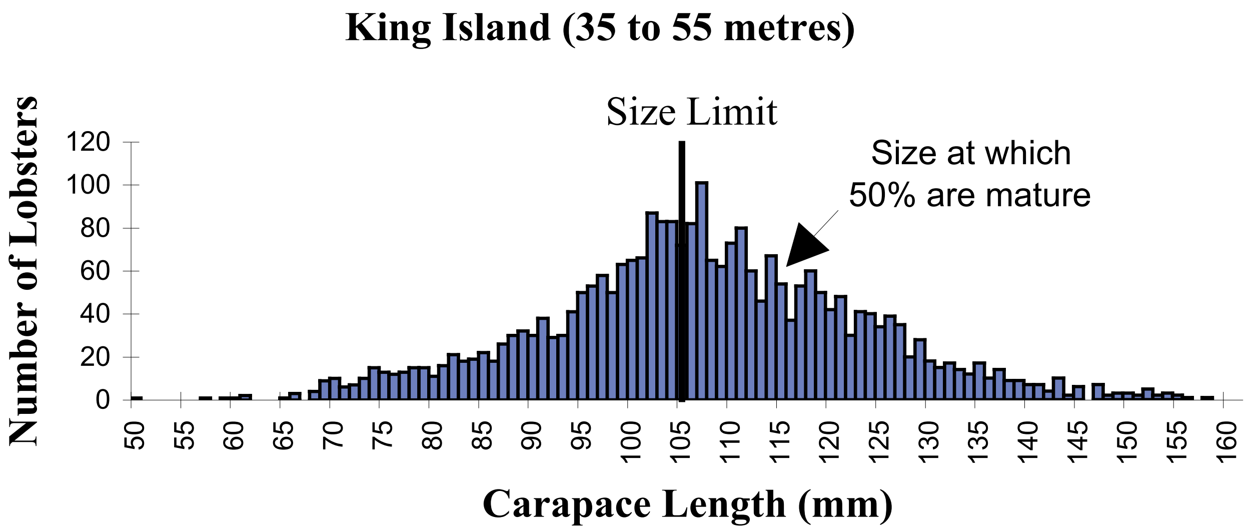


Figure 6. Estimated probability of control and on-grown lobsters moving from release reef to neighbouring reef. Movement of each treatment group was estimated by 3 parameters; movement on survey 1, surveys 2 to 6, and surveys 7 to 8



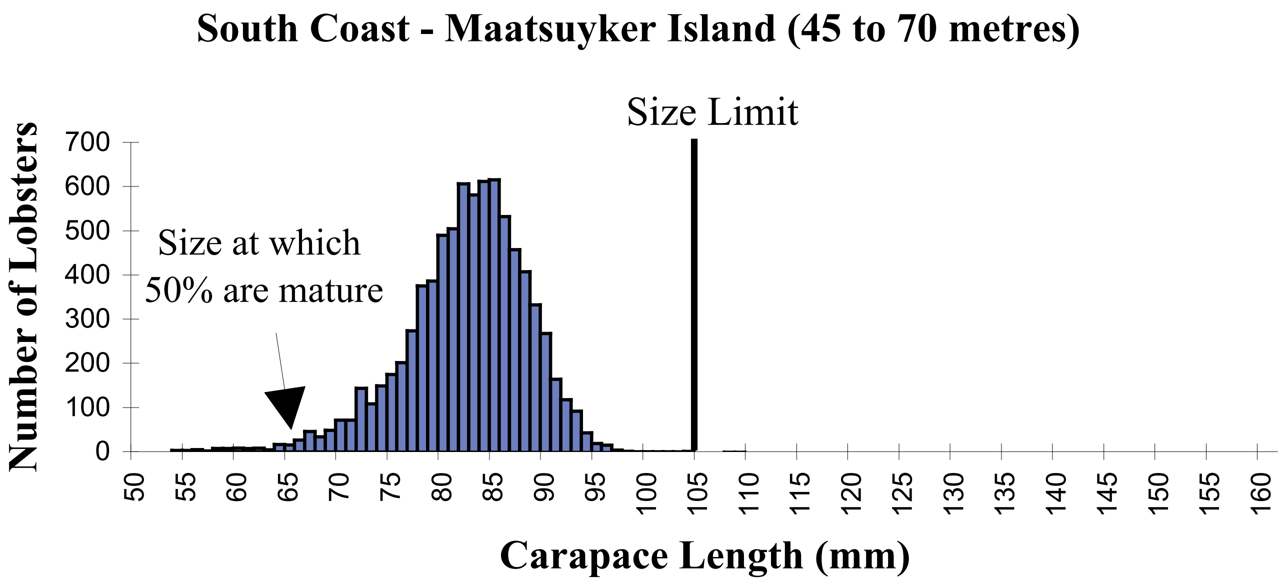


Figure 7. Survival estimate determined from multi-strata Cormack Jolly Seber modelling for control and on-grown lobsters pooled and estimated by a single parameter.

The survival estimate of 95% was the same for both on-grown and control lobsters, and did not vary between sampling areas or across time (Figure 7). This should be considered a conservative estimate of survival (i.e. the actual figure may be higher), as it may retain an emigration bias, and has not been adjusted for tag loss. For a more detailed account see FRDC final report – Project No. 1999/314 (Gardner *et al*., 2000). For the site tested, these results indicated that after one years culture reseeded lobsters do have the ability to enhance wild populations.

Translocation of adult animals

In southern Tasmanian waters there are large areas of dense populations of female rock lobsters that never reach legal size. The cause of these 'slow growing' populations is uncertain but may be a combination of density-dependant and environmental effects. The number of lobsters is estimated to be in the millions and while they don't contribute to yield, egg production is approximately 100% of the unfished stock. In contrast, egg production in the north of the state is less than 10%, well below the management target of 25%.

Sexual maturity in lobsters appears to be related to age rather than size. In southern waters greater than 40m in depth, female lobsters mature at 60 to 65mm CL (carapace length) (Gardner, 1999). In contrast, shallower (<40m) water in northern regions of the fishery, female lobsters mature at sizes greater than 110mm CL (Figure 8).

The growth rate of southern female lobsters from depths greater than 40m is less than 1mm CL per year from an annual moult. In contrast, female lobsters in the north of the state undertake two moults per year with an average moult increment of 6-7mm CL, thus realising a 12-14 mm CL annual increase in growth. Limited tagging information suggests that lobsters shifted to northern waters from southern waters will grow at an increased rate and enter the commercial fishery. However, it is uncertain whether the increased growth rate is equivalent to that of northern lobsters or at the expense of egg production. Translocation of deeper water (>40m) 'speckled' and 'white' lobsters to shallow water is also expected to change the shell colour, over subsequent moults, to red which commands a higher price and further enhances the value of these lobsters.

The utilisation of southern lobsters for both yield and egg production has been a constant request to management by industry for many years. In particular, fishers in the north of the state view translocation as a means to improve both the yield and egg production in a region of the fishery that has been overfished in the past.

There is the potential to move large numbers of female lobsters from southern regions of the fishery were they don't contribute to yield, to northern regions where they would contribute. However, the impact or potential benefits of these translocation exercises for egg production and yield have yet to be evaluated in any detail. A proposal has been constructed with the objectives of determining, 1) the effect of a large-scale removal of 'slow growing' female lobsters on existing lobster populations, 2) the effects of translocation on mortality, growth rate, egg production and shell colouration rates, and 3) the benefit-costs on longer term translocation and the most appropriate scenarios for undertaking such shifts (i.e. the number to be shifted, periods between consecutive shifts etc.).

Discussion

The use of enhancement as a means of restoring severely depleted stocks or improving coastal fisheries is proving to be increasingly popular. With enhancement, there is the belief that you are able to control the productivity of the stock and maintain it at the desired level. Considerable progress in the last decade has been made in stock enhancement worldwide. A total of some 230 species around the world are currently the focus of stock enhancement or sea 'farming' efforts (Gendron, 1998). About 25 countries are actively participating in such initiatives, the majority concentrating on one or two species. Countries such as Japan seem to be leading the way, with programs covering close to one hundred different species.

Several lobster fisheries have placed considerable emphasis on enhancement as a result of stock depletion and/or their economic importance. Research with hatchery reared lobsters in the United Kingdom and Norway has resulted in large numbers surviving to increase both yield and the spawning biomass of the fishery (Bannister, 1998; van der Meeren, 1998). The potential for stock enhancement to be used as a tool to assist current management plans for the Tasmanian rock lobster fishery is seen as encouraging. Puerulus research has implied that enhanced numbers of juveniles translate to increased catch. A linear link has been demonstrated between the settlement of southern rock lobster puerulus and recruitment to the Tasmanian fishery (Gardner et al., *in press*).

With the closure of the life cycle, enhancement of the wild fishery may be achieved by the addition of hatchery reared juveniles. The life cycle of *J. edwardsii* is yet to be closed in culture in Tasmania, with no success past the late phyllosoma (oceanic larval) stage. Limited success has been achieved in both Japan and New Zealand, where phyllosoma have been reared till they metamorphosed into the benthic puerulus stage in culture (Kittaka, 1997; Tong, unpublished data – see Booth 1996). This has been demonstrated only on a small scale. Many biological and technical problems remain in establishing commercial scale production. However, due to the potential benefits, both the Tasmanian aquaculture and wild lobster fisheries are supportive of the ongoing research into the closure of the life cycle.

The on-growing of puerulus (hatchery reared or wild caught) to the 1-year old juvenile stage in culture minimises natural mortality by removing this high mortality phase seen in the wild. When the number of ongrown juvenile lobsters reseeded is above the percentage expected to survive in the wild, an enhancement effect results. The potential of this enhancement benefit is dependant on the survival of these lobsters following release. Our survival results are encouraging for the future of reseeding; however we urge caution in their interpretation. There is evidence that survival varies greatly between habitats and/or regions, and seasonal effects are also likely. The study has shown that obtaining accurate estimates of short-term survival of juvenile lobsters is both possible and practical. The results from the model, and new knowledge on juvenile lobster movement are to be used to determine the likely survival of reseeded lobsters across a range of habitats and geographic regions in a larger scale project (FRDC Project – Evaluating the release and survival of juvenile rock lobsters released for enhancement purposes).

The use of collectors to simulate reef and monitor puerulus settlement has been shown to be successful in Tasmania (Kennedy *et al*., 1991; Gardner *et al*., 1998). Modifying these collectors by attaching a 'mesh collector' to project up into the water column, appears to result in an enhancement in the catch rates of puerulus. The enhanced catch rates may be due to increased surface area as was noted with *Panulirus japonicus* (C. Norman, Tokyo University of Fisheries, Pers. Comm.). The mesh collector may simulate macroalgae growing on shallow reef, which puerulus would normally contact before moving into rock crevices (Yoshimura, *et al*., 1994). It could be postulated that by creating artificial reef, or by reseeding macroalgal cover over existing rocky reef, puerulus settlement could be enhanced. A community based project reseeding the giant string kelp, *Macrocystis pyrifera* at several locations around the state is aiming to reverse massive losses in algal cover that have occurred in the last 40 years (S. Ibbott, Tasmanian Aquaculture and Fisheries Institute, Pers. Comm.).

The addition of artificial reefs or attaching macroalgae (artificial or natural) to existing reefs would be expected to improve settlement in these regions. However, the question still remains as to whether these puerulus would have improved natural survival (i.e. be lost from the system by settlement in poorer regions such as non-reef or if exposed to increased predation) or are we just re-distributing settlement. Further research is needed in this area to determine settlement patterns.

Translocation of lobsters may also prove to be an enhancement tool. The movement of 'slow growing' adult female lobsters from high density, low growth regions in the south of the state to higher growth, lower density regions in the north may provide a means of increasing both yield and egg production. The reseeding of juvenile rock lobsters may also be an effective tool in the enhancement of coastal reef by shifting lobsters from areas of high larval settlement, but low productivity, to areas with higher productivity.

We predict that the high value and demand for lobster resources will lend itself to considering enhancement as a means of maximising the economic return from our coastal waters. The rapid development seen in enhancement and sea ranching around the world is expected to lead to a shift in harvesting the sea from the hunter-gatherer to the sea farmer.

References

Bannister, R.C.A. (1998). Lobster (*Homarus gammarus*) stock enhancement in the United Kingdom: hatchery-reared juvenile do survive in the wild, but can they contribute significantly to ranching, enhancement, and management of lobster stocks. In: Gendron, L., 1998 (Ed). Proceeding of a Workshop on Lobster Stock Enhancement held in the Magdalen Islands (Québec) from October 29 to 31, 1997, *Canadian Industry Report of Fisheries and Aquatic Sciences* 244

Booth, J.D. and Tarring, S.C. (1986). Settlement of the red rock lobster, *Jasus edwardsii*, near Gisborne, New Zealand. *New Zealand Journal of Marine and Freshwater Research* **20**, 291-297.

Booth, J.D. (1996). Phyllosoma raised to settlement. *The Lobster Newsletter* **8**(2), 1 and 12.

Cooch, E. and White, G. (1999). Program MARK: analysis of data from marked individuals. Documentation files available at: http://canuck.dnr.cornell.edu/mark/

Crear, B., Mills, D., Ritar, A., Thomas, C. and Hart, P. (1998). Rock lobster (*Jasus edwardsii*) aquaculture: annual report 1997/98. Tasmanian Aquaculture and Fisheries Institute Internal Report.

Gardner, C., Cawthorn, A., Gibson, I., Frusher, S., Kennedy, R.B. and Pearn, R.M. (1998). Review of the southern rock lobster *Jasus edwardsii* puerulus monitoring program: 1991-1997. Marine Research Laboratories - Tasmanian Aquaculture and Fisheries Institute, University of Tasmania. Technical Report No. 52.

Gardner, C. (1999). Rock Lobster Fishery Assessment Report: 1999. Marine Research Laboratories - Tasmanian Aquaculture and Fisheries Institute, University of Tasmania, pp58.

Gardner, C., Mills, D., Ibbott, S., Willcox, S. and Crear, B. (2000) Preliminary investigation towards ongrowing puerulus to enhance rock lobster stocks while providing animals for commercial culture. FRDC Final Report, pp56.

Gardner, C., Frusher, S.D., Kennedy, R.B. and Cawthorn, A. (in press). Relationship between settlement of southern rock lobster puerulus *Jasus edwardsii* and recruitment to the fishery in Tasmania, Australia. *Marine and Freshwater Research.*

Gendron, L. (ed.) (1998). Proceeding of a Workshop on Lobster Stock Enhancement held in the Magdalen Islands (Québec) from October 29 to 31, 1997, *Canadian Industry Report of Fisheries and Aquatic Sciences* 244.

Herrnkind, W.F. and Butler, M.J. (1994). Settlement of spiny lobster, *Panulirus argus* (Latreille, 1804), in Florida: Pattern without predictability? *Crustaceana* **67**, 46-64.

Kennedy, R.B., Wallner, B. and Phillips, B.F. (1991). Preliminary investigations of puerulus settlement of the rock lobster *Jasus novaehollandiae* in southern Australia. *Revista De Investigaciones Marinas*, **12**, 76-82.

Kittaka, J. (1997). Culture of larval spiny lobsters: a review of work done in northern *Japan. Marine and Freshwater Research* **48**(8), 923-930.

Manly, B.F.J. (1985). A test of Jackson's method for separating death and emigration with mark-recapture data. *Res. Popul. Ecol.* **27**, 99-109.

Phillips, B.F. (1986). Prediction of commercial catches of the western rock lobster *Panulirus cygnus*. *Canadian Journal of Fisheries and Aquatic Science* **43**, 2126-2130.

van der Meeren, G.I., Agnalt, A., and Jørstad, K.E. (1998). Lobster (Homarus gammarus) stock enhancement in Norway, Experiences from a large-scale release project from 1990 to 1997. In: Gendron, L., 1998 (Ed). Proceeding of a Workshop on Lobster Stock Enhancement held in the Magdalen Islands (Québec) from October 29 to 31, 1997, *Canadian Industry Report of Fisheries and Aquatic Sciences* 244.

Yoshimura, T., Yamakawa, H. and Norman, C.P. (1994). Comparison of hole and seaweed habitats of post-settled pueruli and early benthic juvenile lobsters, *Panulirus japonicus* (Von Siebold, 1824). *Crustaceana* **66**, 356-365.

THEME 1 — Question & Answer

John Harris to Simon Nicol

Question

You have drawn some important conclusions from the model's results, especially about the benefits of stocking on-grown fish. But have you validated the inherent assumptions that survivorship is unchanged in yearling fish released to the wild, despite hatchery conditions?

Answer

No, we haven't been able to collect data on survival rates.

Session 2

ECOLOGICAL IMPACTS

If it walks like a duck...

Ron West

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University of Wollongong
NSW, 2522

Abstract Only

The idea of releasing fish into Australian estuaries has been around since the turn of the last century and led to the establishment, in about 1900, of the first marine hatchery at Cronulla (NSW). This venture was planned to provide the growing colony with stocks of sole, plaice and other English fish, some of which were transported to the Colony and bred at the hatchery. This soon gave way to the release of fry of the local species, such as bream, whiting and crayfish. Sea cages were established in the adjacent waters of Port Hacking and used for many years for growout pens for local fish and oysters. However, the hatchery was abandoned as a bad investment in about 1920. A hundred years on and what have we learnt about the impacts of restocking local fish species in estuaries? The answer is very little. Most research has concentrated on the survival and recapture of the stocked fish species, and these studies often indicate a high degree of success. However, for many, these successful stockings raise new questions about possible impacts. There are legitimate concerns raised about the introduction of disease to wild populations and the impact of reducing genetic diversity of natural populations. Perhaps more difficult to consider is the impact of these large numbers of released fish on the hundreds of other species occupying a typical estuary. Simple models of predator and prey relationships indicate that a moderate increase in the numbers of a large predatory species, such as mulloway, snapper, bream or flathead, could have a significant impact on the numbers of prey species. For these reasons alone, and until we can show otherwise, stocking of estuaries with fish should be treated in the same way as any other development activity and be accompanied by a review of environmental impacts.

Ecological considerations of stocking hatchery-reared fish into wild riverine populations

Peter Gehrke

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Taylors Beach, NSW, 2315

Abstract Only

Stocking fish into freshwater habitats is undertaken for a number of purposes, including conservation of threatened species; restoration of populations following disturbance; compensation for habitat degradation; to create new fisheries in new habitats; to enhance existing stocks where fish production is perceived to be below desirable levels; to maintain populations in response to recruitment over-fishing; or to intentionally modify fish communities, for example to control pests.

The objectives of stocking programs vary widely, and can result in a wide range of desirable and undesirable ecological outcomes. Desirable outcomes include creation of successful fishreries in man-made habitats that do not support natural populations, and expanding the range of threatened species within their former distribution. Undesirable outcomes include introducing disease into wild stocks, negative competion between hatchery and wild individuals and negative inter-species interactions with lower trophic levels, since most freshwater stocking programs in Australia involve species neatr the top of the aquatic food webs. Introducing new species to a river system carries the additional risk of creating new pest populations. A second concern with stocking into natural populations is the difficulty of discriminating between wild and hatchery produced individuals. Inability to determine the source of fish confounds stock assessment and river health programs, and can even make it impossible to evaluate whether the stocking program achieved its objective. Because of the increasingly degraded condition of many rivers the expectation for increased stocking to enhace natural populations may be unrealistic or unsustainable. Furthermore, the success and implications of stocking are rarely assessed objectively. There is a pressing need to develop formal strategies for planning and evaluating stocking programs to minmise the ecological risks and to maximize the benefits.

Ecological considerations for the stock enhancement of brown tiger prawns (*Penaeus esculentus*) in Exmouth Gulf: an approach facilitated by a bioeconomic model

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Abstract Only

The prawn trawl fishery in Exmouth Gulf, Western Australia, is a well managed fishery harvesting a mixture of prawns, with the brown tiger prawn (Penaeus esculentus) comprising about 35% of the annual catch. However, the annual catches of tiger prawns can fluctuate from year to year (200 to 680 t over the last 10 years), as can environmental conditions when cyclones occur. This natural variability in catches led the industry, managers, and researchers to consider the option of enhancing the natural recruitment of brown tiger prawns by releasing juveniles in wild nursery grounds. A bioeconomic model possible success of stock enhancement, and the scale of the enhancement needed to produce (a) a detectable number of prawns in the fishery and (b) an increase in commercial catches of 100 t (requires about 10 million 1 g juvenile prawns). The development of the model also highlighted the gaps in the knowledge on the ecology of tiger prawns. Our approach to assessing the potential ecological impacts of enhancement has focused on reviewing information on prawn ecology and the effects of increased density on growth and survival of juvenile crustaceans, and identifying potential release sites for the juvenile stages in Exmouth Gulf (funded by FRDC 1999/222). This has been done by surveying the potential nursery habitats (seagrass, algae) of tiger prawns, and the distribution and abundance of both the juvenile prawns and their piscivorous predators. Results from the current study are presented and their implications for pilot scale stock enhancements discussed.

Evaluation of hatchery-based restocking of Shark Bay snapper (*Pagrus auratus*, Sparidae) as a potential management tool – the need for good science and a cautious approach in a World Heritage context

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Abstract

Three separate stocks of snapper, Pagrus auratus, are found in Shark Bay, Western Australia, a conservation value explicitly recognised by the region's World Heritage listing in 1991. The eastern and western stocks found inside the bay have historically been a major attraction for visiting recreational fishers who mainly target spawning aggregations during winter. Quantitative estimates of spawning biomass (from daily egg production surveys), and of recreational catch and effort (from a bus-route creel survey), have only become available in recent years. Both stocks have been shown to be small compared with elsewhere in Australia and New Zealand and the level of recreational exploitation high. Based on advice that eastern gulf spawning biomass was severely depleted, the snapper fishery was closed in June 1998 to allow rebuilding to occur. The status of the western gulf spawning biomass is now of concern and further restrictions targeted at recreational exploitation have recently been introduced. The success of snapper culture both in Australia and overseas has fueled increasing community pressure for hatchery-based restocking of the Shark Bay stocks to be undertaken. Although hatchery-based enhancement of marine finfish stocks has a long history worldwide, critical evaluation of its biological and economic success has generally been lacking. Given the international importance of the Shark Bay marine environment, any evaluation of hatchery-based restocking as a potential management tool for these important snapper stocks requires clear management objectives and a comprehensive pilot study to address the key issues prior to any broad scale or long-term release program

Introduction

Currently in Western Australia management policy regarding the use of hatchery-based enhancement of marine finfish stocks remains to be developed. Equally, there has been little informed discussion on this complex subject within the broader community. However, enhancement trials of two sparid species are soon to commence, one involving black bream (*Acanthopagrus butcheri*) in the Blackwood River and the other snapper (*Pagrus auratus*) in the western gulf of Shark Bay. This paper concerns the latter and discusses (i) the conservation value of Shark Bay and its snapper stocks, (ii) the fishery and its management, (iii) marine stock enhancement in general and, (iv) the proposed project to evaluate the success of hatchery-based enhancement of a snapper population in Shark Bay.

Conservation value of Shark Bay

Shark Bay, located 800 km north of Perth on the central coast of Western Australia, became one of the few natural heritage properties to meet all four criteria when it received World Heritage status in 1991 (Francesconi & Clayton 1996). Commercial fishing, including prawn trawling and beach seining, solar salt production, aquaculture and tourism are the principal economic activities conducted within the bay. Many of the region's 100,000 annual visitors are recreational fishers, attracted by the variety and quality of the local fishing (Francesconi & Clayton 1996, Curnow 1999). Snapper have historically been abundant in the inner gulfs and the key recreational species for local and visiting fishers.

The existence of three separate snapper stocks in the Shark Bay region, an oceanic, an eastern gulf and a western gulf stock has generally been accepted since the late 1980s (genetics, Johnson *et. al.* 1986; otolith microchemistry, Edmonds *et. al.* 1989, 1999; head morphology, Moran *et. al.* 1998; tagging, Moran *et. al.* in press). The genetic variation between snapper populations was explicitly recognised as a key marine conservation value in the original World Heritage nomination of Shark Bay. Current research has provided further evidence to support the multiple stock hypothesis and suggests even greater complexity of stock structure based on genetics (Whitaker & Johnson 1998; Baudains 1999), otolith stable isotopes (Bastow *et. al.* in press) and differences in key biological parameters (size at maturity, growth rate, spawning season, fecundity, G. Jackson unpubl. data) between snapper from different areas of the inner gulfs.

Stock assessment and management

Snapper have supported an important commercial fishery in the Shark Bay region since the turn of the century

(Cooper 1997) with much of the effort conducted outside the bay focused on what is now considered the oceanic stock. Although some commercial snapper fishing has historically occurred inside the bay, i.e. targeting the eastern and western gulf stocks, these have become essentially recreational fisheries since the 1970s (G. Jackson unpubl. data).

As with many marine recreational fisheries, quantitative information on stock status and level of exploitation for inner gulf snapper was lacking until recently. Following community concerns raised in the early 1990s, and indications that snapper spawning aggregations in the eastern gulf were particularly heavily fished during the 1994 and 1995 spawning seasons, the need for adequate assessment of the inner gulf snapper stocks became acute. Snapper are batch spawners producing pelagic eggs over an extended spawning season and the daily egg production method (DEPM, Lasker 1985, Alheit 1993) has been used to estimate spawning biomass for the species in New Zealand (Zeldis & Francis 1998) and South Australia (McGlennon & Jones 1999). Annual DEPM surveys have been conducted in Shark Bay since 1997, to provide estimates of spawning biomass for each inner gulf snapper stock (Table 1, Fig. 1). In addition, annual trap and trawl surveys have been undertaken to estimate the relative abundance of juvenile (0+ year class) snapper for each stock (Fig. 1). Conclusions from the current research are that both inner gulf snapper stocks are small compared with elsewhere in Australia (e.g. Spencer Gulf, South Australia) and New Zealand (e.g. Hauraki Gulf) and recruitment likely to be highly variable.

A recent bus-route creel survey (1998/99 Gascoyne Recreational Fishing Survey, Fisheries WA unpubl. data) has shown recreational catch and effort in Shark Bay to be high; during the survey period, total fishing effort was estimated at 51,000 fisher days/yr (eastern gulf 11,000; western gulf 40,000) with ~ 38 t/yr of snapper caught in the western gulf alone; the eastern gulf was closed to the take of snapper in June 1998, two months after the survey commenced.

The eastern stock spawning biomass was assessed as severely depleted in 1997 based on abundance of 0+ snapper from trawl surveys (November 1996, February 1997) and results of the 1997 DEPM survey. The fishery subsequently closed in June 1998 to allow the spawning stock to recover to an agreed management target of 100t.

The western stock spawning biomass, estimated at ~ 100 t in 1997, has now also declined to a depleted level. Authorities have taken further measures in 1999 to limit recreational exploitation of snapper in the western gulf.

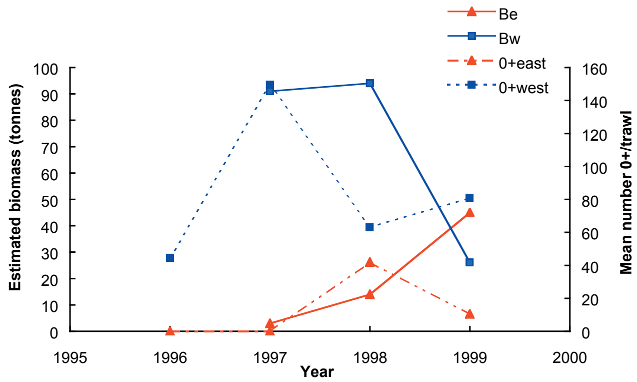

Figure 1. Estimated spawning biomass (annual DEPM surveys) and relative 0+ abundance (annual trawl surveys) for eastern and western gulf snapper stocks.

Potential for stock enhancement

Although marine stock enhancement has 100+ year history, it has become the subject of rigorous scientific debate and investigation only in more recent times (ICES 1991, Danielssen **et. al.** 1994, Nosho & Freeman 1994, Schramm & Piper 1995, Coleman & Travis 1996). Hatchery production of **P. major** (a conspecific of **P. auratus**) for large-scale stock enhancement has been undertaken in Japan since the 1980s and snapper have been successfully reared in recent years in Australia, including Western Australia. In light of this, the community now understandably asks the question 'why not solve the snapper problem by restocking with hatchery reared fish?' It has been strongly advocated by some WA recreational fishing representative groups, sections of the aquaculture industry and is highly attractive.

The first serious proposal to investigate the potential of snapper stock enhancement in Shark Bay was developed soon after the closure of the eastern gulf fishery in June 1998 (Makaira Pty Ltd 1998). The plan was not supported by Fisheries WA on the grounds that (i) the number of snapper to be released was very low compared with numbers of wild fish of a similar size/age (~100 mm

Table 1. Shark Bay inner gulf snapper DEPM biomass estimates (95% boostrapped confidence intervals), 1997 to 1999.

Year	Eastern gulf (t)	Western gulf (t)
1997	3 (1 – 48)	91 (3 – 261)*
1998	14 (1 –54)	93 (29 – 184)
1999	45 (20 – 86)	26 (12 – 43)

* spawning biomass estimated for Freycinet only (data unavailable for Denham Sound) therefore value presented represents underestimate for western gulf stock.

LCF, 0+ fish) occurring naturally in the area at the time (based on trawl survey results, estimated using the swept area method), (ii) resources identified to monitor the fate of the introduced fish post release, and thus evaluate the project's overall success, were inadequate and (iii) that a conventional management strategy was already in place, i.e. fishery closure, and any introductions could subsequently confound its effect.

In contrast to local pro-enhancement groups, Fisheries WA initial step was to review the current, peer-reviewed scientific literature (as opposed to the web pages of pro-restocking agencies around the world) on the subject. The conclusion was (and remains) that marine finfish stock enhancement based on hatchery production remains unproven and requires further evaluation to determine its biological and economic success. Hilborn (1998) strongly argued that the following are essential to any comprehensive scientific evaluation of such enhancement programs:

- estimate the survival of hatchery reared fish, over the longer term, after their release into the wild and determine any subsequent contribution to fishery production
- investigate any negative impacts (biological, ecological) on wild fish as a consequence of hatchery introductions
- estimate all economic costs and determine benefits of the enhancement program

Many marine restocking programs throughout the world have failed to address the above steps. For example, stocking of red drum (*Sciaenops ocellatus*, Sciaenidae) in Texas, where ~ 20-30 million fingerlings (25-30 mm TL) are released each year (McEachron *et. al.* 1998), is regularly cited as proof of the success of marine stock enhancement in relation to the current Shark Bay snapper enhancement debate. However, the Texan program remains to (i) satisfactorily demonstrate the survival of hatchery fish over the longer term (i.e. >1.5 yr), (ii) adequately assess the adult population/fishery production increase attributable to introduced juveniles, (iii) investigate any deleterious effects on wild fish stocks and level of biological interaction and (iv) comprehensively evaluate the economic costs and overall economic benefits of the program.

Proposed evaluation of stock enhancement

Fisheries WA was asked to develop a range of stock enhancement options and associated costs prior to discussions with the Shark Bay community regarding the direction any future hatchery-based restocking should take. Enhancement of the eastern gulf stock was not an option preferred by Fisheries WA, nor after lengthy consultation, by the local Shark Bay community. A smaller scale pilot study, involving the release of ~30,000 hatchery juveniles of various sizes over 2 yr into Useless Inlet (an off shoot of the western gulf) was rejected in favour of a larger scale project in the Freycinet Estuary (southern end of the western gulf), involving the release of ~300,000 fish over a 3 yr period. The following is an outline of the proposed research designed to evaluate the biological and economic success of a trial restocking of juvenile snapper in the Freycinet Estuary.

Fisheries WA maintain that any hatchery-based enhancement of snapper stock(s) in Shark Bay should follow the responsible approach outlined by Blakenship and Leber (1995). The project's success can only be determined by a comprehensive, sufficiently funded evaluation over a timeframe that will allow the majority of released hatchery snapper to recruit to the fishery, i.e. 4 - 5 years after their release.

A management objective for the enhancement project needs to be agreed *a priori*, e.g. hatchery snapper will make up x% of the recreational catch 4-5 yrs after their introduction (if augmentation of fishery production is the objective) *or* x% of spawning biomass in particular area (if acceleration of spawning stock recovery is the objective).

Genetic integrity of the local snapper stocks, given the complex nature of stock structure in the region, will be ensured; the local hatchery contracted to supply juvenile snapper will be directed to collect material (eggs and milt stripped at sea and fertilized eggs transported to hatchery) from ~50 - 100 spawning fish at time of natural spawning in the Freycinet area (July - September). DNA samples will be taken from adult snapper at the time of egg collection and archived for future reference.

In year 1 of the project, ~ 100,000 juveniles will be reared to ~70-80 mm in the hatchery. All fish will be marked using a variety of methods for comparison (North West Marine Technology coded wire tags, visible implant fluorescent tags, thermal marking) and monitored for an adequate period (2 – 3 weeks) to assess tag retention and associated mortality. Prior to their release, a comprehensive trap survey (baited Antillean z-traps) will be conducted in areas most likely to be inhabited by 0+ snapper to estimate the abundance of naturally occurring snapper at the time. Extensive trap surveys carried out between 1998 and 2000 showed that juvenile snapper spend the first 18 months of life in deeper waters (>7 m) in both inner gulfs. Hatchery fish will then be released into these areas and the trap surveys repeated ~ 1 mo. after the first release to determine the distribution of hatchery fish compared with wild stock and the extent of any mixing. Subsequent regular trap surveys will be used to estimate the survival and growth of hatchery and wild fish over the first 2 –3 years of their life. Further releases of 100,000 (tagged) juvenile snapper in years 2 and 3, i.e. total of 300,000 for project, will be carried out to test for differences in growth and survival of hatchery and wild snapper between years. As the snapper grow and move out of the deeper waters frequented by 0+/1+ fish, sampling will shift to using a combination of larger traps and line fishing, and as fish approach a size at which they recruit to the local fishery, by random sampling of recreational catches in the Freycinet area.

To determine the proportion of the recreational catch and/or spawning stock in the area that are derived from hatchery introductions, the recovery of snapper needs to be conducted at least 4 – 5 years after the initial introduction of each batch, hence the 7 year (minimum) timeframe for this project. Egg production surveys and juvenile trawl surveys are scheduled to continue in parallel with the stock enhancement project to provide ongoing assessment of spawning biomass and variation in abundance of 0+ snapper in the Freycinet area over the lifetime of the project.

At completion of the project on the ground, a complete analysis of all costs involved will be undertaken to determine the overall cost-benefits of the project. Given that the enhancement and evaluation project will involve large expenditure of public funds, a clear understanding of any benefits and the main beneficiaries needs to be provided. The opportunity exists to compare results of the enhancement project with outcomes of more conventional management approaches, e.g. the current fishery closure in the eastern gulf, to identify how best funds can be spent in future to achieve sustainable management of snapper stocks in the Shark Bay region.

Summary

Fisheries WA is not against marine stock enhancement *per se*, as has been recently suggested by some individuals involved in the current debate around Shark Bay snapper enhancement. However, based on the scientific evidence available, marine finfish stock enhancement remains to be adequately evaluated. Particular caution is necessary given the World Heritage status of Shark Bay and the high conservation value of its snapper and other fish populations. With application of good science, an adequately funded project, over an appropriate timeframe, will determine the degree of success and associated cost of hatchery-based restocking of snapper in Shark Bay. The project presents an excellent opportunity to compare the success of stock enhancement with stock rebuilding under a more conventional management approach. Such research has application to fishery managers beyond Shark Bay and its snapper stocks.

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References

Alheit, J. (1993). Use of the daily egg production method for estimating biomass of clupeoid fishes: a review and evaluation. *Bulletin of Marine Science* 53(2), 750-767.

Bastow, T. P., Jackson, G., and J. S. Edmonds (in press). Isotopic composition of fish otolith carbonate and elevated salinity: stock delineation of pink snapper, *Pagrus auratus*, in Shark Bay, Western Australia. *Marine Chemistry.*

Baudains, G. (1999). Population genetic structure of pink snapper (*Pagrus auratus*) in the eastern gulf of Shark Bay, Western Australia. Report to Natural Heritage Trust (Project 973340), Canberra.

Blakenship, H. L. and K. M. Leber (1995). A responsible approach to marine stock enhancement. *American Fisheries Society Symposium* 15, 167-175.

Cooper, R. (1997). Shark Bay Legends. Rawlhouse Publishing, Western Australia.

Coleman, F. and J. Travis (1996). (Eds) Marine stock enhancement: a new perspective. *Bulletin of Marine Science* 62(2).

Curnow, I. (1999). A quality future for recreational fishing in the Gascoyne. Fisheries Management Paper No.124, Fisheries Western Australia, Perth.

Danielssen, D. S., Howell, B. R. and E. Mokness (1994). (Eds) Sea ranching of cod and other marine fish species. *Aquaculture and Fisheries Management* 25, suppl. 1.

Edmonds, J. S., Moran, M. J., Caputi, N., and M. Morita (1989). Trace element analysis of fish sagittae as an aid to stock identification: pink snapper (*Chrysophrys auratus*) in Western Australian waters. *Canadian Journal of Fisheries and Aquatic Science* 46, 50-54.

Edmonds, J. S., Steckis, R. A., Moran, M. J., Caputi, N. and M. Morita (1999). Stock delineation of pink snapper and tailor from Western Australia by analysis of stable isotope and strontium/calcium ratios in otolith carbonate. *Journal of Fish Biology*, 55, 243-259.

Francesconi, K. and D. Clayton (1996). Shark Bay World Heritage Property Management Paper for Fish Resources. Fisheries Management Paper No. 91, Fisheries Department of Western Australia, Perth.

Hilborn, R. (1998). The economic performance of marine stock enhancement projects. *Bulletin of Marine Science* 62(2), 661-674.

ICES (1991). The ecology and management aspects of extensive mariculture. *ICES Marine Science Symposium,* 192.

Johnson, M. S., Creagh, S., and M. J. Moran (1986). Genetic subdivision of stocks of snapper, *Chrysophrys unicolor*, in Shark Bay, Western Australia. *Australian Journal of Marine and Freshwater Research* 37, 337-345.

Lasker, R. (1985). Introduction: an egg production method for anchovy biomass assessment. In: Lasker, R (Ed.) An egg production method for estimating spawning biomass of pelagic fish: application to the northern anchovy *Engraulis mordax*. NOAA Technical Report No. 36, 1-3.

Makaira Pty Ltd (1998). Shark Bay snapper restocking project. Report for the Gascoyne Development Commission, Perth.

McEachron, L.W., Colura, R.L., Bumguardner, B.W. and R. Ward (1998). Survival of stocked red drum in Texas. *Bulletin of Marine Science* 62(2), 359-368.

McGlennon, D. and K. Jones (1999). Snapper (*Pagrus auratus*). South Australian Fisheries Assessment Series 99/13, South Australian Research and Development Institute, Adelaide.

Moran, M.J., Burton, C., and N. Caputi (1998). Sexual and local variation in head morphology of snapper, *Pagrus auratus*, Sparidae, in the Shark Bay region of Western Australia. *Marine and Freshwater Research* 50, 27-34.

Moran, M. J., Jenke, J. and C. Burton. (in press). Movements of pink snapper, *Pagrus auratus*, Sparidae, in the Shark Bay region of Western Australia, as revealed by tagging. *Marine and Freshwater Research*

Nosho, T. and K. Freeman (1994). (Eds.) Marine fish culture and enhancement, conference proceedings. Washington Sea Grant Program, University of Washington, Seattle.

Schramm, H. L., Jnr and R. G. Piper (1995). (Eds) Uses and effects of culture fishes in aquatic ecosystems. *American Fisheries Society Symposium* 15.

Whitaker, K. and M. Johnson (1998). Population genetic structure of *Pagrus auratus* in the western gulf of Shark Bay, Western Australia. Report to Natural Heritage Trust (Project 973340), Canberra.

Zeldis, J., and R.I.C.C. Francis (1998) A daily egg production method estimate of snapper biomass in Hauraki Gulf, New Zealand. *ICES Journal of Marine Science* 55, 522-534.

THEME 2 — Questions & Answers

Charles Todd to Gary Jackson

Question

Will there be an impact from 100,000 releases and if so, how will you assess it?

Answer

The current proposal is to release 100,000 x 0+ snapper (c.70-80 mm LCF) each year for three years; i.e. 300,000 total. [The figure of] 100,000 was not arrived at in any rigorous scientific manner really. The problem is that we need to release a [large enough] number that will allow us to detect any potential effect of introductions but not to put in too many to swamp 'wild' 0+ snapper — particularly given its high conservation value. My feeling is that 100,000–150,000 release per year will give us a good chance of detection / recovery.

Sandy Morison to Gary Jackson

Question

How do you plan to monitor the effects — before and after?

Answer

There is the opportunity to compare between the eastern and western gulfs, an opportunity not available elsewhere in Australia. The opportunity exists to test hypotheses. There is a need to be more sophisticated in our monitoring and assessment.

We have data on spawning biomass and abundance of 0+ snapper collected since 1996-97, i.e. before. Our current plan is to survey (by trapping) the area of the release site immediately prior to fish introductions, to estimate distribution and densities of wild 0+ fish; [and to] repeat the survey soon after release of hatchery fish to estimate the level of mixing. [We can then] record the introduced snapper through to recruitment to the spawning population. [Our strategy provides an] excellent opportunity to compare western gulf (stocked) recovery with eastern gulf (closed to fishing; i.e. conventional strategy) recovery. The benefits will go beyond Shark Bay snapper.

Phil Cadwallader to Neil Loneragan

Question

If the seagrass beds are stuffed (by Cyclone Vance) in the first place, why are you stocking instead of attending to the habitat; i.e. rehabilitating the habitat?

Answer

Our results suggest that the seagrass beds are recovering form the impacts of Cyclone Vance and the full recovery time may be one to two years. I do not believe that we have the technology to rehabilitate seagrass beds at large scales; i.e. square kilometres. If it were feasible, the costs of such rehabilitation would also be very high.

Greg Jenkins to Gary Jackson

Question

If the Shark Bay stocks are rehabilitated, how will the WA Fisheries Department manage them (in the future)?

Answer

As I understand this, Greg, Fisheries WA has explicitly stated that ongoing stock enhancement will not be adopted for Shark Bay snapper stocks over the long term. It does not want the community to become 'addicted' to the hatchery option [of management]. The enhancement tool is only to be used in the short term to accelerate the rebuilding of the spawning stock in the western gulf. Clearly, given the small stocks and increasing numbers of recreational fishers, future levels of 'take' of snapper will be much lower than it historically has been.

John Harris (comment)

There is an important gap in the list if issues being addressed in this session — quality control:

a) In the 1970s and 1980s, quality control over the species being distributed from commercial hatcheries was sometimes poor. In the early days, bags of mixed fish were handed out by hatcheries for stocking and this practice actually facilitated the dispersal of fishes exotic to particular areas. For example, redfin perch juveniles were found among batches of golden perch being released from hatcheries. Also, suspicious first records of carp followed native fish stocking in a number of waters. It's still not clear whether there is absolute prevention of unintended species in hatchery releases.

b) The othere area of quality control relates to disease management. There is huge potential to spread viruses like EHN or barramundi picorna-like virus, or parasites like the tapeworm Bothriocephalus. As far as I'm aware, there are very few effective controls to prevent the spread of disease organisms and infected vector animals by hatcheries.

Dave Pollard to Gary Jackson

Question

Have they thought about maximum / minimum lengths (slotting) as a means of managing the fishery?

Answer

A slot limit was introduced in the eastern gulf (maximum legal size >50cm<70cm) in 1997 for one year before closure was introduced. Too little, too late. A similar slot limit was introduced in the western gulf at the same time (>45cm, only two fish >70cm). [This rule was] recently changed in the western gulf (now >50cm, only one fish >70cm). Clearly, management arrangements over the past ten years or so have not been adequate. Limiting total effort is the (common) problem with recreational fisheries.

Murray Macdonald to Gary Jackson

Question

Do they have evidence of factors other than fishing that have affected stocks in the inner gulfs?

Answer

No Murray. Based on data available there is not evidence of habitat change that could have resulted in recent declines in the adult biomass in either gulf. Some questions [have been raised] about the effect of prawn trawling on recruitment of 0+ snapper in Denham South but there has been no trawling in the western gulf (since the 1960s) nor Freycinet (ever).

Patrick Coutin to Gary Jackson

Question

Are there any special requirements of fisheries management in a World Heritage area?

Answer

As I read things, on a day-to-day basis, the answer is 'No'. However, if things go bad, I guarantee there will be some federal interest (eventually). However, I believe legislation (I need to check which) has recently changed such that any future release of snapper will need approval from Environment Australia.

Phil Cadwallader (comment)

World Heritage obligations and community interests: government has to manage on behalf of the whole community and not just for the more politically active stakeholders.

Session 3

GENETICS

The Genetic Impact of Stock Enhancement Programs Using Captively Bred Fish

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Abstract

As wild fisheries worldwide become depleted, both public and private fisheries agencies are turning increasingly to stock enhancement programs using captively bred fish. Despite their widespread use, many doubts have been raised about the effectiveness of supplementation programs. Problems associated with stock enhancement programs may result from genetic factors. Loss of genetic diversity is a major risk factor. It can reduce the ability of a population to survive environmental change, new diseases, parasites, competitors or predators. Reduction in genetic diversity also has been shown to result in decreased Darwinian fitness, fecundity and growth, and inbred individuals may be deformed. The main mechanisms that result in genetic problems in captively bred populations are: the use of low numbers of parental stock, inbreeding as a result of mating closely related individuals, raising fish in an artificial environment, using parental stock with low or unrepresentative genetic variation, domination of breeding by a small number of breeding stock, breeding with unequal numbers of parents and swamping of wild populations by genetically homogeneous hatchery fish. This paper will address the genetic implications of using captively bred fish in restocking programs and describe how deleterious genetic effects may be minimised.

Introduction

Overfishing, habitat degradation, barriers to migration, altered flow rates, pollution, competition with exotic species, deforestation, watershed erosion and sedimentation have all combined to reduce wild fish populations (Vrijenhoek, 1998). To counteract this decline there has been an increase worldwide in stock enhancement programs aimed at replenishing wild stocks and assist in the recovery of endangered species (Busack and Currens, 1995). However, there remain doubts as to the effectiveness of these programs and concerns that they may be potentially harmful if fundamental genetic considerations are ignored (Allendorf and Phelps, 1980; Busack and Currens, 1995).

Despite the wealth of knowledge that has been accumulated on the genetic threats in captive breeding programs there remains a large gap between theoretical genetics and the practical realities of captive breeding fish for stock enhancement programs. Therefore the aim of this paper is to acquaint hatchery and fisheries managers with the latest information on genetic threats in captively bred populations and discuss ways of reducing these potentially deleterious threats.

Genetic Diversity

Genetic diversity is an important element in the management and long-term survival of biological populations (Frankel and Soulè, 1981). Genetic diversity gives a population adaptive potential to cope with environmental change, new diseases, parasites, predators, and competitors (Soulè, 1980). Moreover, genetic diversity is the fundamental material for evolution, and the amount of evolutionary change in a population is proportional to the amount of genetic diversity available (Meffe and Ronald Carroll, 1997). Finally, a reduction in genetic diversity has also been shown to result in decreased Darwinian fitness, fecundity and growth. Inbred individuals also have a higher probability of exhibiting deformities due to the expression of deleterious homozygote recessive alleles and the disruption of stable developmental pathways (Ralls and Ballou, 1983).

Inbreeding

Inbreeding is the mating of closely related individuals that share common alleles by decent. Inbreeding, leads to increased homozygosity compared to an outbred population. The negative effects of inbreeding on domestic, laboratory, and zoo populations are well documented and include reduced fecundity and survival of inbred progeny (Wright, 1977; Kincaid, 1976a,b; Ralls and Ballou, 1983; Miller and Hedrick, 1993). Inbreeding has been shown to increase the frequency of deformed individuals in hatchery populations (Aulstad and Kittelsen, 1971; Kincaid, 1976a,b; Gall, 1987). Inbreeding has also been shown to lead to decreased Darwinian fitness and increase the probability of extinction in wild populations (Saccheri *et al*., 1998).

Inbreeding increases the probability of recessive deleterious alleles being expressed because inbred lines are more likely to express recessive traits rather than dominant or over-dominant forms (Frankel and Soulè, 1981). Inbreeding depression is thought to be the subsequent decreased phenotypic fitness resulting from the expression of these recessive deleterious alleles (Hartl and Clark, 1997). Severe inbreeding depression and loss of heterozygosity are direct consequences of poorly managed breeding programs (Vrijenhoek, 1998).

Inbreeding coefficient F, is the probability that two alleles at a given locus are identical by descent. *F* is also an estimate of the relative amount of heterozygosity compared to the source population. Therefore, *F* can be used as a direct estimate of genetic variability relative to the variability of an outbred population. ΔF is the per generation change in the inbreeding coefficient, which remains constant irrespective of breeding system (Frankel and Soule′, 1981). Gjedrem (1976) estimated for salmonids that for every ten percent reduction in variation there is a corresponding five to ten percent depression in growth rate. It is widely accepted that to reduce the effects of inbreeding ΔF should be maintained below one percent (Franklin, 1980; Frankel and Soule′, 1981).

Heterozygosity (*H*) of an individual can be used as an indirect estimator for fitness, because it is well accepted in animal breeding that a reduction in *H* may lead to decreases in viability, vigour, fecundity and fertility. A 25% reduction in heterozygosity in rainbow trout (*Onchorhyncus mykis*s), as a result of inbreeding, was shown to decrease fry survival by 19%, growth by 23%, and increase phenotypic deformities by 38% (Kincaid, 1976a,b). Conversely, increased *H* is believed to increase fitness and growth in some situations and is termed heterosis. Factors that reduce *H* are inbreeding, selection and random genetic drift, which are all exacerbated by the use of small numbers of hatchery broodstock. The rate of loss of *H* per generation, as a result of genetic drift is

$$\Delta H = 1-1/2N \qquad (1)$$

where *N* is the population size where the numbers of males and females are equal, there is no reproductive variance among individuals, and no fluctuations in the number of females (Hartl and Clark, 1997). Genetic drift is the per generation change in allele frequencies brought about by reproductive sampling error. According to formula (1) it can be seen that the smaller the genetically effective population size, the greater the rate loss of variation. Therefore, the maintenance of genetic diversity within a hatchery is directly reliant on the optimisation of the genetically effective population size.

Genetically effective population size

The observation that populations often showed much less genetic variation than predicted led to the development of the theory of genetically effective population size (Wright, 1931). In wild populations the genetically effective population is typically much smaller than the census population size. The genetically effective population (N_e) is the size of an ideal population that is subject to the same degree of genetic drift as an actual population (Hartl and Clark, 1997). Therefore N_e is the size of a real population that has been corrected for factors that reduce N_e, such as sex-ratio biases, harem formation, reproductive variance among individuals and inbreeding.

A recent survey of hatcheries in NSW revealed a practice for hatchery breeding where up to a hundred females are fertilised with the milt from very few males (Moore and Gartside, unpublished). If we compare this hatchery practise to calculations of N_e it is revealed that for every one hundred females fertilised with a single male the effective genetic contribution of the F_1 progeny is the same as if only two males and two females were used. When the number of males and females are not equal N_e can be estimated as

$$N_e = \frac{4N_M N_F}{N_M + N_F} \qquad (2)$$

where N_M and N_F are the number of males and females respectively (Allendorf and Phelps, 1980). It should be noted that the most effective and practical breeding system for the maintenance of genetic diversity within the hatchery is a one male and one female mating.

N_e is also strongly affected by variance in contribution among females, which is estimated as

$$N_e = 4N/(\sigma^2 + 2) \qquad (3)$$

where σ^2 = variance in family size among females and *N* is census population size. It is a common practice in breeding Australian native fish to use broodstock of different ages (Moore and Gartside, unpublished). Because the fecundity of fish is almost invariably related to age as well as body size, the egg production among females is likely to be variable (Baltz, 1990). If we take the hypothetical example of ten females, where seven small females produce 1,000 eggs each and three larger females produce 10,000 eggs each, the variation in reproductive contribution between individuals will reduce the effective genetic contribution to the same as if four equally contributing parents were used. Equalising the reproductive contribution of each female to 1,000 eggs will result in approximately 20 effective females (Allendorf and Ryman, 1987). This task can be greatly accelerated with the aid of an egg counter or using a volumetric counting system which are commonly used in hatcheries already. The important point here is the equalisation of reproductive contribution and not the number of eggs. By separating equal contributions of matings into different tanks or ponds, N_e within the hatchery can be maximised per generation. It is important to note the reproductive contribution will be reduced to that of the least productive female. A point worth considering when selecting or monitoring broodstock.

The common practice of placing several pairs of fish in a tank or pond for spawning and fertilisation (Thurstan, 2000) is not recommended as it is impossible to determine contributions or matings among broodstock. Dominant fish are likely to monopolise matings and therefore contribute disproportionately to the next generation, thereby reducing N_e.

N_e is also affected by fluctuations in the number of breeders (*N*) equal to the harmonic mean of *N* across generations, which is calculated

$$\frac{1}{N_e} = \frac{1}{t}\left(\frac{1}{N_1} + \frac{1}{N_2} + \ldots + \frac{1}{N_t}\right) \quad (4)$$

where N_t is generation and t represents number of generations (Hartl and Clark, 1997). Take the example where broodstock numbers are maintained at 50 for three out of four years and allowed to drop to ten for a single generation. The effective genetic contribution over the four generations has been reduced to 25 per generation. Therefore, to maximise effective contributions across generations, the number of broodstock used should not fluctuate significantly over time.

Indeed, by following sound genetic protocols the genetically effective population size can be double the census population or number of broodstock. This occurs when mating designs are implemented that prevent variance in progeny number that survive to become parents of the next generation (ie. $\sigma = 0$). Under this scenario $N_e = 2N$. Therefore an effective population size of 100 can be achieved from the use of 25 breeding pairs. When $N_e = 100$ the expected increase in inbreeding level per generation is 0.5 %, which is well under the threshold of 1% recommended by Frankel and Soule′, (1981).

Allelic diversity

Until recently, most genetic breeding programs were designed assuming most loci had very low levels of polymorphism, typically one, two, or three alleles. However, recent advances in molecular biology have shown that most loci are characterised by many alleles. Therefore, an important measure of genetic variation is allelic diversity or more specifically the number of alleles at a locus. Heterozogosity has been widely used as a measure of genetic variation, however, heterozygosity is relatively insensitive to reductions in allelic diversity (Allendorf and Ryman, 1987). It is allelic diversity that is likely to give a population adaptive potential to cope with environmental change over evolutionary timescales (Soule′, 1980).

The loss of allelic diversity through captive breeding is usually a result of the failure to successfully capture representative variation of the wild population. The change in allele frequency as a result of this bottleneck is more complicated to predict than its effect on heterozygosity because it depends on the number and frequency of alleles present in the original population (Allendorf and Ryman, 1987). Allelic diversity is much more likely to be lost through a severe population bottleneck than heterozygosity. Heterozygosity levels may recover reasonably quickly after population bottleneck, whereas allelic diversity is expected to recover much more slowly and may take thousands of years to regain pre-bottleneck levels. Some rarer alleles may be lost forever.

To reduce the loss of allelic diversity a hatchery stock should comprise a sufficient number of individuals to capture representative variation of the wild population. The number of broodstock required will depend on the allelic diversity of the wild population being sampled. The higher the allelic diversity the larger the sample needed in order to have a sufficient probability of capturing that variation. Large samples are also required to capture rare alleles that occur at low frequencies within a population (Allendorf and Ryman, 1987). For example, a sample of 230 individuals would be needed to have a 99 percent probability of capturing alleles that occurred at a frequency of 0.01 (Brown, 1988). Brown (1988) has suggested the use of 200 broodfish collected over a period of two minimum generation intervals, or about ten years. As a rule of thumb the broodstock should be sourced from unstocked populations in order to capture remnant variation.

The justification for sampling rare alleles is that although they may occur at a low frequency at present, their potential in the future may be of great importance when environmental conditions change. However, some alleles are likely to be rare within a population because they are deleterious. Therefore breeding and stocking with individuals that carry rare deleterious alleles is likely to increase the frequency of potentially deleterious alleles within the receiving population. Local gene pools are also likely to be swamped by genetically homogeneous offspring if large stockings are made from a single pair mating. The receiving population is therefore likely be compromised after restocking rather than benefiting. These problems can be reduced by changing broodstock regularly, stocking with the progeny of several matings, and limiting the amount of progeny that are stocked into each location.

Monitoring Genetic Variation

It is important to have baseline data on the number and frequency of alleles in the founding stock if we are to gauge the potential importance of their loss to the species of interest. The development of modern molecular biology and population genetics have provided a suite of techniques to examine the level of genetic diversity and structuring within remnant populations or its loss within captive breeding programs. The most powerful techniques commonly employed today involve the screening or direct sequencing of DNA. The most useful of these techniques for population level analysis include the screening of mitochondrial DNA, and microsatellites. Methods for both techniques are well developed and sensitive enough to detect single nucleotide differences among individuals. Additionally, consultation with population geneticist should be considered essential for the design of stock enhancement programs. Unfortunately, in Australia we have very little genetic information for the majority of the species that are currently used for stock enhancement and the damage for many of these species has been done, consequently we will never know the real genetic profiles of these populations.

Artificial Selection

Hatchery stocks are likely to diverge from wild stocks through artificial selection and domestication within the hatchery. Phenotypes that thrive in the relatively stable conditions and relaxed selective pressures of a hatchery may not do so well in the wild (Bryant and Reed, 1999). Domesticated stocks tend to be phenotypically more uniform and behaviourally predictable than their wild counterparts (Vrijenhoek, 1998). This adaptation to captivity and decrease in fitness in wild environments is likely to hinder stocking success. It has been estimated that in highly fecund animals such as fish, up to 90% of selection takes place between fertilisation and the end of the larval stage. Coincidently this is exactly the time that captively bred fish spend in the hatchery. The effects of domestication can be reduced in open hatchery systems by using wild broodstock (Harada *et al*., 1998). However, there remains a conundrum over the age of release to limit domestication. Release the fish too young and natural mortality is very high. Release too late and the probability that fish will become domesticated increases. Despite the problems associated with early release mortality it is still recommended that fish be liberated into the wild as early as possible.

Outbreeding Depression

Populations that are isolated for long periods are likely to accumulate localised adaptive genetic variation. Outbreeding depression is a decrease in fitness as a result of crossing isolated populations of the same species (Emlen, 1991). The two main causes of outbreeding depression are coadaptation and local adaptation (Templeton *et al*., 1986). Coadaptation is the result of a localised population that evolves a gene pool that is internally balanced with respect to reproductive fitness. Local adaptation is the adaptation of an isolated population to a set of regional environmental conditions (Templeton, 1997). Hybridisation among any of these localised populations can result in progeny that are not adapted to any or the wrong environmental conditions. The threat of local adaptation is likely to increase with geographic distance or isolation (Templeton, 1997). To limit the potential threat of outbreeding, individuals should be sourced from the same MU (see next section) or geographic location. Stockings should be made only to the MU (see next section) from which the broodstock originated.

Evolutionary Significant Units and Management Units

As isolated populations diverge they take on their own evolutionary path. The Evolutionarily Significant Unit (ESU) concept was developed to provide a rational basis for prioritizing taxa for conservation effort (eg. captive breeding), given that resources are likely to be limited and the existing taxonomy may not adequately reflect underlying genetic diversity (Moritz, 1994). The main aim of ESUs is to ensure that evolutionary heritage is recognised and protected and evolutional potential inherent across the set of ESUs is maintained. To avoid the reduction of this evolutionary heritage and potential it is recommended that stockings only occur into the same ESU as the broodstock are sourced from. To further reduce the loss of evolutionary potential and the risk of outbreeding, stocking should be kept within the same Management Unit (MU) or deme (for detailed coverage see Baverstock *et al*., 1993; Moritz, 1994; Waples, 1995).

Summary of Recommendations

1. Limit inbreeding by
    - Using large numbers of non related broodstock (see recommendation 2)
    - Limiting sib mating (use stud books and tagging and maintain records of all matings which can be used to determine future matings)
    - Limiting random breeding among individuals (see previous point)
2. Maintain an effective population size of at least (N_e = 100) by
    - Using where possible at least 25 pairs of non-related broodstock (Reciprocal transfer between institutions to decrease the number of fish kept on-site, but only if they are used to stock the same population)
    - Equalising contributions between parents by portioning out equal numbers of progeny into different tanks/ponds for each stocking
    - Maintain equal numbers of males and females
    - Prevent large fluctuations in broodstock number from year to year
    - Separating each breeding pair into a separate tank/pond to monitor breeding contribution and mating success
3. Capture and maintain wild genetic variation by
    - Sampling at least 200 individuals over two minimum generations or 10 years
    - Ensuring that founders have representative genetic variation by employing modern population genetic techniques
4. Limit wild gene pool swamping from genetically homogeneous fingerlings by
    - Ensuring stockings comprise of progeny from at least five mating pairs

- Avoiding repeated matings of the same individuals or their progeny
- Exchanging broodstock regularly (from the same ESU or population)

5. Reduce the effects of artificial selection by
   - Liberating progeny as early as possible
   - Using only wild caught broodstock
6. Reduce the probability of outbreeding depression by
   - Sourcing broodstock from the same ESU or population
   - Avoiding translocations among ESUs or populations

Summary

As most public and private fisheries agencies struggle for dwindling resources it remains important to maximise the positive contributions that stock enhancement programs can make. These contributions can be greatly enhanced with the use of sound genetic protocols. Indeed, through clever manipulation of genetic principles we can not only minimise the deleterious effects of captive breeding programs we can also maximise adaptive potential that populations need for survival in the future.

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References

Allendorf, F.W. and Phelps, S.R. 1980. Loss of variation in a hatchery stock of cutthroat trout. *Transactions of the American Fisheries Society*. **109**:537-543.

Allendorf, F.W. and Ryman, N. 1987. Genetic management of hatchery stocks. *Population Genetics and Fishery Management*. pp.148,150. (N. Ryman and F. Utter, editors) University of Washington Press, Seattle.

Aulstad, D. and Kittlesen, A. 1971. Abnormal body curvatures of rainbow trout (Salmo gairdneri) inbred fry. *Journal of the Fisheries Research Board of Canada.* **28**:1918-1920

Baltz, D.M. 1990. Autecology. *Methods for Fish Biology*. pp.588. (C.B. Schreck and P.B. Moyle, editors). American Fisheries Society, Maryland.

Baverstock, P.R., Joseph, L. and Degnan, S. 1993. Units of management in biological conservation. *Conservation Biology in Australia and Oceania*. pp.287-293. (C. Moritz and J. Kikkawa, editors). Surrey Beatty & Sons, Chipping Norton.

Brown, A.M. 1988. Genetic aspects of the propagation and distribution of fishes. *Proceedings: Fish Genetics Workshop*. pp.38-45. (S.J. Rowland and Barlow, R., editors). Cronulla NSW, August 2000. NSW Agriculture and Fisheries.

Bryant, E.H. and Reed, D.H. 1999. Fitness decline under relaxed selection in captive populations. *Conservation Biology*. **13**:665-669

Busack, C.A. and Currens, K.P. 1995. Genetic risks and hazards in hatchery operations: fundamental concepts and issues. *American Fisheries Society Symposium*. **15**:71-80

Emlen, J.M. 1991. Heterosis and outbreeding depression: a multilocus model and an application to salmon production. *Fisheries Research*. **12**:187-212

Frankel, O.H. and Soule′, M.E. 1981. Conservation and evolution. pp. 65-71, 91. Cambridge University Press, Sydney.

Franklin, I.A. 1980. Evolutionary change in small populations. *Conservation Biology: An Evolutionary-Ecological Perspective*. pp.135-150. (M.E. Soule′ and B.A. Wilcox, editors), Siauer Associates, Sunderland, Massachusetts.

Gall, G.A.E. 1987. Inbreeding. *Population Genetics and Fishery Management*. pp.47-87. (N. Ryman and F. Utter, editors) University of Washington Press, Seattle.

Gjedrem, T. 1976. Possibilities for genetic improvements in salmonids. *Journal of the Fisheries Research Board of Canada*. **33**:1094-1099

Harada, Y., Yokota, M. and Iizuka, M. 1998. Genetic risk of domestication in artificial fish stocking and its possible reduction. *Researchers on Population Ecology*. 40(3):311-324

Hartl, D.L. and Clark, A.G. 1997. *Principles of population genetics*, Third Edition. pp.146-149, 291. Sinauer Associates, Sunderland, Massachusetts.

Kincaid, H.L. 1976a. Inbreeding in rainbow trout (Salmo gairdneri). *Journal of the Fisheries Research Board of Canada*. **33**:2420-2426

Kincaid, H.L. 1976b. Inbreeding depression in rainbow trout. *Transactions of the American Fisheries Society*. **105**:273-280

Meffe, G.K. and Ronald Carroll, C. 1997. Genetics: Conservation of diversity within species. *Principles of Conservation Biology*. pp.162 (G.K. Meffe, and C.R. Carroll, editors). Sinauer Associates, Sunderland, Massachusetts.

Miller, P.S. and Hedrick, P.W. 1993. Inbreeding and fitness in captive populations: Lessons from Drosophila. *Zoo Biology*. **12:**333-351

Moritz, C. 1994. Defining 'Evolutionay Significant Units' for conservation. *Tree*. 9(10):373-375

Ralls, K. and Ballou, J. 1983. Extinction: Lessons from zoos. *Genetics and Conservation: A reference for managing wild animal and plants populations*. pp.164-184 (C.M. Schonewald-Cox, S.M. Cambers, B. MacBryde, and Thomas, editors). Benjamin/Cummings, Menlo Park, California.

Saccheri, I., Kuussaari M., Kankare M., Vikman P., Fortelius W. and Hanski I. 1998. Inbreeding and extinction in a butterfly metapopulation. *Nature*. **392**:491-494

Soule′, M.E. 1980. Thresholds for survival: maintaining fitness and evolutionary potential. *Conservation biology, an evolutionary-ecological perspective*. pp.151-170. (M.E. Soule′ and B.A. Wilcox, editors) Sinauer Associates, Sunderland, Massachusetts.

Templeton, A.R., Hemmer, H., Mace, G., Seal, U.S., Shields, W.M. and Woddruff, D.S. 1986. Local adaptation, coadaptation, and population boundaries. *Zoo Biology*. **5**:115-125

Templeton, A.R. 1997. Coadaptation, local adaptation, and outbreeding depression. *Principles of Conservation Biology*. pp.171-172 (G.K. Meffe, and C.R. Carroll, editors). Sinauer Associates, Sunderland, Massachusetts.

Thurstan, S. 2000. Practical considerations for genetic stock management of native fish hatcheries. *Stock Enhancement of Marine and Freshwater Fisheries*. Australian Society for Fish Biology Workshop Proceedings, Albury NSW, August 2000.

Vrijenhoek, R.C. 1998. Conservation genetics of freshwater fish. *Journal of Fish Biology*. **53**:394-412, (Supplement A).

Waples, R.S. 1995. Evlutionary signifcant ubits and the conservation of biological diversity under the Endangered Species Act. *American Fisheries Society Symposium*. **17**:8-27

Wright, S. 1931. Evolution in Mendelian populations. *Genetics*. 16:97-159

Wright, S. 1977. *Evolution and the genetics of populations*. *Experimental results and evolutionary deductions*. Vol. **3**. pp. 613. University of Chicago Press.

Conservation Genetics and Stocking for Species Recovery Programs

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Introduction

The protection of threatened species (or populations) within their natural habitat is the most desirable form of conservation management for species recovery programs. However, in circumstances where *in situ* conservation is impractical, or fails to halt declines in wild populations, captive breeding and re-introduction programs may make the difference between extinction and survival. Captive breeding and restocking programs, following conservation genetics guidelines, provide a valuable safety-net to preserve endangered species until wild populations can be re-established.

The impacts of genetic processes within captive breeding programs are not theoretical predictions based on models but have been scientifically demonstrated in laboratory studies, captive populations and wild populations. A large number of published papers document the genetic impacts observed at salmonid hatcheries in North America and Europe, where stocking is a mainstay for compensation of losses due to over-harvesting and environmental degradation (see: Ryman and Utter, 1987; Billington and Herbert, 1991; Schramm and Piper, 1991; Cloud and Thorgaard, 1993; Tave, 1993; Thornhill, 1993; Loeschcke, Tomiuk and Jain, 1994; Laikre, 1999, for reviews). The stocking of hatchery-reared fish has escalated worldwide, and is doing so in Australia, despite the warnings of geneticists working on fish populations that hatcheries and hatchery fish may negatively affect the genetic constitution of wild populations (Rowland and Barlow, 1985; Allendorf and Ryman, 1987; Hindar *et al.*, 1991; Waples, 1991; Hard *et al.*, 1992; Cuenco *et al.*, 1993; Campton, 1995).

The concerns expressed by geneticists do not demand the discontinuation of existing stocking programs. Supplementary breeding programs have great potential to assist the conservation of endangered populations. Fish populations can be managed in captivity in order to minimise or prevent the genetic deterioration that occurs when population sizes are reduced and survival is threatened. Further, informed recovery programs can prevent the loss of existing genetic variation and maximise the re-introduction success of stocked individuals. However, if undertaken without sufficient consideration of genetic consequences, stocking programs may become counter-productive and reduce the long-term viability of the threatened population.

Genetic considerations for captive breeding programs and management required to maintain genetic integrity

Six genetic issues are relevant to management of captive populations for stocking as part of species recovery programs. Four of these: the typically low ratio between effective population size (N_e) and actual population size (N); inbreeding depression; loss of genetic variation; and adaptation to captivity; can be reduced or eliminated by selecting appropriate broodstock and using informed captive management practices. The remaining two issues, swamping of remnant gene pools and identification of evolutionary significant units (ESU) and management units (MU), depend on prior knowledge of the genetic substructure of all populations involved and the selection of suitable locations for restocking.

<u>The N_e / N ratio</u>

Genetic processes act on the effective population size (N_e) rather than on the actual or census population size (N). N_e is a standardised estimate of population size that corrects for biases in sex ratio, fluctuations in population size and variance in family size occurring in natural populations (Wright, 1931). N_e is typically much lower than N, and may average in the order of $1/10^{th}$ of the census population size (Frankham, 1995*a*). The N_e/N ratio depends on the natural history of a species (ie. polygamous versus monogamous, high fecundity versus low fecundity, etc.). As natural history can be altered under captive conditions, captive breeding programs can maximise the N_e/N ratio.

Management required

The N_e/N ratio can be maximised by ensuring an equalised sex ratio and reducing the variance in family sizes, ie. by ensuring that each pair contributes the same number of offspring. This may require that excess offspring of highly productive pairs are not used for the stocking program and must be discarded.

To achieve an equalised sex ratio in hatcheries, broodstock should consist of an equal number of males and females at all times. It is a common hatchery practice to mix the milt of several males. Mixing the milt of several males encourages sperm competition. This could lead to a single or small number of males contributing a majority of fertilisations (Gharret and Shirley, 1985; Withler, 1988), resulting in an unequal sex ratio and the reduction of N_e/N. For this reason, the practice of mixing milt of several males should be stopped.

Variance in family sizes occurs when some pairs produce more offspring than others. This has the potential to be greatest in highly fecund species. Therefore, captive fish populations are particularly at risk. By managing populations so that each pair contributes an equal number of offspring each generation, it is theoretically possible to produce an N_e/N ratio of 2 (as opposed to 0.1)(Borlase *et al.*, 1993). That is, the genetically effective population size is double the number of broodstock used. This hatchery management strategy has tremendous potential to benefit the genetic management of captive breeding programs (Borlase *et al.*, 1993). To achieve the equalisation of family sizes the offspring of each pair should be maintained as separate units. At each stocking location, the total number of fish stocked should consist of an equal number of offspring from each breeding pair.

Inbreeding depression

Inbreeding depression is the reduction of reproductive fitness and survival, and the increase of frequencies of mutant phenotypes that results from the mating of close relatives. Poor performance has been associated with inbreeding in captive fish populations (Tave, 1993; Waldmann and McKinnon, 1993; Laikre, 1999) as well as many other taxa (Frankham, 1995*b*). The level of inbreeding within a population is quantified by the inbreeding coefficient (F), which is related to effective population size as:

$$1 - F = [1-1/(2N_e)]^t \qquad (1)$$

where *t* is the number of generations. Animal breeders have identified that strains of domestic animals begin to decline in fertility and performance above a 2 – 3% increase in F per generation (Franklin, 1980; Soulé, 1980). In response, conservation geneticists recommend a slightly more conservative upper limit of 1% per generation for the prevention of inbreeding depression in captive populations of wildlife (Soulé, 1980). Substituting a 1% per generation increase in F into equation 1 (ie. F = 0.01 and *t* =1), gives:

$$1-(0.01) = [1-1/(2N_e)]^1$$

$$0.99 = 1- 1/(2N_e)$$

$$1.01 = 1/(2N_e)$$

$$0.02N_e = 1$$

$$N_e = 1/0.02$$

$$N_e = 50$$

Therefore, the effective population size of captive stocks should be maintained at least as high as $N_e = 50$ to prevent inbreeding depression. However, controlled experimental evidence suggests that inbreeding depression is still detectable at $N_e = 50$ and that $N_e = 100$ may be a more appropriate minimum effective population size (Woodworth, 1996).

Management required

Inbreeding depression can be avoided by ensuring that the N_e of the captive population is never less than $N_e = 50$. Under a system where equalisation of family sizes is used, this would require only 12 - 13 pairs of broodstock per year.

Appropriate management would also include identification of potential broodstock in species studbooks such as those used by domestic animal breeders and zoological parks. The studbook can be used to record pedigrees and identify appropriate partners for each individual. It may also be possible to determine the genotype of potential wild broodstock and decipher the pedigree of wild individuals. Once the pedigree is known, captive populations can be managed under a scheme of 'maximum avoidance of inbreeding' or 'minimizing kinship' (Montgomery *et al.*, 1997) to prevent inbreeding depression.

Loss of Genetic Variation

Populations released into the wild require the ability to adapt to changes in the environment, as well as to parasites, diseases and introduced pests. Genetic diversity is the raw material of evolution (Franklin, 1980). If genetic diversity does not exist within a population, that population has no capability to adapt through selection, leading to its extinction (Franklin, 1980). Additionally, genetic variation represents one of the fundamental levels of biodiversity that conservation organisations should aim to preserve (McNeely *et al.*, 1990).

As with the inbreeding coefficient, genetic variation is related to effective population size (Montgomery *et al.*, 2000). The equilibrium level of genetic variation for quantitative genetic diversity (that used to adapt to change) exists when the input of genetic diversity through mutation equals that lost through drift. Based on this model, the equilibrium level of genetic variation is predicted to occur when $N_e = 500$ (Franklin, 1980). Therefore, $N_e > 500$ is sufficient to prevent the loss of genetic diversity. However, with captive breeding facilities and funding at a premium, conservation geneticists have proposed that maintenance of 90% of genetic variation for a period of 200 years is an achievable objective for the maintenance of captive populations of threatened species (Soulé *et al.*, 1986).

The minimum effective population size for inbreeding depression and loss of genetic variation assumes that the population is maintained as a closed system for many generations in captivity, and/or for founding a new population where the original population is extinct. However, many hatchery programs use a system of supportive breeding of wild populations, where broodfish are rotated between the hatchery and the wild. Consequently, the number of broodstock required in captivity can be somewhat less, as long as the number of hatchery raised progeny do not swamp the genome of the existing wild population (Ryman and Laikre, 1991). Kincaid (1976, 1983) recommends the use of broodstock with at least an $N_e = 100$, while Allendorf and Ryman (1987) suggest $N_e = 200$. As an absolute minimum, 25 males and 25 females should be used as broodstock for supportive breeding programs (Allendorf and Ryman, 1987). With suitable hatchery management, such as equalisation of family sizes, these broodstock can be used to achieve an $N_e = 100$. At this size, 0.5% of the genetic diversity of the population will be lost per generation as predicted by equation 2:

$$H_t/H_o = [1-1/(2N_e)]^t \quad (2)$$

where H_t is genetic diversity at generation t and H_o is the original genetic variation.

Management required

The greater the N_e of the captive population, the greater the proportion of original genetic diversity that will be maintained. For long-term captive breeding programs the ideal population size would be $N_e = 500$ (Franklin, 1980). However an acceptable loss of 10% of genetic diversity over 200 years would require a smaller population, the exact size depending on the generation interval. Extending the generation interval by mating only older animals also allows the maintenance of genetic diversity. An extreme case of extending the generation interval is the cryogenic preserving of eggs, sperm or fertilised eggs. Facilities currently exist within Australia where cryopreservation is available. Pending research on the ability to 'reanimate' frozen cells, cryopreservation has the potential to provide an invaluable tool for the conservation of genetic resources.

For supportive breeding, a minimum $N_e = 100$ for captive broodstock would result in a loss of 0.5% of original genetic diversity per generation.

Adaptation to Captivity

Adaptation to captivity occurs through unintentional changes occurring in captive populations caused by natural selection to their captive environment. Adaptation to captivity can occur as the development of adaptations to increase fitness in captivity (domestication selection) or the loss of characters necessary for life in the wild (predator avoidance behaviours, etc.). Adaptation to captivity can result in reduced fitness in the wild. Hatchery rearing at any stage of the life cycle will lead to selection for improved hatchery performance, even if broodstock are collected from the wild every year (Doyle *et al.*, 1995). The extent of adaptation will depend on the level of genetic diversity within the hatchery population (increasing with increasing N_e) and the level of mortality within captivity.

There are numerous reports of adaptation to captivity in hatchery populations, including the production of fish which are more active, swim near the surface, show decreased stamina and grow faster on hatchery diets. However, in the wild, hatchery fish often show decreased growth, decreased survival, decreased temperature tolerance; and increased swimming activity and aggression leading to greater predation (Greene, 1952; Vincent 1960; Flick and Webster, 1964; Green, 1964; Moyle, 1969; Reisenbichler and McIntyre, 1977; Fraser, 1981; Hynes *et al.*, 1981; Keller and Plosila, 1981; Bachman, 1984; Chilcote *et al.*, 1986; Leider *et al.*, 1990; Swain and Riddell, 1990; Hindar *et al.*, 1991; Mesa, 1991; Ruzzante, 1991; Swain and Riddell, 1991; Fleming and Gross, 1992; Ruzzante, 1992; Fleming and Gross, 1993; Peterson and Jarvi, 1993; Ruzzante, 1994; Peterson and Jarvi, 1995; Johnsson *et al.*, 1996). The relative fitness of hatchery fish when released into the wild has been demonstrated to decrease with increasing numbers of generations in captivity (Reisenbichler and Brown, 1995). Similarly, Weiss and Schmutz (1999) observed decreased growth and survival of 2-3 year old hatchery fish when compared with wild fish. Adaptation to captivity occurs quickly and can reduce reintroduction success in under 10 generations (Frankham and Loebel, 1992). The risks posed by adaptation to the captive environment are often neglected in captive breeding programs despite the large body of evidence demonstrating the potential threat posed.

Management required

The use of equalisation of family sizes may reduce adaptation to captivity (Allendorf, 1993; Frankham et al, 2000). Adaptation to captivity can also be reduced by: using only wild broodstock, reducing mortality at all life stages within the hatchery, releasing fish at the earliest age possible, ensuring captive conditions are as close to the wild conditions as is possible, and maintaining independent breeding programs within a number of hatcheries with a pooling of offspring immediately prior to release.

Swamping of the remnant gene pool

Swamping of the remnant gene pool can occur if remnant populations are stocked too intensively. As fluctuations in N and increased variance in family sizes reduce the already low N_e / N ratio, over-stocking an existing population with captive-bred individuals may reduce the N_e of the wild population and result in increased inbreeding and loss of genetic variation from the population (Ryman and Laikre, 1991). The effect of supplementary breeding on N_e is described by equation 3 (Ryman and Laikre, 1991):

$$1/N_e = x^2/N_c + (1-x)^2/N_w \quad (3)$$

where x is the relative contribution of offspring from the captive parents, (1-x) is the relative contribution of offspring from wild parents, N_c is the effective number of captive parents and N_w is the effective number of wild parents. Although supportive breeding may result in greater observed number of fish (N), the resulting N_e can be smaller than that which existed prior to stocking (Ryman, 1991).

Management required

Swamping of the remnant gene pool can best be avoided by not stocking fish into habitats where a healthy natural population still exists. For threatened species where stocking remnant populations is necessary, estimates of (1-x) and N_w must be obtained so that x and N_c can be altered within the hatchery to maintain the total populations N_e (for examples see Tringali and Bert, 1998).

Identification of population boundaries

Genetic variation exists on two levels, within populations and between populations. To maintain the genetic variation of fish species, between population diversity must be preserved. In addition to the loss of genetic diversity, interbreeding of distantly related sub-populations has the potential to reduce population fitness through outbreeding depression (Waldmann and McKinnon, 1993). Very little information exists on the population substructure of Australian fish. The principle objective of stocking programs should be "First do no harm" (Waples, 1991). Therefore, stocking programs should not be initiated until a genetic survey of the population substructure is done for each species under consideration.

Genetic technologies are available that allow rapid and cost effective assessment of the population structure of fish species. This information can be used to identify evolutionary significant units (ESUs) and management units (MUs) within which broodstock collection and release of hatchery raised fish must be restricted (Ryder 1986; Waples, 1995; Moritz, 1999). Genetic information will also enable the ranking of priority for captive breeding effort among populations.

Management required

Prior to any captive breeding and restocking effort, it is desirable to gain a thorough understanding of the population substructure of the species involved. The precautionary principle would suggest that it is essential to identify this information before any stocking program has taken place. Knowledge of population substructure is necessary for the 0identification of suitable broodstock and stocking sites. Without this information it is quite likely that an irreversible loss of genetic diversity will occur. Further, the survival of unique populations of species could be threatened. To date, all captive breeding programs for native fish in Australia, have been initiated without documenting this crucial information, irrespective of whether they are threatened species or not.

Discussion

Some of the management practices suggested above may require considerable modification of current hatchery techniques, or are at odds with current practices. For example, equalisation of family sizes will require independent maintenance of the offspring of every pair. This will inevitably increase the requirement for space in hatcheries. Further, releasing fish at the earliest age possible is at odds suggestions that survival is greatest in older individuals. The priorities for modifying aspects of hatchery production to meet genetic requirements needs serious and immediate consideration.

A trend of increasing recognition of the importance of genetics to fisheries management has been developing within the last 20 years. Fisheries managers in Europe and North America have begun to implement management techniques that address specific genetic issues. In particular, there is a recent trend for the identification of ESU and MU within salmonid species.

Managers of Australia's fish populations have acknowledged the importance of genetic impacts. NSW Agriculture and Fisheries held a workshop on fish genetics in 1985 (Rowland and Barlow, 1985). Participants at the workshop discussed many aspects of genetics and hatchery production of threatened species, making recommendations for improvement of hatchery production. Recommendations published in the proceedings were consistent with those outlined in this paper. However, very few, if any of these recommendations were acted upon.

Recently, NSW Fisheries has begun to address genetic issues in breeding programs for native freshwater fish by sourcing Australian bass (*Macquaria novemaculeata*) broodstock from three biogeographic regions, and only stocking within those regions. Further, the captive breeding program for the eastern freshwater cod is being undertaken using a set of genetic guidelines (NSW Fisheries, 1999).

Rather than each management agency in Australia developing its own independent genetic programs, captive management should be coordinated with national and international bodies such as the Australasian Regional Association of Zoological Parks and Aquaria (ARAZPA) or the Conservation Breeding Specialist Group (CBSG) of the World Conservation Union (IUCN). These organisations are experienced in the captive management of threatened species and can assist the design and implementation of species recovery programs for threatened species. Australia's fisheries managers are falling behind the international community in implementing genetic management protocols.

Potential exists to improve current stocking programs in Australia. The history of stocking native species in Australia is still quite young. The problems caused by inappropriate captive management techniques overseas can be avoided by applying knowledge and experience gained by previous attempts at recovering threatened species through captive breeding and restocking programs.

References

Allendorf, F. W. (1993). Delay of adaptation to captive breeding by equalising family size. *Conservation Biology* **7,** 416-419.

Allendorf, F. W. and N. Ryman (1987). Genetic management of hatchery stocks. Pages 141-159 in N. Ryman and F. Utter (eds) *Population genetics and fisheries management*. University of Washington Press, Seattle.

Bachman, R. A. (1984). Foraging behaviour of free-ranging wild and hatchery brown trout in a stream. *Transactions of the American Fisheries Society* **113,** 1-32.

Billington, N. and P. D. N. Herbert (eds) (1991). International symposium on the ecological and genetic implications of fish introductions (FIN). *Canadian Journal of Fisheries and Aquatic Sciences* **48 (Supplement 1)**.

Borlase, S. C., D. A. Loebel, R. Frankham, R. K. Nurthen, D. A. Briscoe and G. E. Daggard (1993). Modeling problems in conservation genetics using captive *Drosophila* populations: Consequences of equalization of family sizes. *Conservation Biology* **7,** 122-131.

Campton, D. E. (1995). Genetic effects of hatchery fish on wild populations of Pacific salmon and steelhead: What do we really know? Pages 337-353 in H. L. Schramm Jr. and R. G. Piper (eds) *Uses and effects of culture fish in aquatic ecosystems*. American Fisheries Society, Symposium 15, Bethesda, Maryland.

Chilcote, M. W., S. A. Leider and J. J. Loch (1986). Differential reproductive success of hatchery and wild summer-run steelhead under natural conditions. *Transactions of the American Fisheries Society* **115,** 726-735.

Cloud, J. G. and G. H. Thorgaard (eds)(1993). *Genetic conservation of salmonid fishes.* Plenum Press, New York.

Cuenco, M. L., T. W. H. Backman and P. R. Mundy (1993). The use of supplementation to aid in natural stock restoration. Pages 269-293 in J. G. Cloud and G. H. Thorgaard (eds) *Genetic conservation of salmonid fishes*. Plenum Press, New York.

Doyle, R. W., C. Herbinger, C. T. Taggart and S. Lochmann (1995). Use of DNA microsatellite polymorphisms to analyse genetic correlations between hatchery and wild fitness. Pages 205-211 in H. L. Schramm Jr., and R. G. Piper (eds) *Use and effects of cultured fishes in aquatic ecosystems*. American Fisheries society, Symposium 15, Bethesda, Maryland.

Fleming, I. A. and M. R. Gross (1992). Reproductive behaviour of hatchery and wild coho salmon (*Oncorhynchus kisutch*) – does it differ? *Aquaculture* **103,** 101-121.

Fleming, I. A. and M. R. Gross (1993). Breeding success of hatchery and wild coho salmon (*Oncorhynchus kisutch*) in competition. *Ecological Applications* **3,** 230-245.

Flick, W. A. and D. A. Webster (1964). Comparative first year survival and production in wild and domestic strains of brook trout, *Salvelinus fontinalis*. *Transactions of the American Fisheries Society* **93,** 58-69.

Frankham, R. (1995*a*). Effective population size / adult population size ratios in wildlife: A review. *Genetical Research* **66,** 96-107.

Frankham, R. (1995*b*). Conservation Genetics. *Annual Review of Genetics* **29,** 305-327.

Frankham, R. and D. A. Loebel (1992). Modeling problems in conservation genetics using captive *Drosophila* populations: Rapid genetic adaptation to captivity. *Zoo Biology* **11,** 333-342.

Frankham, R., H. Manning, S. H. Margan and D. A. Briscoe (2000). Does equalisation of family sizes reduce genetic adaptation to captivity? *Animal conservation* **3,** 357-363.

Franklin, I. R. (1980). Evolutionary change in small populations. Pages: 135-149 in M. E. Soulé and B. A. Wilcox (eds.) *Conservation Biology: An evolutionary-ecological perspective*. Sinauer, Sunderland, MA.

Fraser, J. M. (1981). Comparative survival and growth of planted wild, hybrid and domestic strains of brook trout (*Salvelinus fontinalis*) in Ontario lakes. *Canadian Journal of Fisheries and Aquatic Sciences* **38,** 1672-1684.

Gharret, A. J. and S. M. Shirley (1985). A genetic examination of spawning methodology in a salmon hatchery. *Aquaculture* **47,** 245-256.

Green Jr., D. M. (1964). A comparison of stamina of brook trout from wild and domestic parents. *Transactions of the American Fisheries Society* **93,** 96-100.

Greene, C. W. (1952). Results of stocking brook trout of wild and hatchery strains at Stillwater pond. *Transactions of the American Fisheries Society* **81,** 43-52.

Hard, J. J. (1995). Genetic monitoring of life-history characters in salmon supplementation: Problems and opportunities. Pages 212-225 in H. L. Schramm, Jr., and R. G. Piper (eds). *Uses and effects of cultured fishes in aquatic ecosystems.* American Fisheries Society, Symposium 15, Bethesda, Maryland.

Hard, J. J., R. P. Jones, M. R. Delarm Jr. and R. S. Waples (1992). *Pacific Salmon and artificial propagation under the Endangered Species Act.* NOAA (National Oceanic and Atmospheric Administration) technical memorandum, National Marine Fisheries service, NWFSC-2.

Hindar, K., N. Ryman and F. Utter (1991). Genetic effects of cultured fish on natural fish populations. *Canadian Journal of Fisheries and Aquatic Sciences* **48,** 945-957.

Hynes, J. D., E. H. Brown Jr., J. H. Helle and N. Ryman (1981). Guidelines for the culture of fish stocks for resource management. *Canadian Journal of Fisheries and Aquatic Sciences* **38,** 1867-1876.

Johnsson, J. I., E. Petersson, E. Jönsson, B. T. Björnsson and T. Järvi (1996). Domestication and growth hormone alter antipredator behavior and growth patterns in juvenile brown trout. *Canadian Journal of Fisheries and Aquatic Sciences* **53,** 1546-1554.

Keller, W. T. and D. S. Plosila (1981). Comparison of domestic, hybrid and wild strains of brook trout in a pond fishery. *New York Fish and Game Journal* **28,** 123-137.

Kincaid, H. L. (1976). Effects of inbreeding on rainbow trout populations. *Transactions of the American Fisheries Society***105,** 273-280.

Kincaid, H. L. (1983). Inbreeding in fish populations used in aquaculture. *Aquaculture* **33,** 215-227.

Laikre, L. (ed.) & 17 coauthors (1999). *Conservation genetic management of brown trout (Salmo trutta) in Europe*. Report by the Concerted Action on

Identification, Management and Exploitation of Genetic Resources in the Brown trout (*Salmo trutta*) (“TROUTCONCERT”; EU FAIR CT97-3882).

Leider, S. A., P. L. Hulett, J. J. Loch and M. W. Chilcote (1990). Electrophoretic comparison of the reproductive success of naturally spawning transplanted and wild steelhead trout through the returning adult stage. *Aquaculture* **88,** 239-252.

Loeschcke, V., J. Tomiuk and S. K. Jain (eds) (1994). *Conservation Genetics*. Birkhauser Verlag, Basel.

McNeely, J. A., K. R. Miller, W. V. Reid, R. A. Mittermeier and T. B. Werner (1990). *Conserving the Worlds Biological Diversity*. IUCN, World Resources Institute, Conservation International, WWF-US and the World Bank, Washington DC.

Mesa, M. G. (1991). Variation in feeding, aggression, and position choice between hatchery and wild cutthroat trout in an artificial stream. *Transactions of the American Fisheries Society* **120,** 723-727.

Montgomery, M. E., J. Ballou, R. K. Nurthen, D. A. Briscoe and R. Frankham (1997). Minimizing kinship in captive breeding programs. *Zoo Biology* **16,** 377-389.

Montgomery, M. E., L. M. Woodworth, R. K. Nurthern, D. M. Gilligan, D. A. Briscoe and R. Frankham (2000). Relationship between loss of genetic diversity and population size: Comparisons with theoretical predictions. *Conservation genetics* **1,** 33-43.

Moritz, C. (1999). Conservation units and translocations: strategies for conserving evolutionary processes. *Hereditas* **130,** 217-228.

Moyle, P. B. (1969). Comparative behaviour of young brook trout from wild and hatchery origin. *Progressive Fish-Culturist* **31,** 51-56.

NSW Fisheries (1999). Eastern freshwater cod (*Maccullochella ikei*) draft recovery plan. NSW Fisheries, Port Stephens Fisheries Centre, Port Stephens.

Petersson, E. and T. Järvi (1993). Differences in reproductive traits between sea-ranched and wild sea-trout originating from a common stock. *Nordic Journal of Freshwater Research* **68,** 91-97.

Petersson, E. and T. Järvi (1995). Evolution of morphological traits in sea trout parr (0+) through sea-ranching. *Nordic Journal of Freshwater Research* **70,** 62-67.

Reisenbichler, R. R. and G. Brown (1995). Is genetic change from hatchery rearing of anadromous fish really a problem? Pages 578-579 in H. L. Schramm, Jr., and R. G. Piper (eds). *Uses and effects of cultured fishes in aquatic ecosystems.* American Fisheries Society, Symposium 15, Bethesda, Maryland.

Reisenbichler, R. R. and J. D. McIntyre (1977). Genetic differences in growth and survival of juvenile hatchery and wild steelhead trout. *Journal of the Fisheries Research Board of Canada* **34,** 123-128.

Rowland, S. and Barlow, R. (1985). *Proceedings: Fish Genetics Workshop*. NSW Agriculture and Fisheries, Cronulla.

Ruzzante, D. E. (1991). Variation in agonisitic behaviour between hatchery and wild populations of a fish: a comment on Swain and Riddell (1990). *Canadian Journal of Fisheries and Aquatic Sciences* **48,** 519-520.

Ruzzante, D. E. (1992). Mirror image stimulation, social hierarchies, and population differences in agonistic behavior – a reappraisal. *Canadian Journal of Fisheries and Aquatic Sciences* **49,** 1966-1968.

Ruzzante, D. E. (1994). Domestication effects on aggressive and schooling behavior in fish. *Aquaculture* **120,** 1-24.

Ryder, O. A. (1986). Species conservation and systematics: the dilemma of subspecies. Trends in Ecology and Evolution 1, 9-10.

Ryman, N. (1991). Conservation genetics considerations in fishery management. *Journal of Fish Biology* **39(Supplement A),** 211-224.

Ryman, N. and L. Laikre (1991). Effects of supportive breeding on the genetically effective population size. *Conservation Biology* **5,** 325-329.

Ryman, N. and F. Utter (eds) (1987). *Population Genetics and Fishery Management.* University of Washington Press, Seattle.

Schramm Jr., H. L. and R. G. Piper (eds)(1995). Uses and effects of cultured fishes in aquatic ecosystems. American Fisheries society Symposium 15. Bethesda, Maryland.

Soulé, M. E. (1980). Thresholds for survival: Maintaining fitness and evolutionary potential. Pages 151-169 in M. E. Soulé and B. A. Wilcox (eds) *Conservation Biology: An Evolutionary - Ecological Perspective*. Sinauer, Sunderland, Massachusetts.

Soulé, M., M. Gilpin, W. Conway and T. Foose (1986). The Millenium Ark: How long a voyage, how many staterooms, how many passengers? *Zoo Biology* **5,** 101-113.

Swain, D. P. and B. E. Riddell (1990). Variation in agonistic behavior between newly emerged juveniles from hatchery and wild populations of coho salmon, *Oncorhynchus kisutch. Canadian Journal of Fisheries and Aquatic Sciences* **47,** 566-571.

Swain, D. P. and B. E. Riddell (1991). Domestication and agonistic behavior in coho salmon: reply to Ruzzante. *Canadian Journal of Fisheries and Aquatic Sciences* **48,** 520-522.

Tave, D. (1993). *Genetics for fish hatchery managers, 2nd edition.* AVI, Westport, Conneticut.

Thornhill, N. W. (ed.) (1993). *The natural history of inbreeding and outbreeding.* University of Chicago Press, Chicago.

Tringali, M. D. and T. M. Bert (1998). Risk to genetic effective population size should be an important consideration in fish stock-enhancement programs. *Bulletin of Marine Science* **62,** 641-659.

Vincent, R. E. (1960). Some influences of domestication upon three stocks of brook trout (*Salvelinus fontinalis* Mitchell). *Transactions of the American Fisheries Society* **89,** 35-52.

Waldmann, B. and J. S. McKinnon (1993). Inbreeding and outbreeding in fishes, amphibians and reptiles. Pages 250-282 in N. W. Thornhill (ed.) *The natural history of inbreeding and outbreeding.* University of Chicago Press, Chicago.

Waples, R. S. (1991). Genetic interactions between hatchery and wild salmonids: lessons from the Pacific Northwest. *Canadian Journal of Fisheries and Aquatic Sciences* **48,** 124-133.

Waples, R. S. (1995). Evolutionary significant units and conservation of biological diversity under the endangered species act. *American Fisheries Society Symposium* **17,** 8-27.

Weiss, S. and S. Schmutz (1999). Performance of hatchery-reared brown trout and their effects on wild fish in two small Austrian streams. *Transactions of the American Fisheries Society* **128,** 302-316.

Withler, R. E. (1988). Genetic consequences of fertilizing chinook salmon (*Oncorhynchus tshawytscha*) eggs with pooled milt. *Aquaculture* **68,** 15-25.

Woodworth, L. M. (1996). *Population size in captive breeding programs.* Ph.D. thesis. Macquarie University, Sydney, Australia.

Wright, S. (1931). Evolution in Mendelian populations. *Genetics* **16,** 97-159.

Practical Management for Genetic Stock Management of Native Fish Hatcheries

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Abstract

Geneticists can come up with protocols for fish hatcheries on how to manage their breeding stock so that stock enhancement will have a minimal effect on the genetic integrity of wild fish populations.

However, these protocols may fail to take into account a wide number of practical considerations that the fish hatcheries have to work under. Considerations such as: the cost and availability of broodfish; the facilities required to hold broodfish; the expected mortality rates of broodfish; the number of fry produced from each fish; the type of market they are providing fish for; and, the various types of breeding procedures that are used.

These considerations are discussed along side data that has been collected at the NSW Fisheries Native Fish Breeding Program. This program breeds 4 species of native fish and annually releases 2 million fry into NSW inland waters.

Introduction

Breeding methods

Four species of native fish are commonly bred by commercial fish hatcheries in the Murray- Darling Basin. These are Murray cod (*Maccullochella peeli*), golden perch (*Macquaria ambigua*), Silver perch (*Bidyanus bidyanus*), and catfish (*Tandanus tandanus*). The techniques for hatchery production of these species are described in Rowland (1983a, 1983b, 1988, 199?), and Lake (1967). The different breeding strategies of each species have called for different approaches in hatchery production. Accordingly there are differences in survival rates at the several critical stages of hatchery production for each species that affect the genetic input that parent fish will have on the fish produced

Murray cod can be bred by either hormone induced spawning (Rowland, 1988) or by collecting eggs from drums that are placed in ponds where pairs of Murray cod are held (Rowland, 1983). The latter method is the most widely used since it uses less labor, requires less technical skill and generally produces better hatch rates. Hormone induced spawning, however, does enable crossing different brood fish each year.

Pond spawning of Murray cod generally takes place in 0.1 -0.4 ha ponds with 2 to 6 pairs of Murray cod ranging in size from 7 to 15 kg. It may take from 6 to 18 months for newly established pairs of cod to produce eggs but then they will generally spawn each spring for several years. However, the proportion of pairs that spawned at NFC in 1998, 1999, and 2000 was 50%, 77% and 43%. These percentages are expected to improve as the newly paired fish settle down. Annual Murray cod brood fish deaths average 5% at NFC, although winter outbreaks of *Chilodonellosis* can occasionally cause mortality rates higher than 50% if preventative treatment is not taken.

The viability of eggs and larvae from Murray cod held in ponds decreases after 6-7 years (Gunasekera et al, 1998) and brood fish should be released after this time to maintain productivity. This also encourages hatcheries to introduce new genetic material to their ponds. Pond spawning does not prevent the same pairs of fish from mating each year, which reduces the potential genetic variability of the offspring, but an opportunity exists to swap brood fish between other ponds occurs every 2 to 3 years when the ponds should be drained and dried to reduce weed growth and improve water quality.

Murray cod produce between 3,200-7,600 eggs /kg (Rowland, 1985). Hatch rates average about 90 % for pond spawned eggs, but can vary from 50 – 98 %. Rowland (1988) reported average hatch rates of over 77 % for hormone induced spawned Murray cod This rate was lower during routine production at NFC at 54 % and a range of 0 – 95 %. Approximately 5 % of larvae die before the commencement of feeding, the remainder are grown to 35mm fry in earthen ponds where they feed on zooplankton. Most rearing ponds are 0 .3 - 0.4 ha and are stocked at a rate of about 300,000 cod larvae /ha. Survival rates of larvae to fry are generally around 80 % but occasionally lower survival may occur from disease or water quality problems.

Like Murray cod, catfish are also produced from natural spawnings in ponds as attempts at hormone induced spawning proved unsuccessful. Catfish deposit their eggs in a gravel nest making the eggs hard to remove . Hence, they are left to develop in the ponds before being drain harvested as fry. Females produce about 13,000 eggs/kg (Lake, 1967a). The eggs are large and the larvae are well developed so larval mortality is expected to be low. Catfish are not routinely bred at NFC and there is no published information on their production.

Golden perch and silver perch have a marine type breeding strategy with large numbers of small, poorly developed larvae. Brood fish are held in earthen ponds or tanks so the fish can be readily accessed for breeding. Fertile eggs are obtained by hormone induced spawning of ripe fish in hatchery tanks. Pairs of fish are placed in tanks in which they undergo courtship before the male fertilizes the eggs. The eggs can then be transferred to rearing tanks to hatch into larvae. After 5 days they commence feeding and are transferred to earthen rearing ponds to grow to 30 mm fry in several weeks. With a tagging system, such as the PIT tags, it is possible to keep track of which fish are paired together each season.

The mortality rates for golden perch brood fish are low at 2 %, where as for silver perch it is much higher at 20 %. The higher mortality rate for silver perch is associated with post breeding stress from their aggressive courtship behavior. Deaths are unusual at other times of the year for either species, but occasional losses can occur from poor water quality or disease.

Golden perch and silver perch are highly fecund, producing up to 300,000 eggs/kg (Rowland, 199?). However, the number of eggs spawned by individual fish can vary considerably. Over a season 26% of golden perch and silver perch will fail to produce viable eggs. Some fish may only spawn 50,000 eggs others 800,000. Of these, the hatch rates of golden and silver perch eggs averages 87.4 ± 6.8 and 88.8 ±9.5 respectively (Rowland, 1983,1984). These rates have been lower during the routine production of these species at NFC over recent years at 68 % and 62 %.

Golden perch and silver perch larvae are held in tanks in the hatchery until they are ready to feed, which usually takes 5 days. The mortality rate over this period is generally less than 5 % but it can occasionally exceed 80 %. At commencement of feeding, the larvae are released into an earthen pond at rates between 500,000 to 1,000,000 / ha. After 5 to 7 weeks of feeding on zooplankton, the fish will have grown to about 30-35mm and be ready for release. The fish are removed by draining the pond and taken back to the hatchery for counting.

The survival rate of golden perch and silver perch larvae in the rearing ponds is highly variable. This variability is caused primarily by the difficulty of co-ordinating a dense bloom of suitable zooplankton in the rearing pond at the time the first feed larvae are released. High pH at the time of release into the pond and predation by aquatic insects can also reduce survival rates at times. The survival rate for perch larvae at NFC averages 30 %, but ranges from 0 to 80 %.

It is general practice to spawn from 3 to 5 pairs of fish at a time, depending on the number of rearing ponds to be stocked. This makes mixing of the larvae into the ponds relatively easy. With the right conditions though it may be possible to produce all of a hatchery's golden perch fry (over 300,000) from one pair of fish. The average number of fry produced per female that spawned viable eggs at NFC is shown in Table 2. It gives a good indication of the number of brood fish that would be required for a commercial hatchery to meet a production target.

Commercial Hatchery Industry

The number of permits for commercial hatchery production of Murray cod, catfish, golden perch and silver perch in NSW is listed in Table 3. This table also shows the number of permit holders that actually produced fish, the total number of fish produced and the number that were released for public waterway stocking. These figures do not cover the significant number of fish moved to or from the Queensland and Victorian borders.

The distribution of the hatcheries in NSW covers a wide range of the Murray Darling Basin, from the southern Murray region to the Queensland border in the north. Most of the hatcheries are on the western foothills of the Great Dividing Range. This means that most rivers could be stocked from a number of local hatcheries within a few hundred kilometers.

The size of the native fish hatcheries varies from small single-handed operations with just a few ponds to large highly capitalized farms with dozens of ponds. The output of fish from these hatcheries also varies accordingly from several thousand to more than a million fish each year. Most of the smaller hatcheries, especially those run by volunteer angler groups, only supply fish for their local waters. The few larger hatcheries can cater for large orders over long distances, both intra and inter state.

Small hatcheries may only have 2 or 3 rearing ponds and 4 brood fish holding ponds. Typically their brood fish would consist of about 5 pairs of cod and 10 pairs of golden and/or silver perch. Large hatcheries would be several times bigger. For example, NFC holds 200 brood fish of four species in 30 ponds and uses 11 rearing ponds to produce over 2 million fish each year.

As most privately funded public stockings are from funds raised by angling clubs and rarely exceed $5,000, the numbers of fish released at each stocking are small, generally between 1 - 5 thousand Murray cod and 2 – 15 000 golden perch. This could make it difficult, especially for the smaller hatcheries, to follow the recommendation made by Brown (1985) that each stocking should be made up of progeny from 5 pairs of fish. This would not be a problem for Murray cod and catfish as generally at least 5 pairs contribute to the larvae from a rearing pond. On the other hand, individual golden perch and silver perch can often produce enough larvae to stock one or two rearing ponds resulting in up to 300,000 fry.

Most hatchery operators consider obtaining brood fish as one of their biggest problems. Some hatcheries have permits to collect their own fish, but as native fish are difficult to catch in many rivers, considerable effort needs to be made to capture wild fish from rivers. Alternately, fish could be purchased from professional fishermen but supply was irregular, transporting live fish difficult, and the fish were expensive at $25-35 /kg for Murray cod and $10-20 /kg for golden perch. The extra expense of travelling long distances, combined with the low success rates of catching wild brood fish from rivers has led most hatcheries to source brood fish from local farm dams that had been stocked previously with hatchery bred fish. Obviously this practice needs to be stopped.

Discussion

When embarking on any kind of stocking program, consideration must be given to maintaining the genetic integrity of indigenous stocks (Cowx, 1994). This requires obtaining brood fish from local populations, using an adequate number of wild brood fish, and preventing (or at least minimizing, by releasing fry at the earliest possible time) any hatchery based selection.

At this time, there is little information available on the extent of genetically discrete populations of native fish in the Murray Darling Basin. Keenan et al (199?) found seven discrete populations of golden perch, a fish known to under take extensive migrations over thousands of kilometers (Reynolds, 1983). There are likely to be many more discrete populations of other species such as catfish and Murray cod that have much smaller movements. Any future study to determine genetically discreet populations, will be hampered by the extensive stocking of hatchery produced fish that have taken place over the last two decades.

From the data presented in table one, the high variation in several stages of native fish production can be seen. This makes it very difficult to ensure that the contribution from individual parents is equalised A requirement to reduce the number of parents for a breeding program (Brown, 1985). When unequal family contributions occur, at least 100 parents of equal sex ratio is recommended (Carvalho and Cross, 1998). This should be an achievable target if the total number of brood fish for a number of hatcheries that stock an area is combined.

References

Blankenship, H.L. and Leber, K.M. (1995). A responsible approach to marine stock enhancement. American Fisheries Society Symposium 15: 167-175.

Carvalho, G.R. and Cross T.F. (1998). Enhancing fish production through introductions and stocking: genetic perspectives. In: Stocking and Introduction of Fish. Ed. Cowx, I.G. Blackwell Science, Oxford.

Gunasekera, R.M., Gooley G. and De Silva S. (1998). Characterisation of 'swollen yolk- sac syndrome' in the Australian freshwater fish Murray cod, *Maccullochella peeli peeli*, and associated nutritional implications for large scale aquaculture. Aquaculture, **169**, 69-85.

Keenan, C.P., Watts, R.J. and Serafini L.G. (199). Population genetics of golden perch *Macquaria ambigua,* silver perch *Bidyanus bidyanus,* and eel-tailed catfish *Tandanus tandanus* within the murray-Darling basin. Final Report – MDBC project M262.

Lake, J.S. (1967a). Rearing experiments with five species of Australian freshwater fishes. I. Inducement to spawning. Aust.J. Mar. Freshw. Res. **18**, 137-153.

Reynolds, L.F. (1983). Migration patterns of five fish species in the Murray-Darling River system. Australian Journal of Marine and Freshwater Research, **34**, 857-873.

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

Rowland, S.J. (1983b). Spawning of the Australian fish Murray cod, *Maccullochella peeli* (Mitchell), in earthen ponds. J. Fish Biol. **23**, 525-534.

Rowland, S.J. (1984). The hormone- induced spawning of silver perch, *Bidyanus bidyanus* (Mitchell) (Teraponidae). Aquaculture, **42**, 83- 86.

Rowland, S.J. (1988). Hormone-induced spawning of the Australian freshwater fish Murray cod, *Maccullochella peeli* (Mitchell) (Percichthyidae). Aquaculture, **70**, 371-389.

Thurstan, S.J. (1991). Commercial extensive larval rearing of Australian freshwater native fish. Hancock, D.A. (ed) 1992, Larval Biology. Australian Society for Fish Biology Workshop, Hobart, 20 August 1991, Bureau of Rural Resources Proceedings No. 15 AGPS, Canberra.

THEME 3 Questions & Answers

Greg Jenkins to Dean Gilligan and Anthony Moore

Question

a) For fish that spawn in aggregations, you would expect that males with more and stronger sperm would dominate in the offspring. There seems to be a case for treating such species differently to fish that pair. Any comment?

Answer

Certainly dominant fish will monopolise matings. As Darwinian selection suggests, these individuals will most likely be the fittest with the most vigorous sperm. However, for the maintenance of genetic variation in captive breeding programs, one-on-one breeding (irrespective of life history or mating system) is most effective.

Question

b) If you have a natural founder population that is under threat, you would expect a reduction in genetic diversity. Is there a case for introducing genes from another population? And what if the populations are very similar (with respect to fitness)?

Answer

Only as a last resort. It is well known that introducing new genes into a population often leads to increased vigor (heterosis). However, in some circumstances — often where populations are isolated for long periods — the crossing of locally adapted gene complexes can reduce population viability via outbreeding depression. Additionally, any supplementations should be limited to fish taken from locations of close geographic proximity, to avoid outbreeding depression. Unfortunately, we have very little information on stock/species boundaries in Australian fish and almost no data on evolutionarily significant units or management units from which to base these decisions.

Sandy Morison to Anthony Moore

Question

In a few species, recent events have often caused fragmented populations. So how do you know if the current isolated populations are locally adapted or just remnants from a fragmented, single population?

Answer

It is very difficult to tell if populations have locally adapted gene complexes. However, as a general rule of thumb the more goegraphically separate and isolated populations the more chance they have of adapting to different localized environments. The use of the ESU concept proposed by Craig Morritz suggests that historical isolation will manifest as reciprocal monophyly of mitochondrial sequence data. Contemporary fragmentation will not have this effect as approximately four *Ne* generations are required to reach that level of divergence.

Andrew Sanger to Dean Gilligan and Anthony Moore

Question

Having listened to Stephen's presentation, do you have any comment about the broodstock practices employed at Narrandera?

Answer

Limiting random mating by keeping only a single breeding pair per pond or tank and equalising parental contributions are the first and most important steps. A higher exchange of broodstock would also be advantageous.

Alf Hogan to panel

Question

Australian (and Queensland) waterways are characterised by intermittent streams and rivers represented by refuge waterholes for lengthy periods; and then you have occasional flooding and rapid population expansion. We must have bottlenecks and then massive in-breeding, and this [phenomenon] has been going on for thousands of years. Comment?

Answer

Certainly wild populations often go through natural population bottlenecks; however, it is the severity and length of the bottleneck that will determine how much genetic diversity is lost. Some natural populations, such as the Australian lungfish, currently have very little detectable genetic diversity believed to result from severe and prolonged population bottlenecks. These populations now have reduced adaptive potential and therefore have a higher probability of extinction if the present environmental conditions change and we see anthropogenic-induced change all the time. Yes, inbreeding does occur naturally and its impact on the population depends on the level of inbreeding and the genetic load (deleterious alleles) of the population.

Wild populations have very high mortality and very few individuals survive long enough to pass on their genes to the next generation. However, in the hatchery, very high survival rates can be produced because limiting factors such as food availability, space, predators, competitors and diseases are controlled. Therefore the impact of a single captive mating on the genetic diversity of the next generation can have a much higher (orders of magnitude) impact than [can] a wild mating.

John Harris (comment)

In 1985, NSW Fisheries held a workshop at Cronulla where genetic guidelines for hatcheries and stock enhancement were defined. This was followed in 1989 by a workshop at the UNSW. These workshops published proceedings and they formed the basis for operations at departmental hatcheries.

Dave Pollard (comment)

Narrandera was originally established with the purpose of breeding inland fish to stock farm dams and, later, artificial impoundments. It's a question of purpose: what is the hatchery trying to do: raise fish for food, or raise fish for the conservation of genetic diversity? Operations for these two purposes can have diametrically opposed genetic objectives and should be kept strictly separate. It should be remembered however, that there can be a continuum from breeding fish for threatened species conservation and recovery, through enhancement of wild stocks for fishery purposes, to aquaculture (in captivity).

Andrew Sanger (comment)

The only river stockings from Narrandera have been or threatened trout cod.

Richard Tilzey ("a trivia item")

The burgeoning Atlantic salmon industry in Tasmania was at one stage reduced to a broodstock of only seven female fish.

Brendon Ebnder to Stephen Thurstan

Question

a) Are male cod guarding the nest? And, if so, doesn't that negate the problem of a dominant male being able to fertilise multiple females in your ponds?

b) Widespread hatchery distribution in the Murray-Darling Basin may be beneficial for some species. Perhaps this is not the case for silver perch because broodstock may not be obtained locally, thus a genetic problem is created.

**[Response not recorded]

Phil Cadwallader (comment)

A problem for farm dam stocking is the issue of escapees. Although fish may be bred with aquaculture as the objective they will inevitably escape and may contribute to local riverine stocks.

Andrew Sanger to Andrew *Bearlin*

Question

Do you have any comment regarding [the] new project to look at genetic issues in the Murray-Darling Basin?

Answer

The Department of Natural Resources and Environment and the Queensland Department of Primary Industry have started assessing the project as two phases. First is the continuation of the Keenan, Watts and Serapini (1995) studies on Murray cod, trout cod and silver perch. Second is making an inventory of hatchery holdings of broodstock; and then exploring [any] relationships between the two.

Session 4

MEASURING SUCCESS - MARINE AND ESTUARINE FISHERIES

Restocking of black bream *(Acanthopagrus butcheri)* into WA estuaries

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Abstract only

Black bream Acanthopagrus butcheri, which completes its life cycle within estuaries, is one of the most important recreational and commercial fish species in the estuaries of southern Australia. The confinement of each population of A. butcheri to its natal envoronmentmeans that, in those cases where fishing pressure is sufficiently high to reduce markedly the abundance of this species in an estuary, the population in that estuary cannot be replenished natuarally by immigration from other systems. His can, and has resulted in depletion of the species in some estuaries.

In 1994, the Aquaculture Development Unit of the South Metropolitan College of TAFE commenced investigating the culture requirements for black bream in WA with a primary objective to restock this species into the depleted estuarine system of the Blackwood River in south-western Australia. A trial stocking of black bream in the Swan River was undertaken in 1995 in collaboration with Fisheries WA, Murdoch University and the WA Recreational Fishing Advisory Committee. A total of 767 externallt tagged black bream measuring c.a. 150 mm T.L. were released. Over a three-year period, a 12.6 recapture was recorded with an average of 317 days at liberty and an average recapture distance from the release site of 2.1 km (maximum distance 42 km).

Funding has been allocated from the FRDC to undertake a stock assessment of black bream in the Blackwood River, followed by restocking and monitoring. A restocking program of black bream in the Blackwood River estuarie offers an excellent opportunity to assess the degree to which a depleted stock of an estuarine species can be rehabilitated. However, it must be recognized that such an assessment cannot be successful without first obtaining sound information on the biological status of the restocking program and subsequent monitoring of the black bream stock in this estuary. This paper discusses the proposed restocking program with emphasis on selection of broodstock, methods for identifying released individuals and the subsequent monitoring of the bream stock.

Monitoring the Maroochy Estuary Fish Stocking Program 1995-99

Adam Butcher, David Mayer, Darren Smallwood, Mathew Johnston, Lew Williams, and Stephen Clapham

Queensland Department of Primary Industries
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Abstract

This pilot program was designed to evaluate the success of stocking juvenile dusky flathead (Platycephalus fuscus) and sand whiting (Sillago ciliata) into the Maroochy River estuary, southeast Queensland. At the time of its commencement (July 1995) it was the largest of its kind in Australia. One of the objectives was to undertake monitoring in association with the two experimental stocking releases. This required a measure of how the population density of the two fish species changed as a result of the stocking of numerous hatchery-reared fingerlings into the estuary. Densities of the two stocked species before and after the stocking events were estimated by three statistical models. All indicated that the population density of dusky flathead had increased (>30%) during the first 12 months after stocking, but that sand whiting densities remained relatively stable. Populations of both species declined substantially after the February 1998 fish kill, which confounded the effect of the first stocking. The pilot project was terminated before the effects of the second stocking could be observed. It was not possible to conclude confidently that the stocking events increased the population of fish in the river. The appearance of hatchery-reared fish in the commercial and recreational catch suggested that they contributed to an increase in the total population, but the possibility of stock displacement cannot be ruled out entirely. Environmental changes associated with the fish kill evidently reduced the opportunity for natural recruitment, thereby opening up an ecological niche that the hatchery whiting exploited. This is a clear indication of the potential for stocking programs to replenish depleted natural fish populations.

Introduction

The Maroochy Estuary Fish Stocking Program had its origins from recommendations of a Queensland Government review into recreational fishing in 1993. One of the recommendations of this review was to examine the stocking of recreationally important species in estuarine waters such as Pumicestone Passage (southern Queensland). However, following two major fish kills in 1993 and 1994, the government of the day directed DPI Fisheries to investigate estuarine stocking in the Maroochy River. The Maroochy Estuary Fish Stocking Pilot-program commenced in July 1995, following a 'scoping' workshop in September 1994 to review the contemporary knowledge and practices in estuarine fish stocking. The pilot-program was designed to evaluate the success of releasing juvenile dusky flathead and sand whiting into the Maroochy River. It was the largest estuarine stocking program in Australia in 1995. At the time of its commencement, commercial production technology had not been developed for either of the two target species, dusky flathead (Platycephalus fuscus) or sand whiting (Sillago ciliata).

The Maroochy River is located 120 km north of Brisbane (Figure 1). It has a small estuary some 26 km long (Anon 1998) that has been classified as moderately disturbed (Anderson 1993). There is a major population-centre, Maroochydore, on it southern downstream bank and a smaller urban development on the downstream northern bank. There are two substantial Zostera sp. seagrass beds in the lower reach. Further upstream riparian vegetation comprises a mixture of pristine mangrove forests and agricultural species.

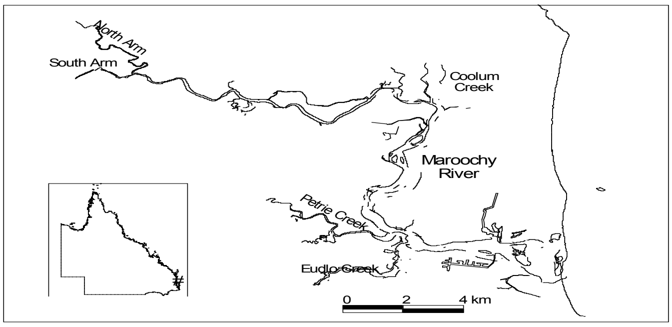

Figure 1. Location of the Maroochy River and major tributaries in southeast Queensland.
Coastline data in this figure are copyright Commonwealth of Australia, provided by AUSLIG.

One of the objectives of this program was to undertake a full-scale monitoring program in association with the experimental stocking program. This was a very broad objective, which in part demonstrates the inadequate comprehension of estuarine stock enhancement issues prevalent in Australia at that time (Palmer 1995). To advance the understanding of monitoring programs associated with estuarine stocking exercises, this objective was interpreted as 1) does stock size increase following stocking, and 2) will hatchery-origin fish survive, grow and recruit into the recreational and commercial sector catches?

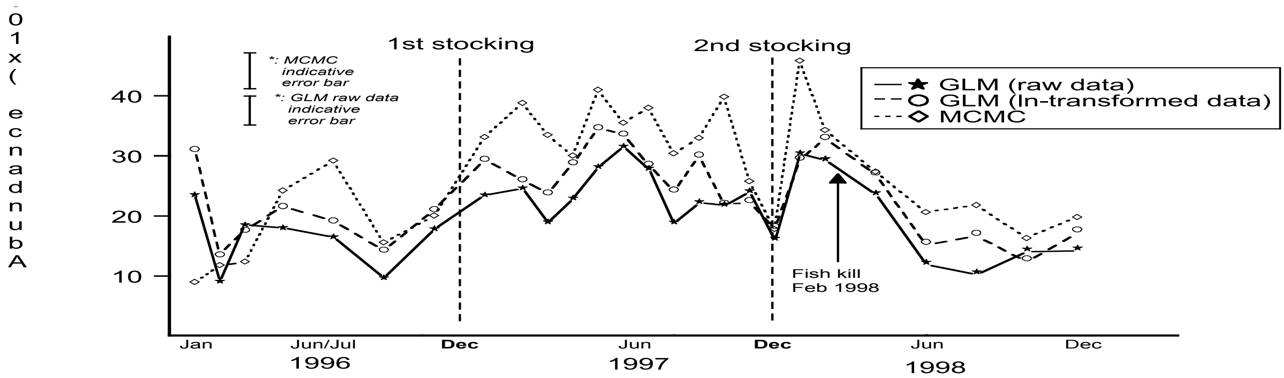

Figure 2. Abundance estimates of dusky flathead >6 cm SL in the Maroochy River.
*: Confidence intervals are indicative 2-way 95%, for the GLM and MCMC raw data series only.

Methods

The program began in January 1996 with a 12-month pre-stocking fishery-independent survey to assess natural populations of both species. Four gear types were used, depending on the topography at each sample site. These included fyke nets at sites with intertidal channels, fence nets at intertidal sites with terrestrial boundaries on at least one side, ring nets on mid-stream intertidal sites and beam trawling for all sub-tidal sites. The results from this survey was used to obtained an estimate of pre-stocking densities (Knight 1997) and preferred juvenile habitat for each species. A range of stocking rates was examined, depending on production capacity. Then between December 1996 and May 1998, 120,000 dusky flathead and 335,000 sand whiting were stocked, using a proportional scatter-stocking approach (Cowx 1994). Scale pattern analysis (SPA) (Willett 1996) was used to differentiate hatchery-reared from wild fish.

The effectiveness of stocking was assessed using indices of population density and survival derived from recreational and commercial catches and independent sampling. Fishery-independent sampling was continued after stocking to track growth and movement of hatchery-bred fish and to monitor total population size within the river. Three models were used to estimate densities of both species over time. These were (1) a parametric analysis of raw data, (2) a parametric analysis of logged transformed data to smooth some of the catch variability, and (3) Markov chain Monte Carlo simulation. Changes in the chosen species densities through time were investigated by fitting Fourier curves to the population abundance time-series and estimating both the predicted trends and the observed post-stocking effects on the populations (Butcher et al. 2000). This enabled comparison of the effects of the stocking against what might have happened if stocking had not occurred.

Recreational and commercial catches were sampled to determine whether hatchery-bred fish were surviving and being recruited into the commercial and recreational catch. This involved sampling recreational and commercial catches to obtain scale samples. These were then analysed for probable origin (hatchery or wild) (Willett 1996). In addition, catch rates from both sectors were analysed by general linear modelling to determine whether they changed as a result of stocking.

Results and Discussion

All three population abundance models demonstrated a gradual increase in the population of dusky flathead between January 1996 and February 1998 (Figure 2). However, sand whiting showed no clear trend in population densities between January 1996 and February 1998 (Figure 3). Following a flood-related fish kill in late February 1998, populations of both species declined and then appeared to recover by late 1998.

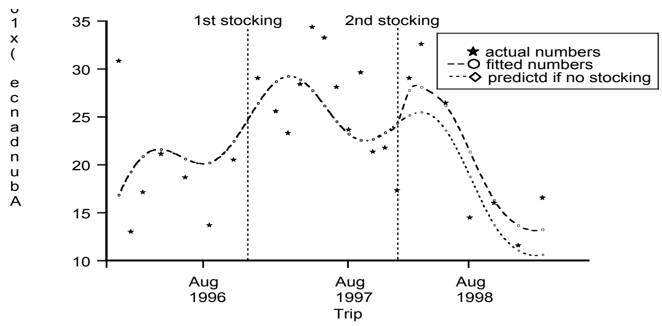

Figure 3. Abundance estimates of sand whiting >4 cm SL in the Maroochy River.
*: Confidence intervals are indicative 2-way 95%, for the GLM and MCMC raw data series only.

A Fourier curve analysis of abundance estimates indicated there was no significant increase in overall density of either species subsequent to stocking. However, a stocking signal was detected for each species about 12 months after the first stocking of dusky flathead (Figure 4) and six months after the first stocking of sand whiting (Figure 5). The variability in the sample catches, length of signal-delay, catastrophic changes in the ecology of the system at a critical time after stocking (fish kill) and the termination of the project prior to any chance of detecting an effect of the second stocking all contributed to this.

Several authors (Blankenship and Leber 1995, Cowx 1998) have cautioned against short stocking trials because of this temporal detection problem and the scoping workshop also acknowledged that it would take from five to seven years to run an effective stocking pilot program.

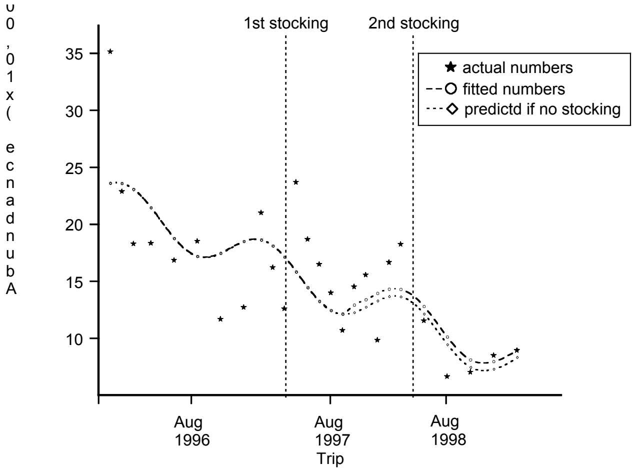

Figure 4. Actual, fitted and predicted numbers of dusky flathead in the Maroochy River.

Scale pattern analysis provided positive evidence of recruitment of hatchery fish into the wild population. Initially the dusky flathead hatchery to wild ratio was relatively low (<20%) from 6 months after the first stocking until the fish kill in February 1998 (Figure 6). This result can be attributed to high stocking and post-stocking mortality amongst hatchery-origin dusky flathead, combined with continual recruitment of wild dusky flathead juveniles. The second dusky flathead stocking event occurred in December 1997, prior to the fish kill in February 1998. After the fish kill, even though total catches declined, the ratio of hatchery to wild dusky flathead increased. Ratios of hatchery-origin sand whiting increased from 2 months after the first stocking in April 1997 as stocked fish grew and became catchable in the sampling gear (Figure 7). This ratio began declining after November 1997, probably due to the influx of wild-origin recruits. The fish kill in February 1998 caused a marked decline in overall catches of sand whiting. However, the second stocking in April–May 1998 produced a positive response with an increase in the ratio of hatchery origin fish (up to 50%) in what was probably an under-exploited habitat i.e. a recruitment bottleneck following the February 1998 fish kill. We believe this is evidence of successful estuarine stocking.

Scale Pattern Analysis has provided positive evidence that hatchery origin fish can survive, grow and recruit into creels. Similar results have been achieved with mullet and Pacific threadfin in Hawaii (Leber et al. 1995, 1998), barramundi in north Queensland (Rimmer and Russell, 1998) and red drum in Texas (McEacheron et al. 1998). The monitoring program detected an appreciable proportion of hatchery-origin fish of both species recruiting into the recreational and commercial sectors. Analysis of samples from both sectors indicate that up to 47% of recreational and 28% of commercial catches may be hatchery sourced dusky flathead and 44% of recreational and 52% of commercial catches were hatchery sourced sand whiting. However, recreational catch rates of sand whiting between 1994 and 2000 give a somewhat confounding picture (Figure 8). Average catch rates were around 17 sand whiting/fisher/trip in 1994. This rate declined in 1995, but increased to a maximum of 22 in 1996. There is no data available for 1997. All recreational fishery catch surveys conducted in 1998 occurred after the February fish kill. Consequently, the catch rate was very low (8 fish/fisher/trip). This rate rose to 12 in 1999 and declined slightly to 11 in 2000. If sand whiting take 12 to 18 months to grow to legal size, then clearly the effect of the first stocking was lost in the fish kill of February 1998. The effect of the second stocking may have influenced the subsequent resurgence in catch rates. There are insufficient recreational catch data available for analysis of the dusky flathead catch, as the majority of fishers target sand whiting.

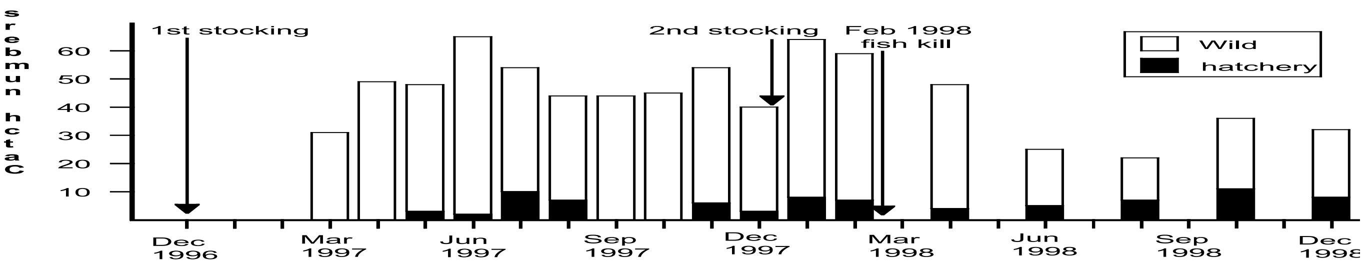

Figure 5. Actual, fitted and predicted numbers of sand whiting in the Maroochy River.

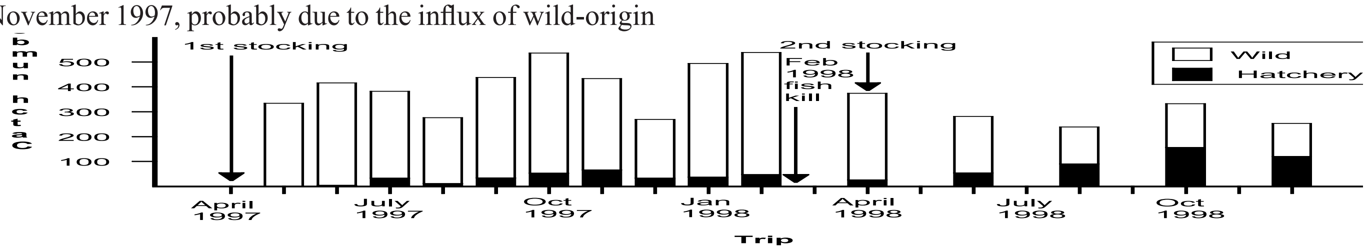

Figure 6. Numbers of hatchery-origin and wild dusky flathead in each fishery-independent sample from April 1997 to December 1998.

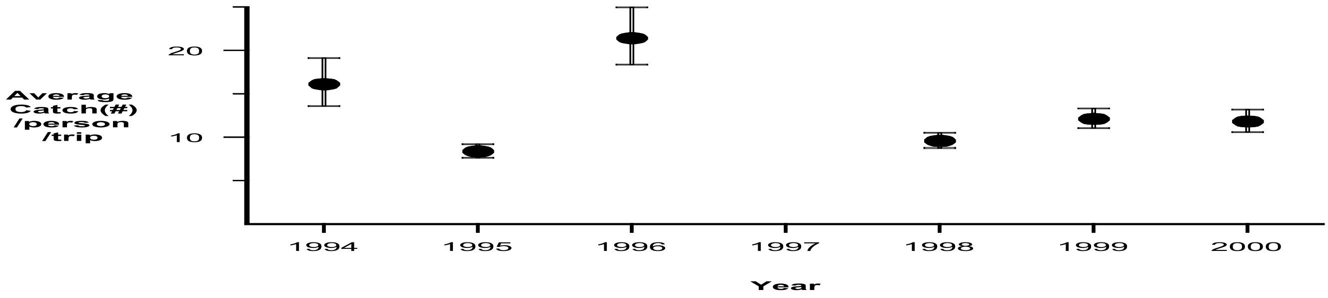

Figure 7. Numbers of hatchery-origin and wild sand whiting caught in each fishery-independent sample from March 1997 to December 1998.

Analysis of the commercial catch data indicate that overall dusky flathead catch rates declined by nearly 50% between 1988 and 1997. However, this decline has been cyclic, with a 30% decline between 1995 and 1997. Dusky flathead were expected to be of legal size by 18 to 24 months after the first stocking (December 1996). The catch rate has increased by 10% between 1997 and 1999. Given the fish kill in February 1998, this increase was probably due to the stocking program, but natural variation cannot be discounted. The commercial sand whiting catch rate has also been very cyclical, decreasing by 24% between 1988 and 1990, increasing by nearly 40% by 1992, and declining again. However, between 1997 and 1999 the catch rate has been relatively stable. Sand whiting were expected to be of legal size in 12 to 18 months after the first stocking (April 1997). Given the fish kill in February 1998, the stable catch rate may be attributed to successful fish stocking.

Acknowledgments

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References

Anderson, J. 1993. State of the rivers: Maroochy River and tributary streams: An ecological and physical assessment of the condition of streams in the Maroochy River catchment. *Report prepared by John Anderson in conjunction with Maroochy Shire Council and Dept. of Primary Industries.* Water Resources, pp. 127.

Anon, 1998. Maroochy Shire; state of the environment. *Maroochy Shire Council* pp. 142.

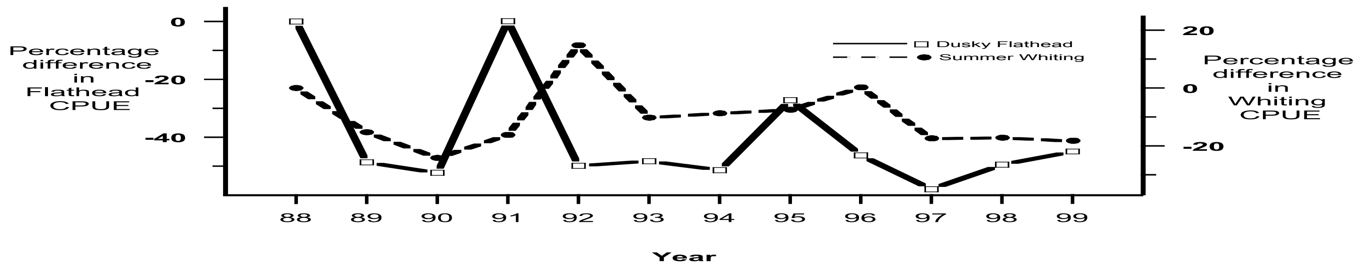

Figure 8. Mean catch rates (and 95% CI) from recreational fishing club competitions in Maroochy River.

Conclusions

The Maroochy Estuary Fish Stocking Program has shown that monitoring of estuarine stock enhancement is technically feasible, but is very demanding in terms of both human and financial resources.

Assessing a measurable increase in the population if either species has proven a more complicated issue to deal with, primarily because of the difficulty in attaining adequate statistical precision to detect changes in the population size within an inherently variable system.

This program has successfully demonstrated that hatchery-reared fish can survive the rigours of stocking and grow to recruit successfully into the recreational and commercial sector catches, influencing the catch rates from these sectors.

Blankenship, H.L. and Leber, K.M. 1995. A responsible approach to marine stock enhancement. In “Uses and effects of cultured fishes in aquatic ecosystems. American Fisheries Society Symposium 15” (eds. Schramm, H.L. and Piper R.G.) pp167–175.

Coxw, I.G. 1994. Stocking strategies. *Fisheries Management and Ecology* **1**:15–30.

Cowx, I.G. 1998. Stocking strategies: issues and options for future enhancement programs. In “Stocking and Introduction of Fish. Fishing News Books”. (ed. I.G. Cowx). pp. 1–13.

Knight, S. 1996. *Estimating the number of whiting and flathead in the Maroochy River*. Honours Thesis, Queensland University of Technology. pp. 76.

Leber, K.M., Brennan, N.P. and Arce, S.M. 1995. Marine enhancement with striped mullet: Are hatchery releases replenishing or displacing wild stocks In “Uses and effects of cultured fishes in aquatic ecosystems. *American Fisheries Society Symposium 15”* (eds. Schramm, H.L. and Piper R.G.) pp376–390.

Leber, K.M., Brennan, N.P. and Arce, S.M. 1998. Recruitment patterns of cultured juvenile Pacific threadfin, *Polydactylus sexfilis* (Polynemidae), released along sandy marine shores in Hawaii. *Bulletin of Marine Science* **62**:389–408.

McEacheron, L.W., Colura, R. L., Bumguardner, B. W. and Ware, R. 1998. Survival of stocked red drum in Texas. *Bulletin of Marine Science* **62**:359–368.

Palmer, P.J. 1995. Enhancing non-impounded fisheries: a review of current literature with relevance to southern Queensland. *Department of Primary Industries QI95022*. pp. 104.

Rimmer, M.A. and Russell, D.J. 1998. Survival of stocked barramundi, *Lates calcarifer* (Bloch), in a coastal river system in far northern Queensland, Australia. *Bulletin of Marine Science* **62**:325–336.

Willet, D.J. 1996. Use of scale patterns to evaluate stocking success of silver perch, *Bidyanus bidyanus* (Mitchell), release at two different sizes. *Marine and Freshwater Research* **47**:757–761.

A review of Abalone Stock Enhancement

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Abstract

Abalone stock enhancement experiments are reviewed. Stock enhancement is most likely to be successful in carefully selected sites where there are good habitat characteristics, yet low productivity occurs due to various historical or ecological reasons.

Interventions to alter the habitat or increase the stocks are the main enhancement practice. Habitat interventions imply a slow recovery of the stock as it mainly relies on natural recruitment success. Three stages in the life history of abalone have been used to enhance natural stocks. Although larvae can be produced in large quantity at very low cost, larval seeding is apparently not recommended because the larval stage is a strongly density-dependant phase, greatly affected by environmental factors. Broodstock translocation should be considered only when juvenile seeding would not prove cost-effective, because the expected recovery is slow as it mostly relies on unpredictable natural settlement and recruitment.

Size and density of the seed are key factors in juvenile out-planting experiments. Natural and handling mortality is expected to decrease with the increasing size of the seed and the optimum re-seeding size would vary according to predator communities. The density of juvenile release should not exceed what the natural carrying capacity of a site is likely to be. The behavioural quality of the stocked juveniles is also a determining factor.

The seed should be carefully selected to minimize the risk of contamination of the natural population with disease or parasites, as well as the impact on the local genetic diversity.

Introduction

In recent years, abalone has fetched very high price on the Asian market, increasing the pressure on abalone fisheries worldwide. Presumably as a result, several natural stocks have been depleted overseas and local declines have been reported in Australia (Shepherd et al.. 2000, Shepherd and Rodda 2000). At a time when the increasing international demand may put a higher pressure on Australian abalone fisheries, artificial enhancement should be taken into consideration in order to revive or enhance some of the local stocks.

The aim of this paper is to review the previous experiments that have been carried out worldwide, including Australia, and extract generalizations and recommendations. Artificial enhancement and extensive culture of abalone populations has already been practiced in various countries such as Japan, USA, New Zealand, South Africa and Australia with very variable results. In Japan, where abalone is part of the culture, stock enhancement had already started in the 1970's and is highly subsidized by the local prefectures. In most other countries, where abalone is valued only on the export market, the technique must first be proven profitable and only evaluation experiments have been carried out. Despite receiving substantial public funding in some countries for political reasons, fishery enhancement projects have seldom been rational or economical (Hilborn 1998).

Artificial enhancement is most likely to be successful in carefully selected sites where, the habitat characteristics (i.e presence of food and protection from predators) are good, but low productivity occurs due to one or a combination of the following factors:

- Past Over fishing or poaching,
- High natural mortality of the juveniles (absence of cryptic habitat) (Schiel, 1993),
- Absence of encrusting corallines on the habitat resulting in low survival of post-settlement juveniles (McShane 1995, Shepherd and Daume 1996),
- Unsuccessful settlement of larvae due to environmental factors such as current patterns and the location of the reef (Shepherd 1990, McShane 1992),
- Unsuccessful reproduction due to very low density of adults (Sluczanowski 1984, Pennington 1985) or small population size under some minimum viable population density (Shepherd and Brown 1993, McShane 1995).

Two main types of management strategy may be used to restore reef productivity: intervention to alter the habitat, or increase the stock. These two solutions will be discussed below.

Definition of an abalone stock

The general characteristics of an abalone stock are an important issue, as abalone has a very specific habitat and ecology. An abalone stock has been defined as "a panmictic group of individuals that share a common gene pool and are more or less isolated during reproduction from all other conspecifics". This means that the spatial dimensions of a stock are defined by the scale over which favourable habitat is continuous, permitting intermingling of juveniles and adults (Shepherd and Brown, 1993). The gene pool remains localized and isolated as larvae do not often settle far from their parent's reef (Brown and Murray 1992, Prince et al. 1987, 1988). However, depending on the oceanographic characteristics of an area, abalone metapopulations can exist which include subpopulations that are held together by larval dispersal (Shepherd and Brown 1993, Rodda et al. 1997).

The size of the stock and its relationship with the surrounding environment has important implications on the choice of the enhancement technique to be used.

Choice of suitable site

Many authors have emphasized the importance of careful site selection before starting enhancement programs (Tegner and Butler 1989, Schiel 1993, Seki and Tanigushi 2000, Shepherd et al. 2000). It is important to take the natural history of the animal into account as well as the history of the site. Sites where poaching is the main cause for depletion are unlikely to be successful unless public education programs take place and fisheries closures are strongly enforced (Dovetail Consulting Inc. 1999). Schiel (1992, 1993) has found that habitats prone to regular siltation or sand movement, which may partially bury juvenile habitats, are not suitable for stock enhancement program as these habitats result in high mortality levels.

In recent years, better understanding of the natural history of each abalone species has allowed more appropriate site selection. Tegner and Butler (1989) underlined that to find a site with a suitable rocky habitat is probably the most difficult aspect of seeding. Other requirements such as temperature, depth, water movement and food supply are usually much easier to meet. The type of habitat is important as it provides protection from predators and allows good survival especially for the more vulnerable juveniles. Each area will present a particular predator community, which may have implications for the seeding technique required (reviewied by Tegner and Butler 1989). More recently, reviews of stock enhancement literature have shown that the lack of understanding of the factors regulating natural populations is a key for the failure of most enhancement experiment (Olla et al. 1998, Shepherd et al. 2000). For example, Shepherd and Clarkson (in press) showed a functional response of predatory wrasses to increased prey (abalone) density and so explained the density-dependant mortality of post-settlement juvenile abalone on corallines.

Habitat interventions

Predator removal

Only a few studies have considered the removal of predators as a solution to improve the survival of transplanted abalone. It was suggested that the abalone stock enhancement success in Japan was partly due to intense fishing of predators (Tegner and Butler 1989). Predators and scavengers are attracted by transplanted animals, which have not yet recovered from handling stresses (Tegner and Butler 1989). Tegner and Butler (1985a) reported that crab and other crustaceans may account for about one third of the known mortality of both hatchery and wild abalone in their study area. Shepherd (1998) was able to apportion abalone mortality between crabs and wrasses, the mortality due to crab predation appeared constant over time while predation by wrasse appeared much more variable depending on the density of these wrasses on the reef.

Thus the seed must be handled with care to prevent stress or injuries that would attract predators. In order to be efficient, predator removal must be carried out regularly as most predators are highly mobile and move toward areas where food is more abundant (Tegner 1985).

Artificial habitats

It is difficult here to draw a border between ranching and stock enhancement when the use of artificial habitat is considered (Shepherd et al. 2000). The use of artificial habitats may have different purposes: to provide protection from predators to the juveniles, to increase the habitat space or to allow a survey of cryptic juvenile populations for stock assessment (Davis 1995).

Different artificial habitat designs are described in McCormick et al. (1994). The Japanese seeding experiments using artificial reefs usually yielded lower mortality rates than on natural reefs (reviewed in Shepherd 1998). The study in France by Flassch and Aveline (1984) showed that artificial habitats restraining the movement of juveniles, protecting them from predators, and especially designed to collect drift algae may be used to grow out juvenile to market size. A similar device could be used to rear juveniles on depleted reefs. In order to improve the carrying capacity of a reef, algal aforestation was also practiced in Japan (Uki 1989).

Marine Protected Areas (MPA)

Marine refugia of suitable size can be considered for three main reasons: the enhancement of egg production, the maintenance of genetic diversity and places for scientific experiments. The size of the refugia is a critical issue as they must be large enough to allow the self-sustainability of the local population (Shepherd and Brown 1993). The protection of areas which are part of enhancement project is essential (Tegner 2000). Fishing closure must be easily enforced to prevent the poaching or fishing of the transplanted animals (Tegner 1993).

The recovery of depleted populations using habitat intervention will be very slow as it relies on the occurrence of natural recruitment. As shown by several authors (Shepherd et al. 1985, McShane and Smith 1991), natural recruitment is highly variable and unpredictable from one year to another. Furthermore, the early life stages of abalone are highly density-dependant allowing only a limited recruitment to the fishery each year (Shepherd et al. 2000). Thus habitat interventions are seldom considered alone and are usually carried out in parallel with a type of stock intervention.

Stock interventions

Larval seeding

It's only in recent years that larval seeding has been considered as a potential intervention for stock enhancement. Only a few experiments have actually been published and it is obvious that the results have been highly variable. The monitoring of larval seeding experiments is difficult, time-consuming and tedious due to the size of the post-larvae (Schiel 1992) and heterogeneity of the substratum. Because abalone larvae behave as passive particles in the water, except for vertical movement (McShane 1992), larval seeding density depends on the environmental parameters of the reef such as water current and eddies (Rodda et al. 1997, Sasaki and Shepherd 1995, McShane 1992, 1995, Tegner and Butler 1985b). The settlement may be strongly affected by the type of substrate and is usually very patchy (Shepherd and Daume 1996). Daume et al. (1999a, b) have shown that H. laevigata and rubra larvae prefer to settle on crustose corallines and thus the distribution of post-larvae would rely on the patchiness of these algae. Natural settlement has been shown to be highly variable (McShane and Smith 1995, Rodda et al. 1997). Predation by filter-feeders may also affect the larvae before settlement. Predation by deposit feeders such as terebellid polychaetes, and bulldozing by grazers may be important immediately post-settlement.

Three factors: larval dispersal, patchiness of settlement and mortality, cause very strong variability in the success of larval seeding experiments (Shepherd et al. 2000). In a first attempt to use hatchery-produced larvae for stock enhancement, Tong et al. (1987) used a small semi-enclosed gully on an exposed rocky shore in order to reduce the impacts of environmental parameters such as currents. They observed a significant increase in the local density of post-larval abalone. Their results were encouraging and in subsequent experiments, Preece et al. (1997) and Schiel (1992) have used tents made of plankton nets to prevent the larvae from drifting away from the reef. Tents appeared to allow a higher settlement rate on the reef, but the subsequent density-dependant mortality described in Shepherd et al. (2000) negate the use of such devices.

Two different releasing methods have been used in these experiments. Schiel (1992) transported the larvae underwater using plastic bags filled with fresh seawater. Preece et al.. (1997) hosed the larvae onto a given reef surface using a pressurized container holding a known density of larvae.

Despite the relatively good settlement rate obtained by Schiel (1992) (Table 1), the post settlement mortality was so high that the author concluded that the technique was not economically viable and that out-planted juveniles should be preferred for *Haliotis iris*.

Table 1: Larval seeding experiment.

Species (*author*)	**Release density**	**% settlement**	***Inst. M (month^{-1}) 0-2 months***	***Inst. M (mnth^{-1}) 1st year***	***Inst. M (month^{-1}) 2nd year***	***Density after 1 year***	***Density after 2 years***
H. rubra	1600-80000	0.02-1.2% (ave. 0.6%)	-	2.1-3.3	0.5->2.8	1.75-2.75	0-1.67
H. laevigata	2000-120000	0.1-7.8% (ave. 2.1%)	1.8-2.8	2.5-4.7	>1.5->2.2	0.33-0.9	0-0.1?
H. iris	20000	10%	1.0-1.3	ND	ND	ND	ND

Preece et al. (1997) carried out the most complete larval seeding experiments He recorded mortality and density up to 335 days after seeding. The results have been analysed in more detail in Shepherd et al. (2000). They obtained settlement rates (Table 1) varying with the density of the released larvae. The best settlement rate was at 20,000 larvae/m^2 for *H. laevigata* and 1,600 larvae/m^2 for *H. rubra* (Figure 1). Although the calculation of the subsequent survival rates was biased by natural settlement, it appeared to be strongly density-dependant (Figure 2). Mortality was positively correlated with the logarithm of post-larval density. Shepherd et al. (2000) suggest that this is the result of predation, with predators being attracted to dense aggregations of prey.

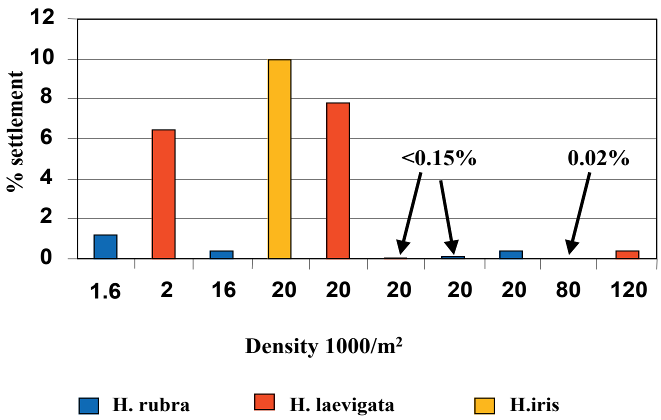

Figure 1: Settlement rate versus release density in larval seeding experiment with *Haliotis iris* (Schiel 1992), *H. rubra* and *H. laevigata* (Shepherd **et al.** 2000)

Generally, the settlement rates obtained in larval seeding experiment range from 0 to 10%. In hatcheries, according to the method used, settlement rates vary according to the type of substrate. On a heterogeneous diatom and bacteria film, the settlement rates usually range from 1-5%. On an homogenous mono-species diatom film it can be up to 10% (Daume pers. comm., Heasman pers. comm.). Recent work using an homogenous cover of Ulvella lens, a green encrusting algae, on plastic plates, settlement rates were up to 67%. Shepherd et al. (2000) suggested that optimal release densities of larval seeding may be quite low because higher densities attract predators into the area. Seeding sites should be carefully selected and sites where historical catches have been high would be preferred. Ideally, the larvae should be sprayed over a large surface of reef from a boat to reduce the cost and labour of the operation. Release should be timed carefully to minimize handling stress and predation, and maximise subsequent growth.

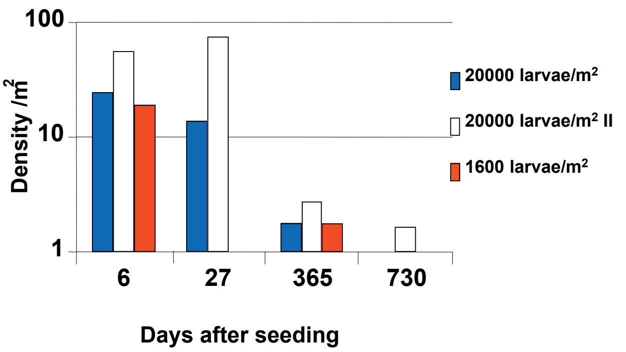

Figure 2: Mortality of *Haliotis rubra* juveniles after seeding (from Shepherd et al**.** 2000)

Even if optimal methods are used, larval seeding is probably not cost-effective because the larval stage suffers strong density-dependant mortality.

Juvenile out-planting

Mortality

All the studies of out-planting report a high initial mortality rate in the early days after transplantation. Stress due to transport and handling is a major issue (McCormick et al. 1994) and affects the transplanted abalone whether they are produced in a hatchery or collected from the wild. Schiel (1992) found that wild transplanted *H. iris* suffered 35% mortality 5.5 weeks after transplantation. Shepherd (1986) noted an average of 10% of the wild juveniles handled and tagged for the purpose of his experiment disappeared in the first day probably due to predation. McCormick et al. (1994) showed that protecting the seed for the first few days significantly reduced mortality.

Mortality rates of natural stock and seed transplants are reviewed and compared in Shepherd (1998). Although Schiel (1993) and Sweijd et al. (1998) suggested that mortality rates become similar to those of natural populations after initial mortalities, Shepherd et al. (2000) suggested that mortality rates were generally significantly higher for hatchery juveniles than for natural juveniles. Clearly more work is needed to determine rates of mortality and the factors that affect mortality.

Impaired behaviour

Many authors reported that hatchery produced seed may have a maladapted behaviour when transplanted into natural reef and consequently suffer more from predation (Tegner and Butler 1989). Impaired behaviour of hatchery juveniles is known from enhancement projects involving other marine and freshwater species (e.g. salmon, reviewed by Olla et al. 1998). Hatchery juveniles often lack appropriate predator escape behaviours, refuge seeking behaviours or activity rhythms.

In laboratory experiments, Schiel and Welden (1987) have shown that hatchery reared juveniles appeared to stay more in exposed areas and are more sluggish than wild ones. Hatchery juveniles are also slower to attach themselves to the substrate. Juveniles adapted to the experimental environment showed improved behaviour compared with juveniles freshly brought in from the hatchery. This suggested that juveniles might need a few days to adapt to their new environment.

Breitburg (in Tegner and Butler 1989) also showed major behavioural differences between wild and cultured animals. The study suggested that these differences might vary according to the type of substrate used. In these experiments, cultured juvenile were also found to stay in more exposed areas and were therefore more susceptible to be preyed on.

Olla et al. (1998) suggest that a good process to condition the juvenile salmon pre-release may greatly reduce the mortality in the first few days. However, such conditioning programs have not yet been elaborated for abalone

Migration and movement

Abalone are known to move over considerable distances (Ault and DeMartini 1987) - e.g. over 250m over 6 months for *H. laevigata* - (Shepherd 1986). Tegner and Butler (1989) report that Californian abalone may migrate over 150m from the seeding site, making them impossible to recover. Migration is a problem because it is not known how movement affects survival estimates (Schiel 1993) or assessments of abundance (Shepherd, 1986, Dixon et al. 1998). Movement of the juvenile abalone is increased after handling or after a disturbance of their habitat (Shepherd and Godoy 1989, Werner et al. 1995). Douros (1985) showed that abalone in high density areas tended to move more than those at low density. Clavier and Richard (1984) and Shepherd (1986) showed that *H. tuberculata* and *H. laevigata* respectively tended to migrate toward the direction of swell or main currents. Shepherd (1986) also noted that the mobility and migration patterns depend on the nature of the reef. Migration was less important on reef where crevice abundance was high. Similarly, Dixon et al. (1998) described that when more "preferred habitat space" was available, the emigration from the reef was decreasing. Momma et al. (1980) (translated by Mottet 1984) mentioned that juveniles tended to migrate from more densely populated areas to areas less densely populated. Davis (1995) confirmed these findings in a later experiment with artificial reefs, where transplanted juveniles migrated out of the studied reefs until the population density stabilised at the natural density level. Dixon et al. (1998) found that juvenile *H. rubra* were moving out of their cryptic habitat where larger adults were removed by fishermen. Movement studies generally show that movement is a diffusion process (Tegner and Butler 1985a, Shepherd and Godoy 1989) so that random walk process would fit movement data. As a result, densities will equilibrate over time.

Releasing devices to reduce handling stress

Releasing devices are usually designed to hold juveniles and reduce stress during transportation, seeding and the first days after transplantation. Various releasing devices have been described in the literature. Some of the devices are used to hold a large number of seed in order to reduce the labour involved in seeding.

Oyster shells have often been used to place a large number of juveniles in natural habitat by the Japanese. However, they did not seem to improve the short-term survival of red abalone, *H. rufescens* in California(Tegner and Butler 1989).

Plastic PVC pipe closed at both end by corrodible wires has also been used and has the advantage that it provides a shelter from predators for the seed after transplantation.

Heasman and Chick (pers. Comm.) have used small rocks placed in wire bag. The migration of the juveniles out of the releasing device was slow suggesting a very low stress at release.

However Schiel (1993) obtained very good survival rate seeding by hand and Shepherd et al. (2000) suggested, with few evidence however, that the use of releasing devices such as abalone shells or concrete bricks made no differences in terms of survival in their experiment.

Assessing results

The results of juvenile out-planting are difficult to assess because this requires long term monitoring of each site. Tagging of the seed is not usually necessary as the diet fed in the hatchery leaves a distinctive mark in the shell that can easily be identified underwater even after long periods of time (Hahn 1989, Schiel 1993, Kojima 1995, Rogers-Bennett and Pearse 1998).

Two ways of assessing results have been used: the collection of empty shells to assess the causes, timing and rate of mortality, and the monitoring live animals for growth and survival rates (Tegner and Butler 1989, Shepherd and Breen 1992). The two methods combined can only give a range of survival rate, maximum and minimum survival rate respectively. Unaccounted shells appear to be very important in most experiments and authors can only guess about the fate of these animals: mortality, migration out of the study site or into cryptic habitats. Although Davis (1995) found a reasonably high rate of recovery of empty shells, 82% on average, Shepherd (1998) showed experimentally that there was a high disappearance rate of empty shells, which would easily bias mortality estimates. These two contradictory results suggest that the disappearance rate of empty shell may greatly vary from site to site.

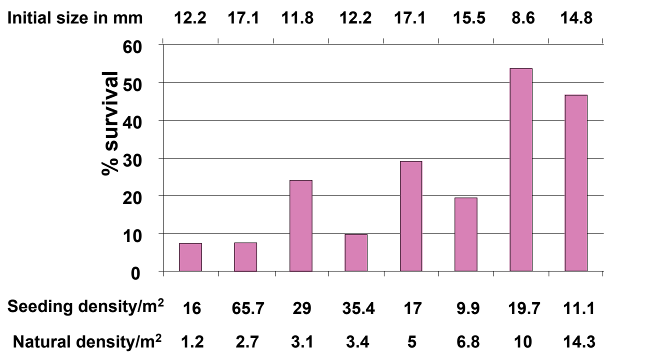

Figure 3: Minimal survival rate of *Haliotis iris* in out-planting experiments (data from Schiel 1993)

The results of juvenile seeding experiment are reviewed in Table 2. The first results obtained in Japan in the 70's suggested that the survival of the seed was correlated to the shell size. Indeed, one can easily imagine that the thicker the shell the less susceptible an abalone is to predators. The study by Inoue (1976, reviewed in Tegner and Butler 1989) suggested that only seed over 40mm in size would yield good survival rates (over 40%). However seed of that size are very expensive to produce and would make most enhancement programmes economically unviable. Later authors have shown that good survival rates could be obtained with smaller seed.

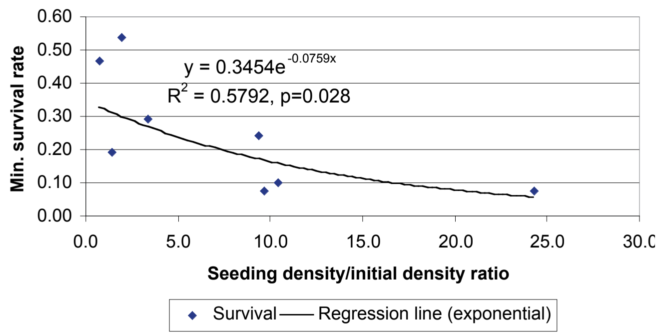

Figure 4: relationship between minimal survival rate and the ratio seeding density/initial density in the seeding experiments of *Haliotis iris* (data from Schiel 1993)

Despite trying seed of variable sizes, Tegner and Butler (1985a) could not get a survival rate better than 1%. However this low survival rate has been common in the seeding experiments carried out in California (Rogers-Bennett and Pearse 1998). These results contrast with those obtained in Japan and New Zealand (Schiel 1993, Kojima 1995).

In these more recent studies, higher survival rates have been achieved. However the variability in the results obtained is difficult to interpret. Only in recent studies have environmental parameters been recorded before and after the release of juvenile (Schiel 1993, Seki and Taniguchi 2000). Importantly, Seki and Tanigushi (2000) have notably shown the habitat preference of seeds changes according to their size and dietary requirements. Schiel (1993) has probably done the most detailed monitoring, recording parameters such as initial density and habitat characteristics. His results provide a better understanding of the mechanisms involved in juvenile out-planting. His results suggest size is probably not the principal factor (Figure 3). It seems that each reef can only sustain a certain density of abalone and natural densities should be estimated to provide an idea of the maximum carrying capacity of a reef before deciding on the seeding densities to use. The best survival rates (>25%) were achieved when the seeding density did not exceed 4 times the initial density (Figure 4). There was a strong negative correlation (R^2=0.658, p=0.014) between the initial density before seeding and the intra-specific competition index (Figure 5) calculated from Begon et al. (1996). The value of k increases with increasing mortality of the seed.

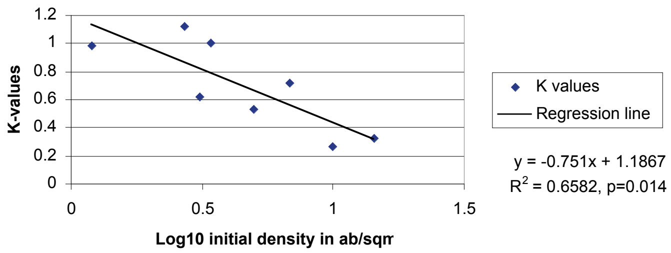

Figure 5: Intraspecific competition index (k=log(seeding density)-log(final density)) vs initial density before seeding (data from Schiel, 1993). K is calculated from Begon et al. (1996).

Genetic considerations

Seeding experiments in the USA have shown that despite the low survival rate of the out-planted seed, they can have a major impact on the genetics of the local stocks. Gaffney et al. (1996) suggested that the adult abalone fished in 1992 from Tyler Bight on the South side of San Miguel Island in the Channel Islands at a site, which had been unsuccessfully seeded in 1979, had genotypic and allelic frequencies similar to hatchery animals. These results should be taken carefully, because they rely on the unlikely assumption that natural recruitment of similar year class was minimal in an area where red abalone remains relatively abundant. They may thus only be an artefact (Tegner 2000). Rogers-Bennett and Pearse (1998) found that their seed represented one third of the local population at the end of their experiment despite a survival rate below 1%. Such a strong representation of hatchery seed may have a significant impact on the gene pool of the local population. In the case of larval re-seeding it is difficult to assess the long-term genetic impact the experiment may have on the local population.

Good hatchery practices are therefore essential to ensure the conservation of the local population biodiversity (Gaffney et al. 1996, Elliott 2000):

- Where possible, the broodstock should come from the populations to be enhanced.
- The broodstock should include at least 5 males and 5 females in order to keep a high level of genetic diversity.

Disease control

It is essential for the protection of the natural abalone populations that all seed or transplants are checked for any disease or parasite infections. Little is known about diseases affecting abalone population, but some disease affecting hatchery populations may cause great damage if transmitted to the natural populations e.g. *Perkinsus olseni* in South Australia (Goggin and Lester 1995), withering syndrome and sabellid polychaete infestations (Tegner 2000), vibrio bacteria (Hahn 1989).

Translocation of adults

Transplantation of adults may be considered to achieve two possible goals:

- The reconstitution a natural abalone broodstock in areas where adult abalone have declined, disappeared or never established (Tegner 1992),
- The redistribution of the biomass of adult abalone over a larger area to decrease population density and improve growth and productivity (Emmett and Jamieson 1988).

Translocation of broodstock is very expensive, but should be taken into consideration to enhance depleted stocks until the survival rates of cultured larvae or seed releases improve (Tegner, 1992).

Transplantation induced stress and injuries (Tegner and Butler, 1985a) may greatly affect the survival rate of the animal transplanted as they may attract predators or scavengers. Although adult blacklip (*H. rubra*) have been shown fairly resistant to handling, animals may need to be protected from predators during the first days after the transplantation occurred. For example, Day and Leorke (1986, pers. comm.) kept tagged animals on raocks in mesh cages for several days prior to release.

In order to reconstitute the broodstock of a certain area, the number of transplanted adults must at least reconstitute a minimal stock abundance to allow successful reproduction (Tegner 2000, Prince et al. 1988, McShane et al. 1988). However, even if transferred adult abalone can successfully reproduce themselves, the successful recruitment of their larvae to the fishery relies on natural events (Shepherd et al.. 1992, Tegner 1992). Rodda et al. (1997) found no correlation between the adult density on a reef and the number of larvae settling. It is important for the success of the translocation that transplanted animals live for a long time so that their continued reproduction can result in the enhancement of the local reefs (Tegner 1992, 2000).

Adult translocation experiments are scarce in the literature and most of them have not been successful (Henderson et al. 1988, Tegner 1992). Their results and the main technical problems identified during these experiments are summarized in Table 3.

Measuring the success of stock enhancement

Schiel (1992) has shown that larval seeding did not prove to be economical and preferred juvenile seeding. But his economic analysis was based on the results of a single larval seeding experiment, which are difficult to extrapolate, as uncertainties and the variability in mortality remain very high even in more recent experiments (Preece et al. 1997).

Adult translocation experiments are too scarce to draw conclusions in terms of economical viability. However it seems clear from the Californian experience that these translocations should be associated with appropriate fisheries closure (Tegner 2000).

The variability in the results of juvenile out-planting experiments is not yet fully understood and more experiments need to be carried out. Schiel (1993) showed that with a comprehensive record of environmental parameters, enhancement techniques could be more reliable. For his large-scale experiment, with survival rates ranging from 7 to 54%, he estimated an Internal Rate of Return (IRR) of only 9.6% after 6 years. Sweijd et al. (1998) estimated that an IRR below 20% would make enhancement programs economically non-viable.

Production costs of the seed are therefore a key issue in enhancement programmes or abalone ranching (Flassch and Aveline 1984, Uki 1989, Kojima 1995) and will largely depend on the production capacity of the hatchery. As abalone is mainly produced for export markets, Sweijd et al. (1998) also underlined the impact exchange rates and fluctuation of market price can have on such operations. In Japan, where abalone are sold on the local market, stock enhancement has been carried out for a long time on large scale, achieving recapture rates ranging from 8 to 51 % each year but in most case they remain between 10 and 30 % (Saito 1984, Kojima 1995). Even though these results appear to be maintained over time, it seems that out-planted seed do not contribute to enhanced natural stocks (Tegner 2000). Indeed, despite the important effort put into enhancement, the Japanese abalone catch appears to have halved in the last 25 years and only a reduction in the fishing pressure will prevent the stock from collapsing (Masuda and Tsukamoto 1998, Seki and Tanigushi 2000).

Conclusion

The 3 types of stock intervention have very different economic and time implications as shown in Figure 6. Juvenile out-planting is often considered to allow the fastest and most reliable recovery of the stocks because it does not rely on natural settlement of post-larvae and avoids the strong density-dependant mortality of the early life stage (Tegner and But;ler 1989, Schiel 1993, McCormick 1994, Shepherd et al. 2000), however this is

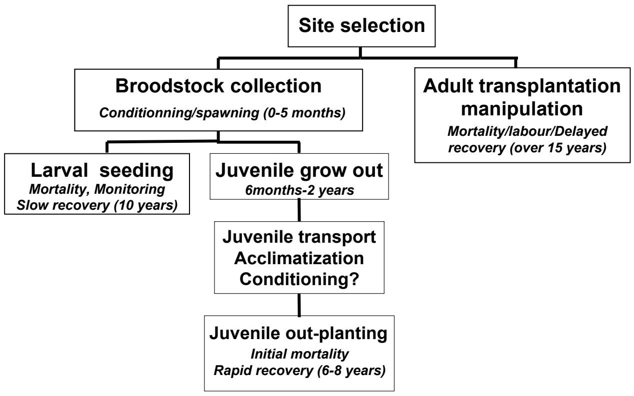

Figure 6: The 3 types of stock intervention and their major technical drawbacks.

also the most expensive technique, and density-dependent mortality may still occur among the out-planted juveniles.

Before stock enhancement is carried out, an environmental risk assessment should be undertaken: the seed should be extensively tested for any contagious disease and should have a minimum impact on the local genetic diversity.

Because of its slow growth rate, land-based culture of abalone remains costly and has an impact on the environment, which is as yet difficult to assess or predict. Abalone enhancement may be the most appropriate solution to balance the loss of productivity of the fishery. Much more research is needed to get a better understanding of the factors determining the growth and mortality of cryptic juveniles. Such research would allow habitat enhancement and juvenile out-planting or adult translocation to be carried out safely and profitably, and they may be the keys to sustain this valuable industry in Australia.

Acknowledgements

Thanks to Darren James for his useful comments.

Table 2: Review of juvenile abalone transplantation experiments (* indicate results cited in McCormick **et al.** (1994))

Country	**Species**	*Reference*	**Initial length (mm)**	**Duration**	**Survival (%)**	**Comments**
Japan	*H. discus discus*	Kojima et al. 1981*	8-18	1 week	0-52	Site-specific mortality.
		Sakamoto et al. 1984*	15-50	2 years	13	Artificial reef.
		Kojima 1995	15-40	2-6 years	12-51	Results collected from fisheries captures (1983-92)
	H. discus hannai	Inoue 1976*	>40	1 year	>60	
		Takeichi et al. 1978	14.4	9 months	49	Importance of site selection. Protection from predators.
		Honma and Iioka 1980*	20-45	2 years	51-65	
		Momma et al. 1980	15-21	1 year	17-33	On artificial reef (concrete cribs).
		Takeichi 1981*	20-50	2 years	25-50	
		Saito 1984*	10-52	16 months	0-30	
			16-35	4 years	5-10	
		Seki and Tanigushi 2000	24.5	28 months	27	Conditioning of the seed in cage for 7days.
			16.5	11 months	37	Use of oyster shell for releasing.
			16.5	5 months	11-24	Site preference of the animal discussed.
	H. d. hannai (wild)	Saito 1979*	40-60	24 years	2-31	
	H. gigantea	Inoue 1976*	>40	1 year	>60	
	H.seiboldi	Inoue 1976*	>40	1 year	>60	
California	*H. fulgens*	McCormick 1994	25	1-35 days	92-99	PVC releasing module. Important Effect of transport.
	H. rufescens	Tegner and Butler 1985a	20-35	1 year	<1	High mortality (44% of shell recovered).
			40-80	1 year	<1	Predator control. Importance of Migration?
		Davis 1995	15-90	100 weeks	18-30	Artificial reef (assemblage of concrete blocks)
		Rogers-Bennett et al. 1998	8.2	2 years	1	Releasing unit. Sea-urchins improve survival.
New Zealand	*H. iris*	Schiel 1993	3-13	2 years	54	
			3-22	1 year	10	
			5-22	1.5 years	7-24	Good record of habitat characteristics. Record of density before and after seeding. Seeding by hand. Minimum survival rates recorded.
			9-49	10 months	19-46	
			6-23	7 months	8	
		Schiel 1992	19	3 years	24	
			26 & 45	5.5 weeks	65	Mortality due to sediments, handling and bad seed quality. Comparison wild/ hatchery, large/small, predator/no predator.
South Africa	*H. midae*	Sweijd et al. 1998	14.8	6 months	27-39	Use of PVC releasing module.
			8.2	6 months	26-28	Minimum survival rates.
		De Waal and Cook 2000.	24-28	2 months	59	
			12-16	2 months	24	
South Australia	*H. laevigata* (wild)	Shepherd 1986	60-95	1 year	44	Substrate dependent.
	H. rubra	Shepherd et al. 2000	12.1		8-16	Use of 3 releasing methods.
France	*H. tuberculata*	Flassch & Aveline 1984	20	2.5 years	40-50	Artificial habitat preventing migration and predation.

Table 3: Results of adult transplantation experiments

Species (source)	Number	Survival (%)	Comment
H. fulgens (Tegner 1992)	4453	58-97	• Poaching ? • No control. • Mortality higher when no predator removal.
H. corrugata (Henderson et al.. 1988)	517	5-83	• Poaching ? • No control. • Handling Injury accounted for 18% Mortality.

References

Ault, J. and J. DeMartini (1987). Movement and dispersion of red abalone *Haliotis rufescens*, in Northern California. *California Fish and Game* **73**, 196-213.

Brown, L. D. and N. D. Murray (1992). Population genetics, gene flow, and stock structure in *Haliotis rubra* and *Haliotis laevigata*. *In* Shepherd, S.A., Tegner, M.J., Guzman del Proo, S.A. (eds.). Abalone of the world: biology, fisheries and culture. Proceedings of the 1st International Symposium on Abalone. Fishing News Books Ltd; Oxford; UK, pp 461-473.

Begon, M, Harper, J.L. and C.R. Townsend (1996). Ecology: individuals, populations, and communities. Blackwell Science, Boston, 1068p.

Clavier, J. and O. Richard (1984). Etude experimentale du deplacement de l'ormeau (*Haliotis tuberculata*) dans le milieu naturel. *Revue des Travaux de l'Institut des Peches Maritimes* **46**, 315-326.

Daume, S., Woelklerling, W.J. and S. Brand-Gardner (1999a). Settlement of abalone larvae (*Haliotis laevigata* Donovan) in response to non-geniculate coralline red algae (Corallinales, Rodophyta). *Journal of Experimental Marine Biology and Ecology* **234**, 125-143.

Daume, S., Brand-Gardner, S. and W.J. Woelkerling, (1999b). Preferential settlement of abalone larvae: Diatom films vs. non-geniculate coralline red algae. *Aquaculture* **174** (3-4), 243-254.

Davis, G.E. (1995). Recruitment of juvenile Abalone (*Haliotis* spp.) Measured in artificial habitats. *In* 'Progress in Abalone Fisheries Research'. Eds S.A. Shepherd, R.W. Day and A.J. Butler. *Marine and Freshwater Research* **46**, 549-554.

Day, R.W. and A. Leorke (1986). Abalone catches – what factors affect them? *Australian fisheries*, October, 32-36.

Dixon, C., Gorfine, H.K., Officer, R.A, and M. Sporcic (1998). Dispersal of tagged Blacklip abalone, *Haliotis rubra*: Implications for stock assessment. *Journal of Shellfish Research* **17**(3), 881-887.

Douros, W. J. (1985). Density, growth, reproduction and recruitment in an intertidal abalone: Effects of intraspecific competition and prehistoric predation. M. A. thesis, University of California, Santa Barbara, pp. 112.

De Waal and P. Cook (2000). Abstract of the abalone symposium 2000 in Cape Town, South Africa.

Dovetail Consulting Inc. (1999). A strategy for rebuilding abalone stocks in British Columbia, a report on the workshop on rebuilding abalone stocks in British Columbia. Fisheries Ocean Canada, Nanaimo, B.C., February 23-26, 1999.

Elliott, N.G. (2000). Genetic improvement programmes in abalone: what is the future? *Aquaculture research*, **31**(1),51-59.

Emmett B. and G.S. Jamieson (1989). An experimental transplant of northern abalone, *Haliotis Kamtschatkana*, in Barkley Sound, British Columbia. *Fishery Bulletin US* **87**, 95-104.

Flassch, J.P. and C. Aveline (1984). Production de jeunes ormeaux a la station experimentale d'Argenton. Centre National pour l'Exploitation des Oceans, Rapports Scientifiques et techniques numero 50.

Gaffney, P. M., Powell, R.V., Hedgecock, D., Powers, D. A., Morris, G. and L. Hereford (1996). Genetic effects of artificial propagation: Signals from wild and hatchery populations of red abalone in California. *Aquaculture* **143**(2-4), 257-266.

Goggin, C.L. and R.J.G. Lester (1995). *Perkinsus*, a protistan parasite of abalone in Australia: a review. *In* 'Progress in Abalone Fisheries Research'. Eds S. A. Shepherd, R.W. Day and A. J. Butler. *Marine and Freshwater Research* **46**, 689-695.

Hahn, K. O. (1989). Biotic and abiotic factors affecting the culture of abalone. In K. Hahn (ed.). Handbook of culture of abalone and other marine gastropods. CRC Press, Bocca Raton, Florida, pp 113-134.

Hahn, K. O. (1989). Nutrition and growth of abalone. In K. Hahn (ed.). Handbook of culture of abalone and other marine gastropods. CRC Press, Bocca Raton, Florida, pp 135-156.

Heasman, M. (2000). Abalone Aquaculture annual workshop, August 2000. Duniden, New Zealand.

Henderson KC , D.O. Parker and P.L. Haaker (1988). the survival and growth of transplanted adult pink abalone, *H. corrugata*, at Santa Cataline island. *California Fish and Game* **74**:82-86.

Henderson, K. C., Parker, D. O. and P.L. Haaker (1988). The survival and growth of transplanted adult pink abalone, *Haliotis corrugata*, at Santa Catalina Island. *California Fish and Game* **74**(2), 82-86.

Hilborn, R.(1998). The economic performance of marine stock enhancement projects. *Bulletin of Marine Science,* **62**(2),661-674.

Honma, N. and K. Iioka (1980). Experimental studies on the release of the cultured big seeds of abalone. Report of Yamagata Prefecture Fisheries Experimental Station, **123**, 1-14.

Inoue, M. (1976). Abalone. *In* Japanese Fisheries Cooperative Association, Aquaculture handbook, **1**,19-61.

Kojima, H. (1981). Mortality of young Japanese black abalone, *Haliotis discus discus* after transplantation. *Bulletin of the Japanese Society of Scientific Fisheries,* **47**,151-159.

Kojima, H.(1995). Evaluation of abalone stock enhancement through the release of hatchery-reared seeds. *In* 'Progress in Abalone Fisheries Research'. Eds S. A. Shepherd, R.W. Day and A. J. Butler. *Marine and Freshwater Research*, **46**, 689-95.

Masuda, R. and K.Tsukamoto (1998). Stock enhancement in Japan : Review and perspective. *Bulletin of Marine Science* **62**(2), 337-358.

McCormick, T.B., K. Henderson, T.S. Mill, and J. Altick. (1994). A review of abalone seeding, possible significance, and a new seeding device. *Bulletin of Marine Science,* **55**,680-693.

McShane, P.E. (1991). Density-dependent mortality of recruits of the abalone *Haliotis rubra* (mollusca Gastropoda) *Marine Biology* **110**,385-389.

McShane, P.E. (1992). Early life history of abalone: a review. *In* Shepherd, S.A., Tegner, M.J., Guzman del Proo, S.A. (eds.). Abalone of the world: biology, fisheries and culture. Proceedings of the 1st International Symposium on Abalone. Fishing News Books Ltd; Oxford; UK, pp 120-138.

McShane, P.E. (1995). Recruitment variation in abalone: its importance to fisheries management. *In* 'Progress in Abalone Fisheries Research'. Eds S. A. Shepherd, R.W. Day and A. J. Butler. *Marine and Freshwater Research*, **46**, 555-570.

McShane, P.E., Black, K. P. and M.G. Smith (1988). Recruitment processes in Haliotis rubra (Mollusca: Gastropoda) and regional hydrodynamics in southeast Australia imply localised dispersal of larvae. *Journal of Experimental Marine Biology and Ecology*, **124**, 275-203.

McShane, P.E. and M.G. Smith (1991). Recruitment variation in sympatric populations of *Haliotis rubra* (Mollusca: Gastropoda) in Southeast Australian waters. *Marine Ecology Progress Series*, **73**,203-210.

McShane, P.E. and J.R. Naylor (1995). Depth can affect post settlement survival of *Haliotis iris* (Mollusca: Gastropoda). *Journal of Experimental Marine Biology and Ecology,* **187**, 1-12.

Momma, H., Kobayashi, K., Kato, T., Sasaki, Y., Sakamoto, T., and H. Murata (1980). On the artificial propagation method of abalone and its effects on rocky shore. I. Remaining ratio of the artificial seed abalone (*Haliotis discus hannai* Ino) on latticed artificial reefs. *The Aquiculture* 28(2), 59-65. Translated by M.G. Mottet in summaries of Japanese papers on hatchery technology and intermediate rearing facilities for clams, scallops and abalone. Washington Department Fisheries Progress Report **203**. 26 pp.

Olla, B.L., M.W. Davis and C.H. Ryer (1998). Understanding how the hatchery environment represses or promotes the development of dehavioral and survival skills. *Bulletin of Marine Science,* **62**,531-550.

Pennington, J. T. (1985). The ecology of fertilization of echinoid eggs: the consequences of sperm dilution, adult aggregation, and synchronous spawning. *Biology Bulletin,* (Woods Hole) **169**,417-430.

Preece, P.A., S.A. Shepherd, S.M. Clark, and J.K. Keesing (1997). Abalone stock enhancement by larval seeding: effect of larval density on settlement and survival. *Molluscan Research,* **18**,265-273.

Prince, J.D., Sellers, T.L. Ford, W.B., and Talbot, S.R. (1988). Confirmation of a relationship between the localized abundance of breeding stock and recruitment for *Haliotis rubra* Leach (Mollusca: Gastropoda). *Journal of Experimental Marine Biology and Ecology*, **122**, 91-104.

Prince, J.D., Sellers, T.L., Ford, W.B. and Talbot, S.R. (1987). Experimental evidence for limited dispersal of haliotid larvae (genus *Haliotis*; Mollusca: Gastropoda). *Journal of Experimental Marine Biology and Ecology,* **106**. 243-63.

Rodda, K.R., J.K. Keesing and B.L. Foureur. (1997). Variability in larval settlement of abalone on artificial collectors. *Molluscan Research,* **18**,253-264.

Rogers-Bennett, L. and J.S. Pearse. (1998). Experimental seeding of hatchery-reared juvenile red abalone in Northern California. *Journal of Shellfish Research,* **17**(3),877-880.

Saito, K. (1979). Studies on the propagation of the Ezo abalone, *Haliotis discus hannai* Ino. I. Analysis of the relationship between transplantation and catch in funka Bay Coast. *Bulletin of the Japanese Society of Scientific Fisheries,* **45**,695-704.

Saito, K. (1984). Ocean Ranching of abalone and scallops in northern Japan. *Aquaculture*, **39**,361-373.

Sakamoto, J. K., Tanaka, K. and K. Kobayashi (1984). (on the utilization of the marine environment for the intermediate culture of laboratory reared abalone seed) Chiba-ken Suisan Skikenjo Kenkyu Hokoku (Chiba Prefectural Fisheries Research Laboratory Reports), 40, 123, 1982. Translated by M.G. Mottet in summaries of Japanese papers on hatchery technology and intermediate rearing facilities for clams, scallops and abalone. *Washington Department Fisheries Progress Report* **203**. 26 pp.

Sasaki, R. and S.A. Shepherd (1995). Larval dispersal and recruitment of *Haliotis Discus hannai* and *tegula* spp. Om Miyagi coasts, Japan. *In* 'Progress in Abalone Fisheries Research'. Eds S. A. Shepherd, R.W. Day and A. J. Butler. *Marine and Freshwater Research* **46**,516-529.

Schiel, D.R. (1992). The enhancement of paua (*Haliotis iris* Martyn) populations in New Zealand. *In* Shepherd, S.A., Tegner, M.J., Guzman del Proo, S.A. (eds.). Abalone of the world: biology, fisheries and culture. Proceedings of the 1st International Symposium on Abalone. Fishing News Books Ltd; Oxford; UK, pp 461-473.

Schiel, D.R. (1993). Experimental evaluation of commercial-scale enhancement of abalone *Haliotis iris* populations in New Zealand. *Marine Ecology Progress Series* **97**,167-181.

Schiel, D.R. and B.C. Welden (1987). Responses to predators of cultured and wild red abalone, *Haliotis rufescens*, in laboratory experiments. *Aquaculture* **60**,173-188.

Seki, T., and K. Taniguchi (2000). Rehabilitation of Northern Japanese abalone, *Haliotis discus hannai* populations by transplanting juveniles. In A. Campbell (ed.). Workshop on Rebuilding abalone stocks in British Columbia. *Canadian Special Publication Fisheries and Aquatic Science*130 pp.

Shepherd S.A. and L.D. Brown (1993). What is an abalone stock: implication for the role of refugia in conservation. *Canadian journal of Fisheries and Aquatic Science* **50**,2001-2009.

Shepherd, S.A. and P.S. Clarkson (2001). The diet, feeding, food preferences and predation of the temperate blue-throated wrasse, *Notolabrus tetricus*. *Marine and Freshwater Research* (*in press*).

Shepherd, S.A. and K.R. Rodda (2000). Sustainability demands vigilance: evidence for serial decline of the greenlip abalone fishery and a review of management. (*in prep*.).

Shepherd, S.A. (1986). Movement of the Southern Australian abalone *Haliotis laevigata* in relation to crevice abundance. *Australian Journal of Ecology* **11**,295-302.

Shepherd, S.A. (1990). Studies on southern Australian Abalone (genus *Haliotis*). XII. Long-term recruitment and mortality dynamics of an unfished population. *Aust. J. Marine and Freshwater Research* **41**,475-492.

Shepherd, S.A. (1998). Studies on Southern Australian abalone (genus *Haliotis*) XIX: Long-term juvenile mortality dynamics. *Journal of Shellfish Research* **17**(3), 813-825.

Shepherd, S.A., Preece, P.A., and R.W.G White (2000). Tired nature's sweet restorer? Ecology of abalone (*Haliotis* spp.) stock enhancement in Australia. In A. Campbell (ed.). Workshop on Rebuilding abalone stocks in British Columbia. *Canadian Special Publication Fisheries and Aquatic Science*130 pp.

Shepherd, S. A. and S. Daume (1996). Ecology and survival of juvenile abalone in a crustose coralline habitat in South Australia. P. 297-313. In Watanabi, Y., Yamashika Y. and Oozeki Y. (eds). Survival strategies in early life history stages of marine resources. Balkema, Rotterdam.

Shepherd, S.A. and C. Godoy (1989). Studies on southern Australian abalone (genus *Haliotis*) XI. Movement and natural mortality of juveniles. *Journal of the Malacological Society of Australia* **10**, 87-95.

Shepherd, S. A. and P.A. Breen (1992). Mortality in abalone: its estimation, variability and causes. In Shepherd, S.A., Tegner, M.J., Guzman del Proo, S.A. (eds.). Abalone of the world: biology, fisheries and culture. Proceedings of the 1st International Symposium on Abalone. Fishing News Books Ltd; Oxford; UK, pp 276-304.

Shepherd, S.A., Clarkson, P. S. and J.A. Turner (1985). Studies on the southern Australian abalone (genus *Haliotis*). V. Spawning, settlement and early growth of H. scalaris. *Transaction of the Royal Society of South Australia* **109**, 61-62.

Shepherd, S.A., Rodda, K.R. and K. Vargas. (2000). A chronicle of collapse in two abalone stocks with proposals for precautionary management. (in prep.).

Sluczanowski, P. R. (1984). A management oriented model of an abalone fishery whose substocks are subject to pulse fishing. *Canadian journal of Fisheries and Aquatic Science* **41**, 1008-1014.

Stoner A.W. and R.A. Glazer (1998). Variation in Natural mortality: implication for stock enhancement. *Bulletin of Marine Science* **62**,427-442.

Sweijd, N., Q. Snethlage, D. Harvey and P. Cook (1998). Experimental abalone seeding in South Africa. *Journal of Shellfish Research* **17**(3),897-904.

Takeichi, M., Tashiro, M. and T. Yada (1978). Place of release and survival rate of artificially raised young abalone, *Haliotis discus*. *The Aquiculture*, 26(1), 1-5. Translated by M.G. Mottet in summaries of Japanese papers on hatchery technology and intermediate rearing facilities for clams, scallops and abalone. *Washington Department Fisheries Progress Report* 203. 26 pp.

Takeichi, M. (1981). Experimental studies of the cultured seeds of abalone, Haliotis discus hannai. Rep. 1980's Tohoku Block Aquaculture Conference pp. 27-31.

Tegner, M. J. (1992). Brood-stock transplants as an approach to abalone stock enhancement. In Shepherd-SA (ed.); Tegner-MJ (ed.); Proo-SAG-del (ed.). Abalone of the world: biology, fisheries and culture. Proceedings of the 1st International Symposium on Abalone. Fishing News Books Ltd; Oxford; UK, pp 461-473.

Tegner M.J. (1993). Southern California Abalone: Can stocks be rebuilt using marine Harvest Refugia ? *Canadian journal of Fisheries and Aquatic Science* **50**,2010-2018.

Tegner M.J. (2000). Abalone enhancement in California: What we've learned and where we go from here. In A. Campbell (ed.). Workshop on Rebuilding abalone stocks in British Columbia*. Canadian Special Publication Fisheries and Aquatic Science*130 pp.

Tegner, M.J. and R.A. Butler (1985a). the survival and mortality of seeded and native red abalone, *H. rufescens*, on the Palos Verdes Peninsula. *California Fish and Game,* **71**,150-163.

Tegner, M.J. and R.A. Butler (1985b). Drift-tube study of the dispersal potential of green abalone (*H. fulgens*) larvae in the southern California bight: implications for recovery of depleted population. *Marine Ecology Progress Series*, **26**,73-84.

Tegner, M. J. and R.A. Butler (1989). Abalone seeding. In K. Hahn (ed.). Handbook of culture of abalone and other marine gastropods. CRC Press, Bocca Raton, Florida, pp 157-182.

Tong, M.J., P.K. Dayton, P.B. Edwards, and K.L. Riser (1987). Enhancment of natural population of the abalone, *Haliotis iris*, using cultured larvae. *Aquaculture* **62**,67-72.

Uki, N. (1989). Abalone seedling production and its theory (3). *International Journal of Aquaculture and Fisheries Technology* **1**, 224-231.

Werner, I., Flothmann, S., and G. Burnell (1995). Behaviour studies on the mobility of two species of abalone (*Haliotis tubercultata* and *H. discus hannai*) on sand: Implications for reseeding programmes. *In* 'Progress in Abalone Fisheries Research'. Eds S. A. Shepherd, R.W. Day and A. J. Butler. *Marine and Freshwater Research* **46**:681-8.

Measuring the success of stocking barramundi (*Lates calcarifer*) (Bloch) into a coastal river system in far northern Queensland, Australia

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Abstract

Concern about declining catches has resulted in the release of hatchery produced barramundi fingerlings into selected coastal rivers in an effort to enhance the fishery. As part of a study to investigate the efficacy and cost-benefits of barramundi stock enhancement, controlled releases of about 152,000 fingerlings have been made into the Johnstone River in northern Queensland since 1993. All of these stocked barramundi have been marked with coded wire tags to allow their discrimination from naturally recruited fish and determination of fish size-at-release, stocking site and release year class in subsequent recaptures. Stocked fish took about three years to reach the minimum legal size of 580 mm total length and were subsequently recruited into the recreational and commercial fisheries. Stocked fish comprised about 16% of barramundi from relevant size classes of the catch of recreational fishers but only 8% of the commercial catch. Most stocked fish (57%) were recaptured within 3 km of their release site, but 42% undertook intra-riverine movements of up to 37 km. Five fish made coastal or inter-riverine movements. The choice of stocking location is important, as a number of factors, such as water quality, can impact on stocking success. The catch rate of fish stocked into a release site in the upper tidal reaches of the Johnstone River was significantly higher than those stocked in the estuary or in freshwater. There was no significant difference in the numbers of 30-40 mm and 50-60 mm fish being recaptured. Fish from early stockings have matured and are now making contributions to the spawning stock. There was an increase in CPUE in the recreational fishery from 0.11 fish per angler hour in 1994 to 0.23 fish per angler hour in 1997 but CPUE declined to 0.15 fish per angler hour in 1998. Preliminary cost-benefit analyses have shown that <1% of stocked fish need to be caught by fishers to recover the direct costs of stocking. These data suggest that stocked barramundi are contributing to the fishery in the Johnstone River and there is some evidence that catch rates have improved.

Introduction

Barramundi, *Lates calcarifer* (Bloch), is a large, catadromous centropomid found throughout most of the Indo-west Pacific including the coastal rivers of tropical Australia (Greenwood, 1976). In north-eastern Australia, barramundi spawn in coastal waters and estuaries just before or during the wet season from October to February (Dunstan, 1959; Russell and Garrett, 1985). In a tagging study to determine the movements of juvenile barramundi in north Queensland tidal creeks, Russell and Garrett (1988) found that most barramundi were recaptured close to their original release location.

Barramundi are a popular and highly sought after recreational and commercial food and sports fish, however in recent years fishers have expressed concern over perceived declines in stock numbers. There is a paucity of information on the health of barramundi stocks but available statistics from the east Queensland commercial fishery suggest there has been a historical decline in stock size (Russell, 1987). More recent data also confirm a decline in commercial barramundi catches (Williams, 1997). The reasons for the decline of the fishery are contentious but habitat degradation and over-exploitation appear to be major factors (Russell, 1987). Fisheries managers have attempted to respond to this situation and, since 1981, have progressively introduced a range of management initiatives directed at effort reduction (Russell, 1988) and further restrictions are likely to be introduced. Major components of the present management strategy include a closed season, area closures, a recreational angling bag limit of five fish, commercial gear restrictions and a minimum legal size of 580mm and maximum legal size of 1200mm.

To assist in the recovery of exploited fish stocks, Leber et al. (1995) suggested that such restrictive management measures could be augmented by an additional management strategy - stock enhancement. Marine fish stock enhancement in Australia is very much in its infancy and prior to about the late 1980s few, if any, serious stocking attempts had been undertaken. Marine fish stocking in Australia started to come of age with the advent of mass rearing technologies for native marine and catadromous species. The development in the late 1980's and early 1990's of efficient and cost-effective technology for producing barramundi fingerlings (Rutledge and Rimmer, 1991) has made stock enhancement a viable management option in northern Australia. There is now widespread support for barramundi stock enhancement programs, particularly amongst recreational fishers. Numerous community-based stocking groups have been formed to promote stock enhancement in coastal streams. To satisfy demands for information on efficacy of barramundi in coastal rivers the Department of Primary Industries commenced an experimental stocking program for barramundi in the Johnstone River in north Queensland at the end of 1992. The objectives of that program were:

- To develop appropriate stocking strategies for barramundi in coastal rivers;
- To assess the contribution that stocked fish make to both the commercial and recreational sectors of the barramundi fishery; and
- To document the costs and benefits of this stocking program.

Munro and Bell (1997) considered that three basic pieces of information are needed to measure the success of stock enhancement programs: the rate of recovery of released individuals at harvest size, the cost of producing the additional individuals and the unit value of the harvested animal. The last two requisites are available for barramundi stock enhancement and have been used in cost-benefit analyses (eg. Russell and Rimmer, 1997,1999; Rimmer and Russell, 1998). The contribution of cultured juveniles to wildstocks can be measured in at least four ways including the proportion of released animals in commercial catch, increases in total catch following enhancement, the survival rate of released individuals at time of first harvest and the ratio of cultured individuals to the estimated recruitment from wildstock (Munro and Bell, 1997).

In this paper we use a number of the methods suggested by Munro and Bell (1997) and others for measuring stocking success including proportion of stocked fish in the recreational and commercial fisheries, fishery enhancement and cost-benefits. We also present data on stocking strategies for maximising survival of stocked individuals and the biology and movements of stocked barramundi in the Johnstone River.

Study site

The study site used for these experiments is the Johnstone River, about 90 km south of Cairns in northern Queensland. The Johnstone River rises on the Atherton Tableland and flows into the Coral Sea near the township of Innisfail (17o32'S,146o02'E). The river bifurcates about five kilometres from its mouth into the North and South Johnstone Rivers. It has a small catchment of about 1630 km2 and sugar is the dominant land use on the coastal plain (Russell and Hales, 1993). The river has a narrow coastal plain (less than 30 km wide) and an escarpment prevents the upstream movement of fish from coastal areas to the upper tableland. Agricultural activities have impacted on wetland habitat within the catchment, with an overall reduction of about 60% over the past fifty years (Russell and Hales, 1993). The river supports a multi-species recreational line fishery and a seasonal commercial gill net fishery that is restricted to the lower estuary. There are about five part-time commercial fishers operating in the catchment. Prior to the commencement of our experiments the river had not been previously stocked with barramundi.

Methods

Barramundi fingerlings used for these stockings were spawned from broodstock held at the Northern Fisheries Centre (NFC) in Cairns and grown-out to between 25 and 35 mm total length (TL) using extensive larval rearing techniques (Rutledge and Rimmer, 1991). After harvesting from the ponds, fish were held at the NFC hatchery prior to their release and on-grown as necessary. The original experimental design required that equal numbers of two size classes of fish, one small (30-40mm TL) and one large (50-60 mm TL) be stocked in three different habitat types (lower estuarine, upper tidal and freshwater) in the Johnstone River. This design was undertaken annually for three years beginning in 1992/93, but modified in an effort to obtain more information on the suitability of other secondary stocking locations and size classes. The first of these changes, starting in 1993/94, involved the stocking of a freshwater swamp system and later, in 1995/96, an extra two estuarine sites were. To discriminate the hatchery fish from wild fish, all barramundi were marked with coded wire tags prior to release. Russell and Hales (1992) successfully implanted coded wire tags into the cheeks of barramundi as small as 30mm TL and obtained high survival and retention rates, and found that tagging had no significant effect on long term survival or growth. They were able to achieve tagging rates of between 250 and 270 fish per hour.

Initially, monitoring involved using a boat mounted, Smith-Root (7.5GPP) electro-fisher to catch barramundi that were subsequently scanned with a Northwest Marine Technology wand detector. A small (2 mm) mesh beam trawl was also used to irregularly sample fish in the lower estuary. All fish found to contain tags were retained and the tags were extracted and decoded. Once the stocked fish had reached legal size (580 mm TL), anglers were asked to retain the heads of all captured barramundi and return them to a central repository where they were subsequently checked for the presence of tags. As an incentive, a small reward was offered to all anglers who returned tagged fish. Selected commercial catches from the Johnstone River were regularly inspected for the presence of coded wire tags. All tagged fish were weighed and measured before the tag was recovered and decoded.

Catch and effort data on the recreational fishery in the Johnstone River were collected using voluntary angler record cards. These cards requested details of the size and number of the species caught, the number of anglers in the party and the time spent fishing. Anglers were requested to complete the cards after each fishing trip and return them using a post free mailing address or conveniently located drop boxes. Cards were widely available and a field liaison officer was available to provide, where necessary, support and assistance. The program was terminated in August 1998 due to lack of resources.

Data were stored on a relational database and size data were analysed using a Generalised Linear Model (GLM) with a logit link and binomial error distribution. In analyses of the proportions of stocked fish in the population, only size cohorts which were likely to contain stocked fish (ie. < 900 mm TL) were considered.

Contribution of stocked fish

The first stocking of barramundi marked with coded wire tags into the Johnstone River was made during the 1992/93 breeding season (January to February, 1993). Since then, the Johnstone River has been stocked with tagged fish over consecutive years. Up to the 1999/00 breeding season, the Queensland Department of Primary Industries had released about 152,000 hatchery reared barramundi at locations in the Johnstone River catchment.

The first indication that stocked fish were surviving in the Johnstone system was in February 1993 when three microtagged fish that were released 12 days earlier were recaptured in a beam trawl about a kilometre downstream of their release site. These fish appeared healthy and had food in their guts. Since then 476 fish from six age classes have been recaptured by commercial and recreational fishers and in the research sampling program. Legal sized fish (≥ 580 mm TL) from the first release in1992/93, were first caught in early 1996.

Contribution to commercial and recreational catch

Figure 1 shows the relative proportions of stocked and wild barramundi harvested by two commercial fishers in 1998/99. The maximum size of stocked barramundi caught was 870 mm and stocked fish are represented in most size groups less than 900mm TL. In the 550-600 and 600-650 mm size classes, stocked barramundi make up 25% and 20% of the catch respectively and about 13% of the catch in all size classes less than 900 mm TL. Using this and all other available commercial data, stocked fish are about 8% of the catch. However, this is probably an underestimate as fish in the commercial catch are generally larger than fish caught in the recreational fishery and stocked fish may not yet be adequately represented in these size classes. Stocked fish also make up about 16% of legal sized barramundi caught by recreational fishers in the Johnstone River.

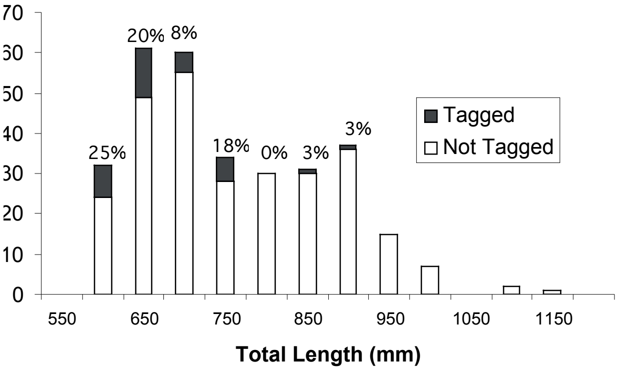

Figure 1. Proportion of fish stocked fish in commercial catches. Only legal size (≥580 mm TL are shown. Recreational fishery catch and effort

From December 1993 to May 1996, 1,142 angler record cards were received detailing the fishing activities of 4,710 anglers and an effort of 11,998 angler-hours. Data were supplied on more than 7,300 fish from over 40 different freshwater, estuarine and marine species. Most fish caught were sooty grunter (*Hephaestus fuliginosus*) (n=1741), pikey bream (*Acanthopagrus berda*) (n=1378), mangrove jack (*Lutjanus argentimaculatus*) (n=577) and barramundi (n=915). The majority of the remaining fish were predominantly marine species.

Annual CPUE increased from 0.11 fish/angler-hour in 1994 to 0.23 fish/angler-hour in 1997 but then decreased to 0.15 fish/angler-hour in 1998 (Figure 2). Data were only collected until August 1998 and the total effort in that year was only 325 angler hours as compared to more than a 1,000 angler-hours in all years except 1995.

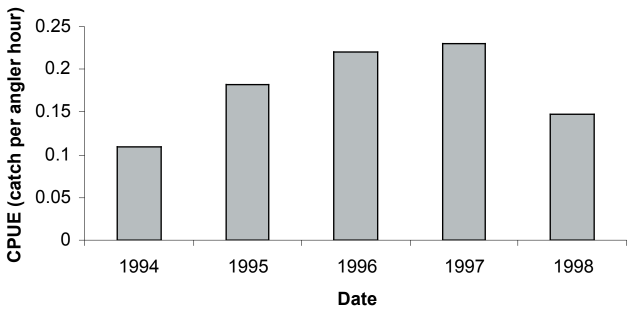

Figure 2. CPUE (number of fish caught per angler hour) for barramundi from the Johnstone River.

Contribution to spawning stock

Most of the stocked barramundi sampled in the Johnstone River were either immature or mature males although some fish from the early stockings had changed sex to female. A spent 903 mm TL female was caught in the mouth of the Johnstone River on the 13 February 2000 suggesting that the stocked fish are now contributing to the spawning stock as both males and females. The first female stocked barramundi, an 805 mm TL fish with developing (Stage III) gonads was caught in September 1999 in the estuary.

Stocking strategies

Optimising size at stocking and selecting the most effective release locations are two strategies that can be used to maximise survival of stocked fish.

Size at stocking

The initial experiment involved the release of equal numbers of fish in two size cohorts, small fish (30-40 mm TL) and larger fish (50-60 mm TL), over a three year period. Analysis of catch rates showed there was no significant difference (P=0.99) in the probability of recapture of these two different size classes.

In 1997/98 and 1998/99 seasons this experiment was expanded to include two additional size classes averaging about 150 mm TL and 300 mm TL respectively. The results of this experiment are not yet available.

Release locations

At least 161 of the 17,000 stocked at each of the three primary release locations between the 1992/93 and 1994/95 have subsequently been recaptured. The upper tidal site proved to be the best site for recaptures followed by the estuarine location (Figure 3).

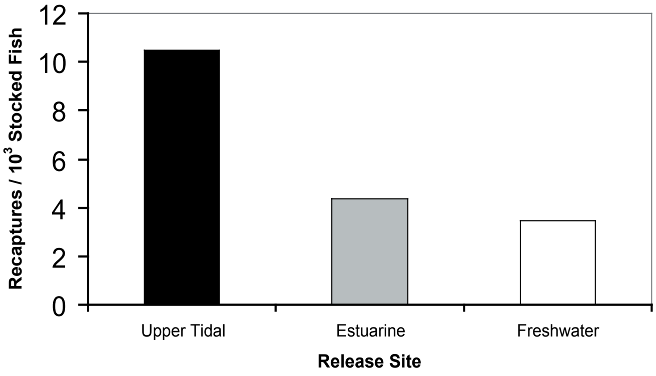

Figure 3. Recapture rate of barramundi released in three different habitat types.

The recapture rate at this site (see North Johnstone River, Figure 4) was significantly greater than the recapture rates at either the freshwater site (P=0.004) or the estuarine site (P=0.009). The recapture rate at the estuarine site (see lower Ninds Creek site, Figure 4) was significantly greater (P=0.009) than the rate from the Nerada freshwater site (see Figure 4).

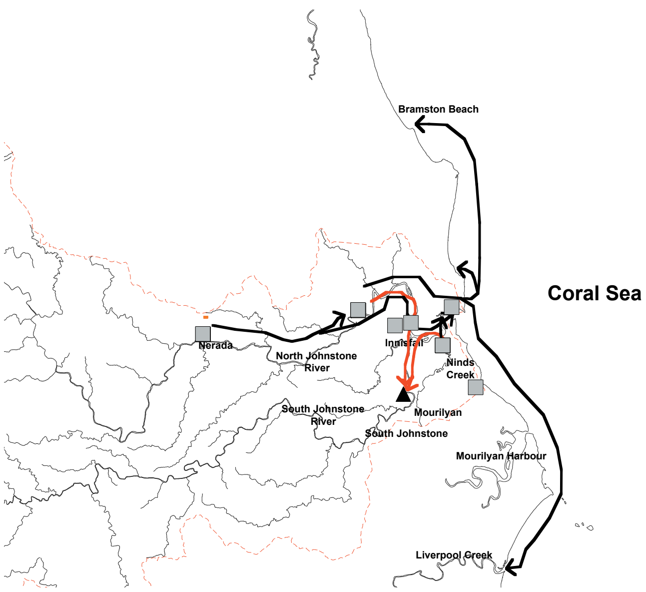

Figure 4. Movement trends of stocked fish. Markers show release sites.

The thick weed beds at the upper tidal site provided excellent cover for the juvenile fish as well an abundant source of food. Survival from estuarine sites, despite the availability of extensive mangrove habitat, was poorer and could be related to increased predation and competition. Some sites have been found to be unsuitable for release of juvenile barramundi. For example, some 8,913 fish were released into the Bulguru freshwater swamp at the headwaters of Ninds Creek (see Figure 4) between 1993/94 and 1995/96, but not one fish from this location has yet been recaptured. The reasons for this are unclear but may be related to periodic declines in the water quality of swamp waters. A lethally low dissolved oxygen saturation (6.6%) and depressed pH (5.3) were measured subsequent to a release in February 1996, and these were thought to have resulted in the newly stocked fish exhibiting distressed behaviour (Rimmer and Russell, 1998).

Biology and movements of stocked fish

Dispersal

Most (57%) of the fish that were recaptured were within three kilometres of their release site. The remainder had undertaken intra-riverine movements of up to 37 km (42%) or coastal or inter-riverine movements (1%). Figure 4 shows trends in riverine, inter-riverine and coastal movements by stocked barramundi. Fish stocked at the Nerada freshwater site in the North Johnstone moved downstream to the upper tidal areas (20 km downstream) and into the South Johnstone River. Juvenile fish released in the tidal area of Ninds Creek moved upstream into upper tidal freshwater areas of the North Johnstone and South Johnstone Rivers and into the lower estuary. There appeared to be no discernible trend to the movements of juvenile fish however most larger fish were recaptured in estuarine areas where breeding occurs. Five fish made coastal or inter riverine movements.

Growth

The growth of tagged fish recaptured during this study is shown in Figure 5. The first batch of fish released in 1992/93 took about three years to reach the legal size of 580 mm TL (Figure 5). Growth is rapid during the first twelve months, but then slows considerably in later years. There also appears to be a relationship between water temperature in the Johnstone River and growth of barramundi, with slower growth during the cooler mid-year months. Growth rates increase again in the summer with the onset of warmer water temperatures.

Cost benefits of stocking

The value of each barramundi is estimated at $50 for the recreational fishery (Rutledge et al., 1990), and $25 for the commercial fishery (based on an average barramundi size of 2.5 kg valued at $10/kg). Note that these are direct costs, and do not include flow-on economic benefits that increase the economic value of the resource by a factor of between 2 and 3.

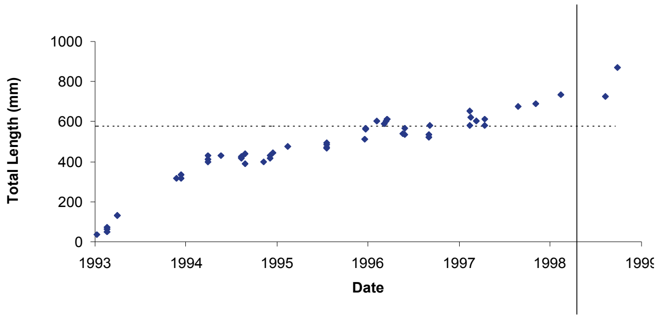

Figure 5. Growth of the 1992-93 stocking year class. Dotted line indicates minimum 580mm TL legal size.

The cost of barramundi fingerlings stocked between 1992 and 2000 is $37,500, at current commercial rates. Previous studies (Russell, 1988) have suggested that barramundi will be caught in the recreational and commercial fisheries of north-eastern Queensland in a ratio of around 1:3. To recoup the investment of $ 37,500, only 1300 fish need to be captured to cover the costs of the stocking program. This figure represents less than 1% survival of the 152,000 fish stocked to date. It should be noted that our sampling program has already recaptured nearly 500 fish and that about half the fish are yet to enter the fishery.

Discussion and conclusions

In this paper, the survival of stocked barramundi and their subsequent recruitment into the recreational and commercial fisheries is one of the basic metrics used for determining the success of the stocking program. Representatives from most stocking cohorts have been recaptured and stocked fish have been recruited into the recreational and commercial fisheries. In the Johnstone River, stocked fish are now a substantial component of these fisheries.

The fine-tuning of stocking strategies, notably the selection of suitable release locations, has been shown to enhance the survival of stocked fish. In the Johnstone River, release habitat was shown to be important to survival, with recaptures rates from the upper tidal release site, which is rich in aquatic macrophytes and snags, significantly greater than either the freshwater site or the estuarine site. We postulate that these thick weed beds provide plentiful cover for juvenile fish as well as an abundant source of food including small crustaceans and fishes. A series of major floods in 1999 and 2000 have scoured out the weed beds at this site and to date no fish stocked at this site in these years have been recaptured. Continuation of this trend will add weight to our argument that release habitat type is an important factor contributing to stocking survival.

Local environmental conditions at time of stocking may also impact on stocking success and a number of factors, particularly water quality, need to be carefully evaluated prior to the release of fish. For example, there is no indication of survival of any of the fish released into the secondary stocking site in the Bulguru freshwater swamp (See Figure 4). Water quality measurements identified lethally low dissolved oxygen concentrations and depressed pH levels after the last stocking in February 1996, which were consistent with the distressed behaviour exhibited by the fish immediately after release. Low dissolved oxygen in streams after periods of heavy rain can be the result of influx or re-suspension of oxygen demanding materials as a result of storm water input (Graczyk and Sonzogni, 1991). Bishop (1980) recorded natural fish kills in the Northern Territory occurring as a result of oxygen deprivation due to exposure to anoxic bottom waters disturbed by flood rains. While coastal swamps and lagoons are natural nursery habitats for juvenile barramundi (Moore, 1982; Russell and Garrett, 1983,1985), some of these areas can be environmentally volatile. Such habitats should be selected as stocking sites only after a rigorous assessment of their suitability, including water quality.

Overseas studies have shown that, for some species, size-at-release is an important determinant of later survival. For example, Leber et al. (1995) found that size-at-release of stocked mullet (Mugil cephalus) influenced survival and that the critical release size for this species was 70 mm TL. The results of this study indicate that the size of fish at stocking (30-40 mm TL or 50-60 mm TL) does not affect their survival. An experiment is currently underway to determine the survival of larger size classes (150 mm and 300 mm) however the results are not yet available. The effective minimum size of stocking for barramundi is not known but a trial stocking of 15 mm fish in the Burrum River in Central Queensland resulted in negligible survival (J. Burke, pers comm.). Further examination of the survival of different sizes classes of fish needs to be undertaken to determine the optimal (in cost-benefit terms) size-at-release.

Stocked fish in the Johnstone River took approximately three years to reach the minimum legal size of 580 mm TL and this is consistent with the growth rates of natural stocks of barramundi in Papua New Guinea (Reynolds and Moore, 1982) and the Gulf of Carpentaria (Davis and Kirkwood, 1984). Recaptures of stocked fish have shown that some barramundi do make substantial intra-riverine movements, both upstream and downstream, although most fish (57%) were recaptured within three kilometres of their release site. Some fish have made coastal or inter-riverine movements supporting evidence from earlier Australian studies that suggested some limited movements do occur (Davis, 1986; Russell and Garrett, 1988).

In marine stocking programs world-wide one of the most difficult issues to resolve is if stocking is actually resulting in increased production or simply displacing existing wild stocks. Using catch data is one technique which is commonly used to address this issue but even when there are reliable and accurate data on catches, intra and inter year variability and other factors means that long term data are needed. There are no commercial catch data available specifically for the Johnstone River, as government regulations require all data to be pooled into 30" by 30" grids. The grid that includes the Johnstone River also contains a number of other river systems and quite a large area of coast thus confounding any trends that may have been the result of stocking. Data on the recreational catch of barramundi that were supplied voluntarily by fishers does suggest a progressive increase in CPUE between 1994 and 1997 but it declined in 1998. Catch rates of barramundi in the recreational fishery prior to the recruitment of stocked fish are low but comparable to those in similar wet tropic coast streams (Russell and Hales, 1996). These data, while indicating that recreational catch may be increasing as a result of stocking, need to be viewed with caution and an independent confirmation is desirable. The high proportion of stocked fish in both the commercial (8%) and recreational catches (16%) also suggests that the contribution of stocking to the fishery may be substantial. There is evidence that stocked barramundi are now part of the breeding stock (both males and females) in the Johnstone River and therefore contributing to natural recruitment.

Costs-benefit is another useful measure of this stocking program. Using a simple break-even analysis, it was calculated that only about 0.86 % of all stocked fish needed to be caught to recoup the costs of purchasing fingerlings. This analysis is quite conservative and does not include provision for indirect economic benefits (Rutledge et al., 1990) or indirect costs. If these catch rates are achievable, then these data suggest that stocking has the potential to provide considerable economic benefits to the local community.

Traditional means of addressing the issue of falling catches such as restrictions on gear and effort may not be sufficient to arrest the decline and fisheries managers may have to look at other measures. Stock enhancement is one fisheries management tool that, if used judiciously, has the potential to provide significant long term benefits to a fishery. Before the implementation of stocking programs, it is advantageous to first determine the best release strategies to ensure maximum survival on a least cost basis and to ascertain the impacts that these releases could have on existing wild stocks. The use of such information in the planning of a stock enhancement program, together with the application of the responsible approach principles (Blankenship and Leber, 1995), should ensure a cost effective program with a high likelihood of success.

Acknowledgments

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Bibliography

Bishop, KA (1980). Fish kills in relation to physical and chemical changes in Magela Creek (East Alligator River system, Northern Territory) at the beginning of the tropical wet season. *Australian Zoologist* **20**, 485-500.

Blankenship, HL and Leber, KM (1995). A responsible approach to marine stock enhancement. *American Fisheries Society Symposium* **15**, 167-175.

Davis, TLO (1986). Migration patterns of barramundi, Lates calcarifer (Bloch), in van Diemen Gulf, Australia, with estimates of fishing mortality in certain areas. *Fisheries Research* **4**, 243-258.

Davis, TLO and Kirkwood GP (1984). Age and growth studies on barramundi, Lates calcarifer (Bloch) in northern Australia. *Australian Journal of Marine and Freshwater Research* **35**, 673-690.

Dunstan, DJ (1959). 'The barramundi *Lates calcarifer* (Bloch) in Queensland waters'. CSIRO Division of Fisheries and Oceanography, Technical Paper Number **5**, 22pp.

Graczyk, DJ and Sonzogni, WC (1991). Reduction of dissolved oxygen concentration in Wisconsin streams during summer runoff. *Journal of Environmental Quality* **20**, 445-451.

Greenwood, PH (1976). A review of the family Centropomidae(Pisces: Perciformes) *Bulletin of the British Museum (Natural History) Zoology* **29**, 4-81.

Leber, KM (1995). Significance of fish size-at-release on enhancement of striped mullet fisheries in Hawaii. *Journal of the World Aquaculture Society* **26**, 143-153.

Leber, KM, Brennan, NP and Arce, SM (1995). Marine enhancement with striped mullet: are hatchery releases replenishing or displacing wild stocks? *American Fisheries Society Symposium* **15**, 376-387.

Moore, R (1982). Spawning and early life history of barramundi, *Lates calcarifer* (Bloch) in Papua New Guinea. *Australian Journal of Marine and Freshwater Research* **33**, 647-661.

Munro, JL and Bell, JD (1997). Enhancement of marine fisheries resources. *Reviews in Fisheries Science.* **5**(2)185-222.

Reynolds, LF and Moore, R (1982). Growth rates of barramundi, *Lates calcarifer* (Bloch) in Papua New Guinea. *Australian Journal of Marine and Freshwater Research* **33**, 663-670.

Rimmer, MA and Russell, DJ (1998). Stock Enhancement of barramundi *Lates calcarifer* (Bloch) in a coastal river system in far northern Queensland, Australia. *Bulletin of Marine Science*. **62**(2):325-336.

Russell, DJ (1987). Review of juvenile barramundi *Lates calcarifer* wildstocks in Australia. In: Management of Wild and Cultured seabass/barramundi *Lates calcarifer* (ed. by J.W. Copland and D.L. Grey), pp. 44-49. Proceedings of an International Workshop, Darwin, Australia. Australian Centre for International Agricultural Research, Proceedings Number 20.

Russell, DJ (1988). 'An assessment of the east Queensland inshore gill net fishery'. Report Number QI88024 (Queensland Department of Primary Industries, Brisbane) 57pp

Russell, DJ and Garrett, RN (1983). Use by juvenile barramundi, *Lates calcarifer* (Bloch),and other fishes of temporary supralittorl habitats in a tropical estuary in northern Australia. *Australian Journal of Marine and Freshwater Research* **34**, 805-811.

Russell, DJ and Garrett, RN (1985). Eary life history of barramundi, *Lates calcarifer* (Bloch), in north-eastern Queensland. *Australian Journal of Marine and Freshwater Research* **36**, 191-201

Russell, DJ and Garrett, RN (1988). Movements of juvenile barramundi, *Lates calcarifer* (Bloch), in north-eastern Queensland. *Australian Journal of Marine and Freshwater Research* **39**, 117-123.

Russell, DJ and Hales, PW (1992). Evaluation of techniques for marking juvenile barramundi *Lates calcarifer* (Bloch), for stocking. *Aquaculture and Fisheries Management* **23**, 691-699.

Russell, DJ and Hales, PW (1993). 'Stream Habitat and Fisheries Resources of the Johnstone River Catchment'. Report No. QI93056. QI96008 (Queensland Department of Primary Industries, Brisbane) 59pp

Russell, DJ, Hales, PW and Helmke, SA (1996). 'Stream habitat and fish resources in the Russell and Mulgrave Rivers Catchment'. Report Number QI96008 (Queensland Department of Primary Industries, Brisbane) 52pp

Russell, DJ and Rimmer, MA (1997). Assessment of Stock Enhancement of barramundi Lates calcarifer (Bloch) in a coastal river system in far northern Queensland, Australia. In *'Proceedings of 2nd World Fisheries Congress'*, 28 July-2 August, 1996, Brisbane, Queensland.pp 498-503.

Russell, D.J. and Rimmer, M.A. (1999). Stock enhancement of barramundi (*Lates calcarifer*) in a coastal river in northern Queensland, Australia. In 'Proceedings of Annual International Conference of the World Aquaculture Society'. Sydney, Australia. 26 April-2 May, 1999 p 659..

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

Rutledge, W, Rimmer, M, Russell, DJ, Garrett, R and Barlow, C (1990). Cost benefit of hatchery-reared barramundi, *Lates calcarifer* (Bloch), in *Queensland. Aquaculture and Fisheries Management* **21**,443-448.

Williams, L.E.(Ed.) 1997. Q*ueensland's Fisheries Resources – Current Condition and Recent Trends 1988-1995*. Queensland Department of Primary Industries, Brisbane 101pp.

THEME 4 Questions & Answers

Gary Jackson to Adam Butcher

Question

You must be disappointed that funding was pulled out just as results were coming in. Have people learned to keep funding going?

Answer

No.

Andrew Sanger to John Russell

Question

How do you really know whether you have enhanced the stock?

Answer

World-wide, many stocking programs experience difficulty in demonstrating increased production. We designed a program to monitor barra. catches by recreational fishers through voluntary catch cards. Monitoring proved difficult and expensive to maintain and the results were inconclusive. We are now using CPUE from research sampling.

John Harris (comment)

One useful way of getting rigorous information from anglers is to follow the example of the NSW Fisheries Research Institute and its angling catch database. This [database relies on] a collaboration between organised anglers and the research agency in a systematic monitoring of catch, effort and size structure in freshwater recreational fisheries. It turned out to be highly effective in information gathering and cost efficiency

Sandy Morison (comment)

You can get good data from recreational anglers when you target keen fishers and work closely with them.

Sandy Morison (comment) to Greg Jenkins

Thermal marking of otoliths is a good technique that could be considered for evaluating stock enhancements. [You] may get better discrimination between wild and hatchery fish than with scale marking, although the preparation of samples requires a bit more work.

Dave Pollard to John Russell

Question

Do you have any comment on genetic protocols with respect to community-based stocking in Queensland, and if so, what is being done there?

Answer

[I recommend you] refer to Leber and Blankenships's work on stocking protocols and guidelines [which we follow]. Also, Queensland has a policy of recycling broodstock obtained from individual local rivers, although there is a difficulty of keeping lots of broodstock because of the costs and size of the fish. We don't mix different strains of barramundi in stocking, and numbers to be stocked are controlled under permit.

Philip Gibbs (comment)

Genetic issues are critical and should always be considered in this context.

Paul Humphries to John Russell

Question

I wish to comment on design. Baseline signal gathering is critical - even though people are under political pressure to stock. Also it is critical to design the 'experiment' and make sure there are replicates and/or control systems. These measures will obviate flawed design and defend analyses and results later.

Answer

We did consider the possibility of using a control when designing our experiment to assess the success of the barramundi stockings. However, all of the adjacent rivers had previously been stocked so we had to use other methods.

Patrick Coutin to panel

Question

Has any consideration been given to looking after the fish, or acclimatising them, after their release? An example is the predator removal in the abalone work.

Answer

(John Russell) Yes, we have been doing some experiments to see if we can pre-condition juvenile barramundi before they are released into the wild, thus enhancing their chances of survival.

Alf Hogan (comment)

We do try to acclimatise, but fish are often caught quickly and brought back by fishermen. What about predators?

Answer

(John Russell). We did consider using predators as part of the preconditioning mentioned above, but we did not proceed with the idea.

Peter Gehrke to Adam Butcher

Question

There has been much talk of stock enhancement with respect to one or two species. Do you have any information on whether any other species in the system have been suffering a decline? Monitoring of all species may show whether other species have recovered from decline without being stocked, and which may provide references against which to assess the effects of stocking within the same system.

Answer

To date we have concentrated on the two species — dusky flathead and sand whiting — but we do have data for some 70 species in our database. I was interested in the work you did with Australian bass and I would like to examine [undertaking] a similar approach with our database.

Rob Day to panel

Assessing the impact of stock enhancement is similar to before-and-after control/impact studies. There is an extensive literature on the experimental design needed. Essentially you need several control rivers while you monitor the enhanced stock in the stocked river, otherwise you cannot interpret changes over time. The problem is that it is difficult to get funding for strongly controlled experiments in stock enhancement programs. We have to stand together and refuse to do the work if there is not enough funding allocated for worthwhile / meaningful studies.

Answer

**[Response not recorded]

Richard Tilzey (comment)

We shouldn't get bogged down - it's really horses for courses. Depends on the objectives of the project: either more fish for recreational anglers (put-and-take) or general species population enhancement for (e.g.) spawning biomass increase. Need a sliding scale.

Neil Loneragan: comment on design to Greg Jenkins

Question

We all have a tendency to regard our own 'system' of interest as unique. However, we should still think about experimental design and what other systems might be used as 'reference' systems to help us evaluate the success of enhancement.

and a question to John Russell

What is the impact of [stocking] 20,000 fish a year in the Johnstone River? Do you have any information on the effect of size at release on survival of the released fish? Do you have any idea of what the natural recruitment of barra. in the Johnstone River is, and how the releases of 20,000 juveniles for each year compare with the natural recruitment?

Answer

There is no significant difference in survival of the two smaller size classes of fish that we have stocked. We have not yet analysed the data for the larger size classes, however. Only small numbers (<1,000, total) of the larger size classes have been stocked.

John Harris to Greg Jenkins

Question

I am interested to consider whether habitat influences recruitment success with the black bream, and the objectives of the black bream estuary stocking. [John draws comparison with the Australian bass fishery in eastern Australia.] The breeding of these species is strongly controlled by stream flow in the winter spawning season. Have you considered such things as rainfall, habitat and so on for black bream? Would you care to comment?

Answer

The purpose of the restocking is to replenish the depleted stock of black bream in the Blackwood River estuary and to attempt to gain an insight into the influence of weather patterns and habitat on recruitment.

Dave Pollard to Adam Butcher

Question

You picked Maroochy River as a good site for stocking — although it has had two recent fish kills. Maybe not such an ideal site after all?

Answer

The fish kills were agriculturally based, and causes have been addressed since. [One of the] more recent kills was a one-off event due to flooding washing decaying vegetation downstream from an upstream impoundment.

Simon Nichol (comment)

Quite often it transpires that we experimentally put everything into the one river (= a resources problem). This technique [carries] a higher risk from environmental variation and political interference. Better to spread the stock enhancement across several rivers experimentally.

(Adam Butcher) I agree with your sentiments, Simon. I would like to see the use of control sotes as standard procedure for future marine stocking exercises.

Session 5

MESURING SUCCESS – FRESHWATER FISHERIES

Lake Mokoan - Home of the Quarter Pounder? A research and management case study

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Abstract

Lake Mokoan, near Benalla in Victoria, is a popular recreational fishery for native fish, having been stocked regularly with Murray cod and golden perch by Fisheries Victoria since 1988/89. In recent years the stocked population of golden perch has dominated the angling catch. As the success of the stock enhancement became more widely known the angling pressure exerted on this water is also reported to have escalated. The current perceptions of many anglers are that angling is removing most of the golden perch at about 20 cm (total length) before they reach their full potential. There is currently no bag or size limit on golden perch in Victoria and anglers are calling for the application of regulations, both bag and size limits, in an effort to increase the quality of the catch and share it more equitably.

Current research incudes netting surveys, competition monitoring and a creel survey that are designed to gather hard-data on the current status of the stock, and the catch. We aim to predict the effect of changes in fisheries management (stock-enhancement, and catch regulation) through the collection of catch-and-effort and size/age composition data.

We present a recent model that describes extremely slow growth for golden perch from Lake Mokoan. We speculate that this poor growth may be a symptom of high stock-density, and that this may be related to a shift in the trophic structure of the fish community. This being the case, imposing restrictive bag and size limits for Lake Mokoan may exacerbate the situation, unless steps are first taken to reduce the stock-density. Golden perch are normally relatively fast growing and are relatively long-lived. Therefore it may be possible to sustain a "better quality" fishery with periodic pulses of stock-enhancement rather than restrictions on the angling catch.

Introduction

Lake Mokoan is a shallow, turbid water storage reservoir at Winton in the Broken River Basin, near Benalla, formed in 1971 when a dam was constructed across the lower end of the old Winton Swamp. It has a shoreline of 52km, a surface area of 7,900ha and a capacity of 365,000Ml (Tunbridge et al. 1991). Lake Mokoan has a lot of standing and submerged timber, and is surrounded by scattered forest and grazing country.

Throughout the 1970's and 1980's the lake was an important redfin angling water but this fishery has been in decline over the last decade (Tunbridge *et al*. 1991), the reduction in redfin numbers may have been caused by environmental factors such as turbidity. Fisheries Victoria has regularly stocked the impoundment with both golden perch and Murray cod since 1988/89 and a promising native fishery has developed. Lake Mokoan is currently managed as a native fish water although the occasional redfin, goldfish and abundant carp are also present.

Lake Mokoan is a regulating storage that receives water from the Broken River and returns it as required for downstream irrigation and domestic water demands, thus the water level fluctuates. In 1992 there was a change in the operation of Lake Mokoan, with the managing authority Goulburn-Murray Water agreeing to maintain water levels between 40% and 50%, and flushing with new water in winter/spring. Current operating targets aim to keep the water levels between 42% and 70% of full supply level.

Key Issues

As the success of the Fisheries stock enhancement at Lake Mokoan has become more widely known, the angling pressure on this water is also reported to have escalated. Anglers were calling for the application of regulations, both size and bag limits, in an effort to increase the quality of the catch and to share it more equitably. No regulations are currently in place for the capture of golden perch, however proposed regulations (Fisheries (Catch Limit) Regulations 2000) include new a new minimum size of 30cm, a daily bag limit of 10 and a possession limit of 10. The new regulations are intended to provide increased protection against excessive fishing pressure and to define and encourage responsible recreational fishing practices so that community benefits from recreational fish resources can be maximised.

Research in Progress

Current research includes netting surveys, competition monitoring and a creel survey. Netting surveys were undertaken in 1990-1995, 1999, 2000 and 2001. The creel survey was developed in consultation with regional fisheries officers, and MAFRI biometric support as a roving design, stratified by season, time of day and fishing area. Fisheries officers from the North east NRE region were commissioned to carry out creel interviews on 117 days over 145 sessions in a 12 month period starting 1

January 2000.

MAFRI and Fisheries Victoria staff also attended the 'Golden classic' fishing competition, October 1999 and 2000. Length and weight information on the catch was recorded, and otoliths were collected from golden perch for ageing.

Results

Netting surveys have indicated good survival from stockings (all year classes present in samples aged); relatively large population of golden perch (creel data, compared to other waters in the State); and slow growth rates of golden perch (from age estimates), compared to ages of golden perch from other waters in Victoria (Figure 1).

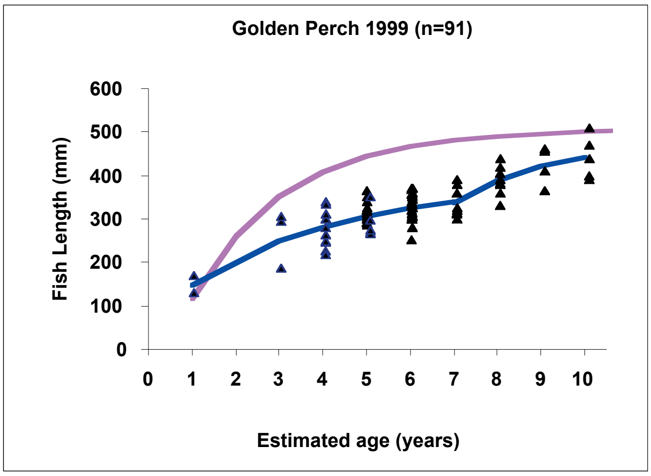

Figure 1. Golden perch ages and growth curves from Lake Mokoan (blue) compared to the growth curve (pink) of 889 golden perch from the Lower Murray-Darling Basin (Anderson et al., 1992).

From creel survey interviews, anglers reported a total retained catch of 4117 golden perch, 6 Murray cod and 116 carp. Other information was also collected, such as the fishing method utilised, number of lines and hooks, frequency of fishing (occasional, regular, active) and angler post codes.

Discussion and Conclusions

The 24 golden perch aged from the March 1999 survey and the 67 golden perch aged from the October 1999 competition seem to show slower than normal growth. This poor growth is likely to be a symptom of high stock density. There appears to have been a change in the growth rates about 1991/92, with slower growth occurring after this date. This is thought to be correlated with a change in water management regimes, with consistently lower water levels occurring after 1992.

Expected outcomes of research will include: Population parameters for golden perch from length frequency and age data; Development of an age length key; Estimates of when the fish enter the fishery and at what age (50 cm size limit for Murray cod) from growth rates; Total mortality rate from catch curve analysis; Catch rates; Total Effort; Total Catch; Discard rates; An understanding of the effect of anglers on the fishery and Estimates of the effects of restrictions on catches (ie proposed regulations).

Summary

The estimated growth rates for golden perch in Lake Mokoan are comparatively low. A decision will have to be made as to what's more important - bigger fish or higher catch rates? Maybe we can have both?

References

Anderson, J.R., Morison, A.K. and D.J. Ray (1992). Validation of the Use of Thin-sectioned Otoliths for Determining the Age and Growth of Golden Perch *Maquaria ambigua* (Perciformes: Percichthyidae), in the Lower Murray-Darling Basin, Australia. *Aust. J. Mar. Freshwater Res.* **43**, 1103-28.

An overview of rainbow trout (*Onchorhyncus mykiss*) stocking success in Lake Eucumbene, New South Wales.

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Absract

The Lake Eucumbene recreational fishery is based on brown (*Salmo trutta*) and rainbow trout. The brown trout population has always been self-sustaining. Whereas self-sustaining rainbow trout populations were also present in the Eucumbene catchment prior to inundation, it is uncertain if was stocked with this species in the early inundation phase. No stocking occurred between 1960 and 1981. Mark-recapture studies found rainbows to be 2-3 times more vulnerable to angling than browns and rainbows dominated catches during the 1960s and early 1970s. Following a continued decline in rainbow trout abundance during the late 1960s and 1970s the lake was stocked with 300 000 yearling rainbows in 1981. These fish had an immediate impact on the fishery and rainbows again dominated catches during the early 1980s. Since 1986, Eucumbene has received periodic stockings of rainbow fry/fingerlings. Stocked fish returns to the angler have not been quantified, but there is little doubt that they made a significant contribution to the fishery. Their contribution to rainbow spawning biomass is unknown. Eucumbene received a large number (1.3 million) of rainbow fry/fingerlings in 2 years preceding the World Flyfishing Championships held in the district in 1999. Subsequent growth and condition of these fish appeared poor and over-stocking probably occurred. Overall, little is known of the fate of stocked fish. Given the importance of Eucumbene as a recreational fishery, a quantitative appraisal of the effectiveness of stocking practices should be given a high priority.

Introduction

Lake Eucumbene is the largest impoundment created by the Snowy Mountains Scheme, having a surface area of 145 km^2 and a volume of 4.8 km^3 at full supply level. The lake began flooding in 1957 but did not attain full supply level until 1976. From 1959 onwards, Eucumbene has constituted a major recreational fishery based on populations of brown trout (*Salmo trutta*) and rainbow trout (*Onchorynchus mykiss*). Prior to inundation, the Eucumbene catchment contained self-reproducing populations of both species and these expanded to occupy lentic waters. However, an anecdotal report from a long-standing Monaro Acclimatisation Society member suggests the rainbow trout population may have initially been supplemented in 1958 or 1959 by a release of fingerlings from the Gaden Trout Hatchery near Jindabyne, NSW. At this time, Monaro Acclimatisation Society volunteers made trout releases from this hatchery and the details of such releases were not always recorded. In any event, Eucumbene was not stocked again for over 20 years, with the trout fishery being sustained by natural recruitment.

During the late 1950s and early 1960s, when lentic waters were more or less constantly inundating new ground, Eucumbene provided exceptional fishing. The abundance of drowned terrestial food items resulted in rapid trout growth and fish became habituated to feeding in shallow littoral waters where they were accessible to anglers. Declines in catch rates and mean fish size began in the mid-1960s (Tilzey 1972). Such declines are to be expected following the inundation phase of an impoundment. However, catch rates (kg/hr) continued to decline throughout the 1970s, except when lake-level reached record heights in 1970, 1971 and 1976 (full supply level) and again inundated new ground. The decline in rainbow trout catch rates was much more pronounced than that for brown trout and reflected declining rainbow trout abundance. The ratio of brown to rainbow trout in lentic waters increased from 1:1 in the mid-1960s, when rainbow trout comprised about 70% of the angling catch, to about 4:1 in the late 1970s. Mark and recapture studies (Tilzey 1972, Faragher & Gordon 1992) showed the annual fishing mortalities of rainbow trout to be between 2 to 3 times greater than those for brown trout. Hence, the decline in rainbow trout abundance caused a marked fall in the overall catch rate for both species. Whereas high fishing mortalities (22-30% p.a.) undoubtedly contributed to declining rainbow trout abundance, recruitment studies also found the survival of young-of-the-year fish vacating natal streams and entering lentic waters to be of a very low order (Tilzey 1972). Tilzey (1979) also flagged that, because of increased dietary segregation between brown and rainbow trout in lentic waters, the lake could support a larger rainbow trout population. Faced with this ongoing decline in Eucumbene rainbow trout abundance, NSW Fisheries first decided to stock lentic waters with this species in 1981.

Stocking history

Rainbow trout releases are summarised in Table 1. The 1981 release of yearling fish was made in a somewhat opportunistic manner. A commercial trout farm near Blowering Dam, NSW was declared bankrupt and the fish were purchased at a bargain-basement price ($A0.10 each) from the receivers. With the exception of a 1995 release of fish purchased from a commercial trout farm near Adaminaby, NSW, releases came from NSW

Fisheries hatcheries at Jindabyne (Gaden) and Ebor (Dutton), NSW.

Growth of stocked fish

No targeted monitoring of the 1981 release was conducted. Similarly, no concise measurements of fish size at release were taken, but lengths were estimated to range from 20-30 cm (B. Richardson pers.com.). Immediately following the release, numerous complaints from anglers about having to release fish under the legal retention limit of 25.4 cm suggest many fish were below this size. Available length frequencies from the angling catch (Fig. 1) show that virtually all fish had passed this limit by early winter 1982, with a mean length of around 28-29 cm at age 2 years (i.e. August 1982). Subsequent growth during the following spring/summer indicated that the bulk of fish would have attained a size of around 40 cm at age 3 years. The 1986, 1987 and 1988 releases were marked by fin-clipping with the specific aim of assessing/validating rainbow trout growth rates in lentic waters (Faragher 1992). The mean lengths of recaptured fish at age 2 years were 37.5, 37.8 and 40.2 cm, respectively, with fish reaching a length of about 46 cm at age 3 years (Faragher 1992). Lengths at age for the 1986-88 releases were greater than respective values for the 1981 release and similar to those for naturally spawned fish that recruit to the lake early in their first year of life.

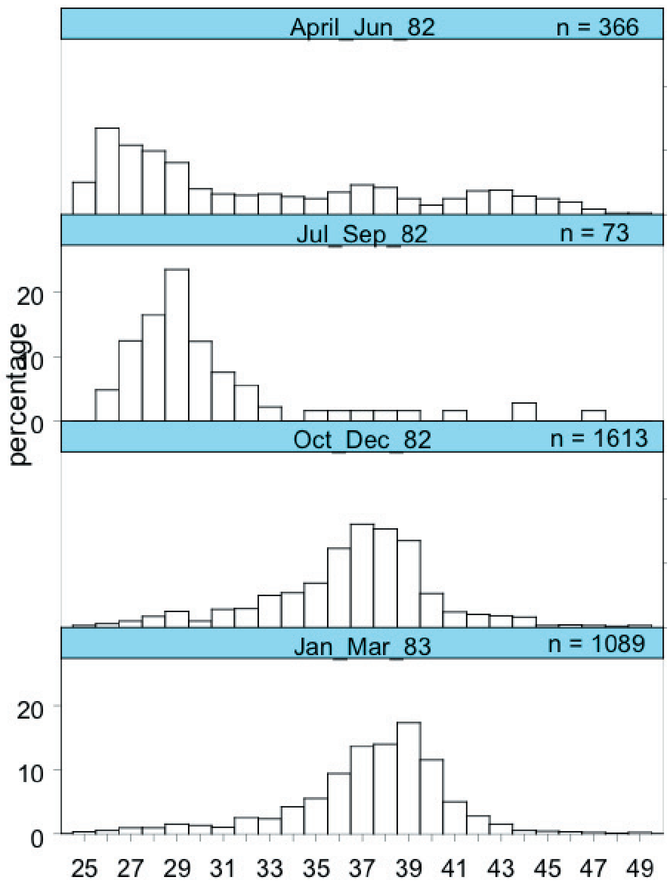

Figure 1. Percentage length frequencies of rainbow trout in the angling catch.

No quantitative monitoring of subsequent (1994-2000) releases has been undertaken. Some of these releases were very large, 600 000 in 1995 and 700 000 in 1996 (Table 1), in anticipation of the World Flyfishing Championships to be held in the district in 1999. However, personal observation of fish angled from the lake during 1997 to 1999 found most juvenile (< 30 cm LCF) rainbow to be in poor condition (weight against length) compared with that in earlier years. Discussions with other anglers found general agreement with this observation. This strongly suggested that the growth rates of these large releases were lower than those reported for earlier releases.

NUMBER	YEAR	MONTH	SIZE	SOURCE
300 000	1981	12	Yearling	Blowering trout farm
30 000	1986	4	Fingerling	Gaden hatchery
50 000	1987	4	Fingerling	Gaden hatchery
25 700	1988	4	Fingerling	Gaden hatchery
21 000	1994	8	Fingerling	Gaden hatchery
200 000	1995	1	Fingerling	Adaminaby trout farm
300 000	1995	9	Fry	Dutton hatchery
100 000	1995	2	Fingerling	Gaden hatchery
300 000	1996	9	Fry	Dutton hatchery
100 000	1996	2	Fingerling	Gaden hatchery
300 000	1996	12	Fry	Gaden hatchery
300 000	1997	12	Fry	Gaden hatchery
40 000	1998	2	Fingerling	Gaden hatchery
50 000	2000	4	Fingerling	Gaden hatchery

Table 1. Summary of rainbow trout releases into Lake Eucumbene.

Harvest and survival of stocked fish

Few quantitative data are available. Following the 1981 release, rainbow trout representation by number in the total angling catch rose from 35% in the 1981/82 season to 83% in 1982/83, remained high at 72% in 1983/84, but fell to around 55% in 1984/85 and 1985/86 (Faragher 1993). There is little doubt that a large proportion of these fish were caught, probably in excess of 50% overall. Tilzey (1972) recorded recapture rates of up to 30% p.a. for marked rainbow trout during the period 1968/69 to 1970/71 and Faragher and Gordon (1992) recorded 27% in 1987/88. However, the comparative proportion of rainbow trout in the catch during the 1980s would have been inflated by the decreasing catchability of brown trout because of a shift to benthic feeding (Faragher 1983). Whereas Tilzey (1972) recorded recapture rates between 10 and 12% p.a. for marked brown trout, Faragher and Gordon (1992) recorded 9%, for the same times as above. The latter recaptures included catches from the brown trout spawning run which was not open to fishing during the earlier period. Also, fishing effort on the lake has certainly risen significantly since 1968/71. Following the 1986-1988 releases of fin-clipped fish, Faragher (1992) monitored two fishing competitions in November 1989 and recorded representations of 1.6% (2/127) and 4.1% (8/195) of marked fish in the catch. However, the overall harvest of these releases remains unknown. Faragher (1992) noted that there was a low recognition rate of fin-clipped fish by anglers. Nothing is known of the harvest rates of releases from 1994 onwards.

Again, virtually nothing is known of what contribution to the spawning population was made by stocked fish. Tilzey (unpublished data) monitored rainbow trout spawning runs in 1968, 1969 and 1970 and found them to be dominated by 3 year-old (>60%) and 4 year-old (>30%) fish, with comparatively few 2 and 5 year-olds. Nearly all the 2 year-olds were male fish. Hence, females have to survive to 3 years to contribute to spawning biomass. Faragher (1992) conducted partial trapping of the rainbow trout spawning run in 1988 and 1989 and found fin-clipped fish to comprise 6.4% and 4.4%, respectively, of the total numbers of fish aged 3 years or more trapped. Some stocked fish clearly survive long enough to contribute to spawning biomass, but their contribution remains unquantified.

In Eucumbene inlets, brown trout spawn at least two months before rainbow trout (Tilzey 1972, 2000). Tilzey (1972) observed that the earlier hatching (and greater fry size) of brown trout gave them a competitive advantage over the later hatching rainbow trout in shared natal streams. The 1995 and 1996 releases from the Dutton hatchery were made because the rainbow brood-stock there matures significantly earlier in the year than do Snowy Mountain adults and it was hoped that an earlier spawning by these stocked fish would reduce the brown's competitive advantage. However, no subsequent monitoring of Eucumbene spawning runs was carried out to see if an earlier run by these fish occurred. In any event, it is unclear if the earlier spawning by Dutton fish is a genetic trait or merely associated with the lower latitude and higher water temperatures at Ebor, NSW.

Table 2. Summary of 1969 spawning in Swamp Ck and estimated numbers of the resultant cohorts remaining in stream residence.

	BROWN	RAINBOW
No. Spawners	1911 F (951 M)	339 F (251 M)
No. Ova	2,660,000	1,239,000
Jan 1970	95,930 (3.61%)	3,410 (0.28%)
Mar 1970	59,760 (2.25%)	3,100 (0.25%)
Jan 1971	29,140 (1.10%)	1,240 (0.10%)
May 1971	13,370 (0.50%)	970 (0.08%)

The percentage values are derived from the respective numbers of ova

Discussion

Tilzey (1972) monitored brown and rainbow trout spawning runs and the subsequent fate of the resultant progeny in a major Eucumbene inlet (Swamp Ck) and observed that for both species the vast majority of fry/fingerlings either died or vacated this natal stream shortly after hatching. Estimates of the progressive numbers of the 1969 cohorts in this stream are summarised in Table 2. Growth studies using scale analysis found that size at age in lotic waters was much less than in lentic waters. Thus, the lotic and lentic residence history of a fish could be deduced from its growth history with reasonable confidence. Size/age/growth analysis of fish in the angling catch found that very few of the fish that vacated natal streams at an early age survived to recruit to the rod fishery. For example, the mean percentage age composition of the angling catch for the period 1968/69 to 1972/73 is summarised in Table 3. Note that these percentages do not reflect comparative year class strength as the younger age classes are only partially recruited and mark/recapture studies (Tilzey 1977) showed fishing mortality to increase with size/age. The recruitment history of this same group of fish is summarised in Table 4. Tables 3 and 4 were calculated from seasonal length frequencies of the angling catch and age/length keys derived from ageing 5270 brown and 4077 rainbow trout sampled from lentic waters. The precise timing of emigration from natal streams is unknown but, after the first summer, most movement appeared to take place in autumn/winter. Thus, the '2 years stream residence' category in Table 4 could well contain fish that emigrated in autumn as 1+ year olds. Similarly, the '1 year' category could contain some 0+ fish. The main point is; only a small proportion of the early 'spring/summer' emigrants from all natal streams eventually recruited to the rod fishery. By number, they comprised only 2.9% of the brown trout catch and 7.0% of the rainbow trout catch (Table 4). The survival rate for early emigrants of both species was obviously very low.

These observations led the author to believe that stocking fry/fingerlings into lentic waters would be unproductive because the fish would experience high natural mortality rates. Following a study that allowed rainbow trout spawners sole access to Swamp Ck and found large numbers of the resultant cohort remained in the creek in the absence of competition from brown trout, the author recommended spawning-run manipulation as a more effective method of boosting rainbow recruitment than stocking. However, the subsequent success (albeit unquantified) of fish stocked as small juveniles (Faragher 1992) has subsequently demonstrated that their natural mortality in lentic waters is lower than Tilzey (1972, 1979) anticipated. This suggests that the lotic/lentic interface is probably the area in which high mortality occurs for first-year natural recruits.

Table 3. Mean percentage age composition of the lentic angling catch 1968/69 – 1972/73

AGE (YRS)	1+	2+	3+	4+	5+	>5+
BROWN	1.5	26.6	30.7	23.9	12.2	5.1
RAINBOW	4.7	49.4	33.5	10.2	2.2	

Whereas it is clear that rainbow trout stockings, particularly the 1981 stocking, have made a significant contribution to the Eucumbene fishery, their effectiveness remains unquantified. As rainbow trout fishing mortality in Eucumbene will continue to be high, further periodic stocking will almost certainly be required to maintain the fishery. However, this should not be carried out in the 'hit and miss' manner that typifies recent stockings. Circumstantial evidence strongly suggests that the 1995 and 1996 stockings were too large for the lake to support. Because no scientific monitoring has been carried out in recent years, no hard data are available to support or refute this hypothesis, or to assess if any damage to the lake's ecosystem occurred. Quantifying Eucumbene stocking efficiency and the impacts of stocking should be given a high priority. How to do this in a cost-effective manner remains problematic.

Table 4. Mean percentage age of stream residence for the fish in the lentic angling catch 1968/69 – 1972/73

RESIDENCE (YRS)	<1	1	2	3	4	5
BROWN	2.9	16.5	73.8	6.1	0.6	0.1
RAINBOW	7.0	18.5	71.0	3.3	0.2	

Assessment methods will obviously be determined by management priorities. For example, if an objective is to assess the cost-effectiveness of stocking limited numbers of yearlings against large numbers of fingerlings, a targeted study will be needed to monitor the fate of such releases. Any study aimed at assessing the contribution of stocked fish to the fishery or spawning biomass will need to distinguish between stocked and naturally recruited fish. The marking and subsequent monitoring of releases is a straightforward procedure, but is labour intensive and costly. Moreover, anglers usually do not recognise marks such as fin-clips (Faragher 1992) and often disregard tags, so that targeted monitoring such as a creel survey is required. The most basic and cheapest monitoring method is to assess mean size at age each year. Regular monitoring of the growth and condition of rainbow trout in the lake should be a minimal requirement to assess population status. Both wild and stocked fish share a common food source and should have similar growth rates, although their life and growth histories will vary (see below). Whereas Tilzey (unpublished data) found fluctuating lake-levels to impact on the growth rates of the largely benthic-feeding brown trout, the impact on the largely pelagic-feeding rainbow trout was much less pronounced. Simplistically; if growth rates are declining, there's too many fish in the lake and stocking should cease for at least 2 years, and vice-versa.

A feedback protocol should be firmly established with the hatcheries. At present, the attitude of fisheries officials appears to be; "we've got the fish so they're going in". Stocking is a wonderful placebo for the anglers and a good news item for the Minister. It should be made clear to all that over-stocking can do a lot more harm than good.

If regular monitoring of growth rates is to be carried out, it should be stressed that there is a difference of opinion over the ageing of wild rainbow trout in Eucumbene. Faragher (1992) analysed the scales from recaptures of the fin-clipped fish released in 1986-88 to validate this ageing method. These fish exhibited a distinct false check early in their first year. Faragher (1992) used the mean lengths at age for a single rainbow trout cohort cited by Tilzey (1976) to speculate that Tilzey had over-aged rainbow trout by one year by interpreting this false check as the first annulus. Faragher (1992) overlooked the fact that the mean lengths at age cited by Tilzey (1976) were derived from a cohort dominated by second year recruits to lentic waters. As noted above, this was typical for most naturally spawned cohorts. First year recruits to lentic waters, albeit that comparatively few survived, exhibited similar growth and lengths at age to those described by Faragher (1992). Tilzey (unpublished data) validated his scale ageing by length frequency analysis (Petersen method) in natal streams where distinct 0+ and 1+ modes occurred, monthly sampling of lentic fish and examination of scale margins, and comparisons with observed growth by marked fish. Several authors (e.g. Allen 1951, Lake 1957) have noted that false annuli commonly occur in trout streams where summer water temperatures exceed the optimum for trout. However, false checks do not occur in Eucumbene inlets. It appears probable that the false check observed by Faragher (1992) was associated with hatchery rearing, the trauma of being placed in a wild habitat, or both. Davies and Sloane (1987) found that there was a distinct scale check associated with the liberation of hatchery reared rainbow trout into Dee Lagoon, Tasmania. In Eucumbene, this false check closely resembles the true annulus of naturally recruited fish that have remained in natal streams for a year. When Faragher (1992) found the same general pattern on the scales of a sample of wild rainbow trout he probably interpreted the true annulus as being false and under-aged the fish by one year. In any event, the similarity in scale pattern between stocked and wild fish means scales cannot be used as a distinguishing character.

The age/growth of Eucumbene trout warrants more discussion than is justified here and should be the subject of further debate and publication. Whereas ageing by scale analysis is less labour intensive than ageing by otolith analysis, otoliths should be collected on a regular basis. This has just begun in Eucumbene (R. Faragher pers.com.). Comparison between ages derived from scales and otoliths should be made for both species to assess the ongoing usefulness, or otherwise, of scale analysis. If otolith-ageing becomes the adopted method, the most cost-effective means of analysis is probably via the Central Ageing Facility at Queenscliff, Victoria. Also, possible methods of mass marking hatchery fingerlings via the use of oxytetracycline, or a similar compound, which lays down a mark on the otolith, should be investigated. If such a method can be found, this would expedite the assessment of stocking efficiency, provided adequate monitoring takes place.

Lake Eucumbene is Australia's largest mainland trout fishery and generates a turnover of several million dollars a year for tourist and support industries. In countries such as New Zealand, the United Kingdom and the USA, the worth of such a fishery would guarantee regular scientific monitoring, assessment of fishery status and active management. However, in NSW, the only management of the fishery currently consists of periodic stocking and the only monitoring consists of an annual 'snapshot' of catches from the 'November Trout Festival'. Indeed, referring to stocking as 'management' is probably a misnomer. Important issues such as the current trophic status of the lake, possible changes in trout food composition/abundance/availability and the current levels of fishing effort and harvest are simply not being addressed. Did the massive 1995 and 1996 rainbow trout stockings have an adverse impact on the lake's zooplankton populations? Has the invasion of the oriental weatherloach (*Misgurnus anguillicaudatus*) disrupted the trout's food-chain? The issue of stocking effectiveness can be added to the list. Questions like these cannot be answered in the absence of a comprehensive, ongoing monitoring program for the fishery. As a regular angler and observer of the fishery, the author has no doubts that it has declined over the past 3 years. However, there are no hard facts to prove or disprove this claim. To paraphrase Dylan (1965); "something is really happening here, but you don't know what it is." Do you NSW Fisheries? More of the revenues from the reintroduced NSW angling licence should be directed towards managing the Eucumbene fishery.

References

Allen, K. R. (1951) The Horokiwi Stream. A study of a trout population. N. Z. Marine Dept. Bull. No. 10. 1-231.

Davies, P. E. and Sloane, R. D. (1987) Validation of ageing and length back-calculation in rainbow trout, Salmo gairdneri Richardson, from Dee Lagoon, Tasmania. Aust. J. Mar. Freshwater Res. 37, 289-295.

Dylan, B. (1965) Ballad of a thin man. Highway 61 Revisited. Warner Bros. Inc. © Bob Dylan.

Faragher, R. A. (1983) Role of the crayfish *Cherax destructor* Clark as food for trout in Lake Eucumbene, New South Wales. Aust. J. Mar. Freshwater Res. 34, 407-417

Faragher, R. A. (1992) The growth and age validation of rainbow trout *Oncorhynchus mykiss* (Walbaum) in Lake Eucumbene, New South Wales. Aust. J. Mar. Freshwater Res. 43, 1033-1042.

Faragher, R. A. (1993) The Lake Eucumbene Study 1985-89: Findings and Recommendations. NSW Fisheries Discussion Paper.

Faragher, R. A. and Gordon, G. N .G. (1992) Comparative exploitation by recreational anglers of brown trout (*Salmo trutta* L.) and rainbow trout (*Oncorhynchus mykiss* Walbaum) in Lake Eucumbene, New South Wales. Aust. J. Mar. Freshwater Res. 43, 835-845.

Lake, J. S. (1957) Trout populations and habitats in New South Wales. Aust. J. Mar. Freshwater Res. 8, 414-450.

Tilzey, R. D. J. (1972) The Lake Eucumbene Trout Fishery. The Fisherman. (NSW State Fisheries) 4, 1-9.

Tilzey, R. D. J. (1976) Observations on interactions between indigenous Galaxiidae and introduced Salmonidae in the Lake Eucumbene catchment, New South Wales. Aust. J. Mar. Freshwater Res. 27, 551-564.

Tilzey, R. D. J. (1977) Repeat homing of brown trout (*Salmo trutta*) in Lake Eucumbene, New South Wales, Australia. J. Fish. Res. Bd Canada. 34, 1085-1094.

Tilzey, R. (1979) Eucumbene 1979: Where now? NSW State Fisheries Leaflet No. 5. 1-8.

Tilzey, R. D. J. (2000) Environmental cues in the reproductive migrations of brown trout (*Salmo trutta*) in Lake Eucumbene, New South Wales. ASFB Proceedings

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I draw on research data gathered as an employee of NSW State Fisheries from 1967 to 1980. Andrew Sanger kindly supplied details of post-1988 stocking numbers.

mmary of 1969 spawning in Swamp Ck and estimated numbers of the resultant cohorts remaining in stream residence.

Trout (*Oncorhynchus mykiss*) Production and Stocking in Western Australia: An Examination of the Fishery and Evaluation of the Stock-Enhancement Program in Public Access Waters.

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Abstract.

Although not widely recognised as having high-quality trout waters, Western Australia has a long-history of trout stocking and fishing. Fisheries WA has been producing and stocking trout (mainly Oncorhynchus mykiss) for over 60 years. Most trout have been stocked as fry and ex-broodstock. However, a perception exists of a reduction in the quality of trout fishing in Western Australia for a number of reasons, although hard evidence is generally lacking.

Evidence collected from a fishing club for Waroona Dam strongly suggests that red-fin perch (Perca fluviatilis) are imposing a high mortality on fry-stage trout. One suggested method of mitigating the effect of red-fin predation is stocking trout at a larger size, for example as yearlings, which in the case of Waroona Dam, has led to an increase in trout catches despite a large red-fin population. However, yearling production and stocking impose higher costs relative to fry and thus the benefits of yearling production and stocking, as angler satisfaction and enhanced fish survival, must outweigh the increased production costs.

The overall objective is to examine the fishery in order to develop a research proposal to evaluate the stocking of different age classes of trout into the freshwaters of WA. Firstly, a brief history of trout production and stocking in Western Australia is presented to provide a summary of the investment in trout production for recreational fishing in this State. Secondly, the most recent information about the catch and effort in the fishery is presented to provide information about the size and extent of the fishery. Information available on the impacts of red-fin on rainbow trout are provided in order to determine if in-fact red-fin are a major influence on the quality of the trout fishery. Finally, a theoretical cost-benefit analysis of producing and stocking fry and yearling trout in WA is presented. From this theoretical analysis, yearling trout must have a survivorship at least 17.24 times greater than fry for yearling production to be cost-neutral. This figure can now becomes a clearly defined target and objective to evaluate any trout re-stocking programs in WA.

Introduction

Western Australia has a long-history of producing, stocking and fishing brown (*Salmo trutta*) and rainbow trout (*Oncorhynchus mykiss*). As in other Australian States, trout were introduced as a sport fish around the early 1900's. Unlike most other states, Western Australia had no large, natural freshwater fishes and trout were viewed as the obvious choice to introduce, especially given the long history of translocation and sports-fishing for rainbow and brown trout throughout the World (Molony and Morrissy 2000)

Fisheries WA has been involved in the production and stocking of rainbow and brown trout into a recreational fishery for over 60 years, with most emphasis placed on rainbow trout. Historically, trout have been stocked as eyed-ova, fry, fingerlings and ex-broodstock, with a majority of effort focused on fry production and stocking (Molony and Morrissy 2000). Since approximately the 1980's, there has been a popular perception by the freshwater angling community of a declining quality in trout fishing in Western Australia. Although many reasons are proposed, including salinisation and land-practices, reduction in water access and predators, hard evidence of declining quality and causative processes is lacking.

Meanwhile, the distribution and abundance of another introduced freshwater fish, the red-fin perch (*Perca fluviatilis*), has increased. Red-fin are an aggressive predatory species and are very fecund, especially in the large irrigation dams of the south-west of Western Australia (Morgan et al. 1998; Molony and Morrissy 2000). Red-fin are suggested as one reason for a reduction in trout fishing quality due to the suspected high mortality of young trout stages (Baxter et al. 1985). One suggested method of mitigating the effect of red-fin predation is stocking trout at a larger size, for example as yearlings which are above the size of prey items for most red-fin. This would require a major shift in production and stocking practices in Western Australia, and an associated increase in capital costs and operating costs. Although, the production and stocking of larger fish should reduce predation and enhance survival rates (Moy 1974), there are no quantitative estimates of how much survival would be increased by the production of yearlings. Further, there is no evidence that increased fish survival would equate to increases in catch-rate (for example CPUE), a measure by which the quality of many recreational fisheries are assessed. Nonetheless, increased costs of production must, at least, be outweighed by increased survival rates to make a production switch of this magnitude an economically viable option.

This workshop presentation aims to;

1. Provide a brief history of trout stocking in Western Australia to provide a background of State Investment in trout stocking and enhancement;
2. Provide the most recent estimates of catch-and-effort in the fishery to provide estimates of the size of the fishery;
3. Evaluate the available evidence of the effects of red-fin perch on trout catches; and
4. Present a theoretical cost-benefit analysis of producing and stocking fry and yearling rainbow trout in Western Australia.

Finally, a discussion of salmonid survival rates at different sizes is provided to permit discussion and feed-back for the development of a research proposal to examine the survival rates of trout of different sizes and ages within this licensed recreational fishery. The objective is to evaluate increasing the numbers of trout in the fishery by increasing yearling production without significantly increasing the costs of production and stocking.

History of Stocking Trout in Western Australia.

In 1897, a British fish biologist conducted a survey of the "Southern Districts" of WA and concluded that the "freshwaters (of south-west WA) were devoid of fish of economic value". It was suggested that suitable species of freshwater fishes should be acclimatised and introduced into the rivers of WA for recreational purposes. Although attempts to introduce a range of species were made, most efforts concentrated on the acclimatisation of brown and rainbow trout because of their sporting qualities and extensive history of translocation around the world as a sport fish species. Extensive acclimatisation and stocking trials were made up until 1920, mainly by acclimatisation societies in Western Australia (Molony and Morrissy 2000). Although little information exists, a majority of reports showed disappointing results.

In the 1920s and 1930s, several modest attempts at introducing rainbow trout into waterways were made, again with varying success. However, there are few records of fish being captured during these years. It was suspected that the waters of WA were so unsuitable that few trout could survive because of a lack of appropriate productivity and food sources. However, records of trout captures commenced in the early 1930s and new efforts of trout stocking were made (Chappell 2000).

In 1936, a small hatchery was built in Pemberton, funded by the Fish and Game Acclimatisation, Propagation and Protection Society of WA. These ponds are still used for marron culture today at the South West Freshwater Research and Aquaculture Centre (formally, the Pemberton Hatchery) operated by Fisheries WA.

Stocking of locally produced and collected trout eggs occurred annually from 1936 and the first official fishing season commenced in 1939 (Chappell 2000). Although early production of larvae was modest, about 50,000 fry per annum, more than one million rainbow trout fry were produced in the winter of 1999 at the SWFRAC and over 500,000 rainbow trout fry were stocked into the recreational fishery in 1999. Further, approximately 20,000 brown trout fry, 24,000 yearling rainbow trout and several thousand ex-broodstock trout were released (Table 1). Remaining fish were used for research, private fisheries or aquaculture.

Table 1 :Numbers of rainbow trout fry and yearlings produced and stocked into the public Freshwater Angling Fishery (FAF) by the South-West Freshwater Research and Aquaculture Facility (SWFRAC) since 1970. These figures do not include older fish (ex-broodstock). In years of no supply of fry to public waters the SWFRAC was experiencing an outbreak of disease.

Year	Numbers of fry	Numbers of yearlings
1970	139 000	0
1971	190 000	0
1972	235 000	0
1973	88 000	0
1974	90 000	0
1975	88 000	0
1976	90 000	0
1977	385 000	0
1978	435 000	0
1979	430 000	0
1980	404 000	3 600
1981	138 000	8 900
1982	439 000	19 000
1983	0	5 000
1984	484 000	0
1985	256 000	32 000
1986	3 000	18 000
1987	100 000	12 000
1988	0	11 000
1989	108 000	11 000
1990	249 000	13 000
1991	132 000	11 000
1992	260 000	8 000
1993	358 000	25 000
1994	265 000	26 000
1995	296 500	0
1996	461 000	0
1997	426 000	11 000
1998	305 000	10 000
1999*	530 000	24 800

* Indicates the commissioning of purpose-built yearling ponds at the SWFRAC.

Allocation of trout is decided by a trout stocking committee using guidelines established by Fisheries WA. Briefly, the committee meets twice a year (August to allocate fry and February to allocate yearlings) and consists of representatives of the Recreational Fishing Program, RecFishWest (a peak body representing recreational anglers in WA), the Research Division of Fisheries WA, and the manager of the SWFRAC. Allocation is based on historical allocations (trout are stocked only in waterbodies where there is a long history of stocking), conservation issues, perceived fishing effort and trout-carrying capacity of these locations. The presence of red-fin perch in stocked locations is also considered but to a lesser extent.

In summary, WA has a long history of producing and stocking trout for recreational fishing opportunities and will continue into the future. Therefore, the investment in sustaining this fishery is high.

Recent Information about the Freshwater Fishery.

The Freshwater Angling Fishery (FAF) is one of five licensed recreational fisheries in WA and licence-holders must renew their licences annually. The most recent information about the catch and effort in the public recreational freshwater fishery of south-west WA comes from a survey which commenced in April 1999. A mail survey was conducted using a random sample of 1000 licence holders. From the licensing system, a total 11 906 licence holders were eligible to participate in the FAF, including holders of joint and "umbrella" licences (for access into all licensed recreational fisheries). The revenue realised in 1998/99 from licence sales for Freshwater Angling was estimated at approximately $137 000.

Participation rate

A total of 237 returns were received (23.7 % response rate) and a total of 127 respondents (53.6 %) indicated that they went freshwater angling at least once within the previous 12 months, equating to a total of 6 380 active licence holders (i.e. 53.6 % of 11 906 licences). A further 29 respondents (12.2 %) indicated that they usually participate in the freshwater fishery but did not participate in the previous 12 months (equating to approximately a further 1 457 licences). Eighty one respondents indicated that they have never been freshwater angling (34.2 %, 4 069 licence holders) and are likely to be holders of "Umbrella" licences that do not participate within the FAF although they are entitled to do so.

Effort Estimates

The respondents that participated in the Recreational Freshwater Fishery recorded a total of 411 freshwater angling trips, (mean of 3.24 trips per active licence) consisting of between 2-10 days of fishing (a total of 20 647 fishing trips and an estimated 195 000 angler days). A typical trip involved approximately 2 hours of fishing per day. Most respondents were between 25-54 years old and had 20+ years of freshwater angling experience.

Catch and Landing estimates.

Five species of freshwater fishes are commonly captured in the south-west of WA, including *Oncorhynchus mykiss* (rainbow trout), *Salmo trutta* (brown trout), *Perca fluviatilis* (red-fin perch), *Tandanus bostocki* (native freshwater catfish) and *Acanthopagrus butcheri* (black bream). However, for this workshop paper only information for rainbow trout will be examined.

Catch estimates were calculated for rainbow trout in the FAF of WA (Table 2). Estimates were provided in terms of numbers of fish captured and released. The average weight of just-legal sized trout (assumed to be 450 g) was used to calculate total tonnage. A high degree of catch-and-release of rainbow trout occurs in WA and several reasons for releasing fish were provided by respondents, not just that fish were below legal size. For the purposes of calculating total landings, the weight of a released fish was estimated as 250 g, 50% below the average weight at legal size. It should be noted that due to the catch-and-release ethos, this weight may under-estimate trout landings. The large estimates of standard deviation reflect the wide range of skill that recreational fishers possess in relation to trout capture rates (CPUE).

Table 2.: Estimates of the total number and weight of rainbow trout captured (retained and released) in the FAF during season 1998/99. [Estimate (1 standard error)].

Variable	**Rainbow trout**
Numbers Retained	7 998.8 (702.98)
Numbers Released	14 417.8 (1 779.70)
Total Numbers	22 416.61 (2 482.68)
Weight Retained (kg)	3 599.5 (316.34)
Weight Released (kg)	3 244.0 (400.43)
Total Weight (kg)	6 843.5 (716.77)

Yield per Recruit Stocked

As WA has very few areas of water amenable to rainbow trout reproduction (e.g. few areas with gravels suitable for redd construction), all trout captured in WA are stocked by FWA and an estimate of yield-per-recruit-stocked (YPRS) can be estimated. YPRS can be calculated by dividing the estimated number of trout captured by the number of trout stocked (Table 3).

It should be noted that several assumptions were made, which were;

1. That fry would take one full year to grow into legal size (30 cm TL). Therefore, that fry stocked in 1998 were available in 1999;
2. That yearlings and older fish stocked prior to the season would be of a legal size during the season and available for capture.

Assuming the above, YPRS was approximately 8.1 ± 0.90 % of all stocked *O.mykiss*.

Table 3. : Comparison of the Number of trout stocked and captured in the Freshwater Angling Fishery, 1998/99.

	Rainbow trout
Units Stocked	
- Fry (1998)	255 000
- Yearlings (1999)	20 000
- Ex-broodstock (1999)	1 500
Total Stocked	276 500
Total Number Captured (± 1 standard error)	22 416.6 (2 482.68)
Catch Rate % (± 1 standard error)	8.11 (0.898)

The yield-per recruit estimates may be negatively biased for at least three reasons. Firstly, some fish will survive several seasons and not be captured, becoming available for subsequent fishing seasons. Secondly, as the fishery is broken up into a large number (approximately 30) of discrete fishing areas, not all areas received the same amount of effort and thus fish are more likely to survive in areas of low effort. Finally, the catchability of the two species of trout varies dramatically and is heavily dependent on angler experience and skill.

However, due to the high level of catch-and-release philosophy practised in the fishery, the results may also have a degree of positive bias, especially considering that a similar number of fish are captured-and-released as retained. That is, the results could be influenced by a single fish being captured and released several times within the same season. Research into the catchability and survival of released fishes should be considered.

Although 8.1% is a good rate of return relative to mark-recapture studies, the question raised by the results is; do all age classes of trout contribute equally to the fishery?

Potential Impacts of Red-fin Perch on Trout: A Vivid Example.

Although little scientific data is available for the impacts of red-fin on trout in Western Australia, observations by members of local trout clubs and Fisheries WA staff during trout stocking operations indicate that red-fin perch (*Perca fluviatilis*) are a major predator of trout fry. For example, one trout club will not stock a particular club dam with trout of any size due to the resident red-fin population.

The best evidence for trout predation by red-fin comes from WATFAA (Western Australian Trout & Freshwater Angling Association) catch records for a large irrigation dam in the south west. Waroona Dam and its associated lake (Lake Navarino) form an extensive dam (200 ha) in the Harvey River Catchment. Waroona Dam is the first public access irrigation dam south of Perth (approximately 1.5 hours by road). Waroona Dam has been consistently stocked for 30 years by FWA, mainly with rainbow trout fry. Records kept by the club indicate a relatively high catch rate up until 1981, the year when red-fin were first reported from the dam (Figure 1). Red-fin were illegally stocked by a member of the public, apparently to provide more sport-fish in the dam (*pers. comm.*). After a few years of good trout catches, the number of trout captured declined severely to very low levels. Recently, the trout catches and fishing effort on the dam have increased. This is due to the stocking of yearling trout and ex-broodstock, plus publicity surrounding the stocking, resulting in higher catches and effort.

Although the rainbow trout catch rates at Waroona Dam are indicative of a (high) level of impact imposed by red-fin, the data lack the division of the trout catch into stocking sizes. That is, how much of the catch is contributed by trout stocked as fry and yearlings? Obviously, this is an important research and management issue that should be given a high priority, especially given the impacts of red-fin on small stages of trout recorded in other states (Moy 1974; Baxter et al. 1985). Further, as trout and red-fin are predators, there may be competitive processes occurring, not just predation.

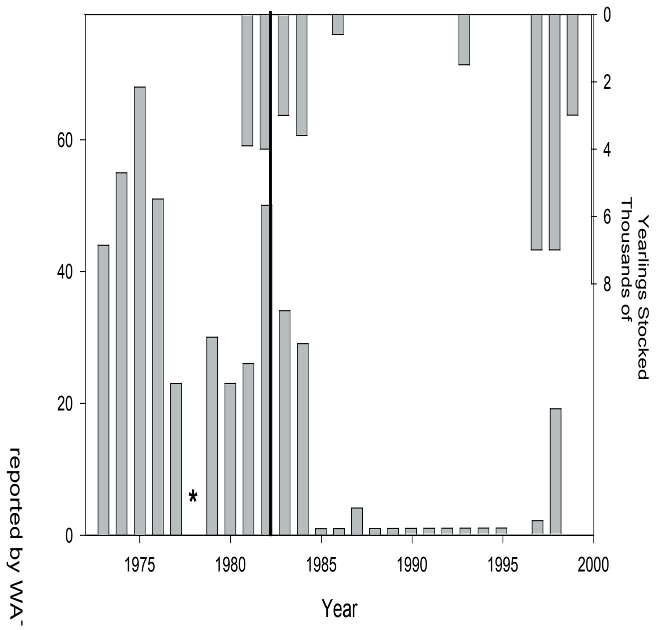

Figure 1: Western Australian Trout and Freshwater Angling Association (WATFAA) catches of rainbow trout from Waroona Dam and FWA fry and yearling rainbow trout stocking, 1973 – 1999. Vertical line represents the year that red-fin perch were illegally stocked into Waroona Dam. [* No club records available]

Theoretical Cost-Benefits of Producing and Stocking Trout of Different Ages and Sizes.

Throughout the world, rainbow trout are stocked at a range of age and sizes. Typically, trout fry and fingerlings (up to 5 cm) are produced and stocked for a variety of reasons including;

- Ability to produce large numbers in a limited space;
- Relatively cheaper to move and stock as more small units can be transported than large units;
- Risk of failure in the production system is minimised as the duration in the hatchery is reduced;
- Relatively cheap as total food requirements are much lower than for holding and growing fish for a long period of time.

As a result, many Agencies throughout the world and in Australia mainly stock trout as fry. However, as fry are relatively small, the predation rate is likely to be much higher than compared to larger trout (Baxter et al. 1985). Thus, in areas where high numbers of predators exist, better survival of trout may result from stocking trout of larger sizes (Moy 1974), for example as yearlings.

However, there are extra costs associated with the production of larger and older trout. These include;

- Increased food costs;
- Increased stocking costs as fewer yearlings can be moved and stocked per trip than fry;
- Increased labour costs; and
- Increased costs to the hatchery due to husbandry of the fish (e.g. use of evaporative cooling towers).

Although the allocation of costs of trout of different ages/stages at the SWFRAC is difficult to analyse due to the multi-purpose nature of the facility (Recreational Fishing, Aquaculture Development, (Native) Fish and Fish Habitat Research), a cost-benefit analysis can be performed based on feeding and stocking costs to provide an estimate of the higher survivorship required of yearling trout compared to fry, to maintain cost-neutrality of operations.

The costs of producing and stocking fish of different age classes will obviously vary considerably. For instance, fry are held for a period of approximately 60 days and consume relatively less food than ex-broodstock that are held for approximately 3 years. Although labour, power and associated running costs of the SWFRAC are difficult to assign to individual life stages of trout, two components, food costs and stocking costs, can be calculated. These calculations, based on information and data supplied by the SWFRAC Manager for 1999/2000, are provided in table 4.

Table 4: Breakdown of Feeding and Transport Costs for fish of each stage produced at the SWFRAC. Calculations of Fry-Units use the costs of producing and stocking fry as 1.00. Note that labour costs, stripping costs and other costs attributed to the running of the SWFRAC are not taken into account.

Stage	Fry	Yearling
Duration at SWFRAC	60 Days	250 Days
Food Cost per Unit (# fry Equivalents)	$ 0.00104 (1.00)	$ 0.0725 (69.71)
Costs per Unit Stocked (# fry Equivalents)	$ 0.0071 (1.00)	$ 0.0672 (9.47)
Overall Costs per Unit	$ 0.0081	$ 0.1397
Overall # of Fry Units	1.00	17.24

The feed costs of producing a yearling rainbow trout are approximately 70 times that required to produce a fry (Table 4). Further, more fry can be transported in the current transporter than yearlings and thus transport costs per fry are much less than per yearling. However, as more fry are produced at the SWFRAC and fry are more readily transported than yearlings, there are more stocking trips and thus higher road distances are travelled. Overall, taking into account feed costs and stocking costs, it costs 17.24 times more to produce and stock a rainbow trout yearling than a rainbow trout fry. Therefore, the break-even point between fry and yearlings would require a survival rate of yearlings to be at least 17.24 times higher than that of fry, (accepting that labour and some other operating costs are not included in the current calculations).

It is generally accepted that the young stages of aquatic species have much higher mortality rates than older conspecifics due to the small sizes of young stages. This is the same for rainbow trout and salmonids in general. For example, Cartwright et al. (1995) estimated that between 5 – 34% of sockeye salmon (*Oncorhynchus nerka*) fry survive one month after stocking in a large lake system, while Jones et al. (1995) estimated mortality rates approaching 100% for eggs and fry of lake trout (*Salvelinus namaycush*) in areas of high densities of predatory fishes. Due to likely differences in predation rates between fry and yearling trout, the question to ask is how much higher is yearling survival compared to fry survival, especially in WA?

The available literature on the comparative success of fry and yearling stocking of rainbow trout and trout in general, is limited. Further, the life-stage terminology often differs from that used in Western Australia. For example, a 'fingerling' trout in Western Australia is approximately 60 – 90 days old, whereas fingerlings may be up to 9 months old when stocked in the Great Lakes (e.g. Hansen et al. 1990), similar to the ages of "yearlings" in Western Australia. Yearlings in many Northern Hemisphere examples are approximately 14 months old (Hoff and Newman 1995), considerably older than WA yearlings. As a consequence, fingerlings and yearlings in Northern Hemisphere studies are likely to be larger than West Australian fingerlings and yearlings, and thus have different rates of survival. For example, fingerlings of lake trout stocked by Hoff and Newman (1995) were between 135 – 140 mm total length, a similar size to small yearlings in Western Australia. (Yearlings used by Hoff and Newman (1995) were between 208 – 229 mm total length, similar to large yearlings produced in WA). It should be noted that fingerlings are not usually stocked in WA as this would involve potential stress to fish during harvesting, transport and stocking in summer.

With these points in mind, a study by Hansen et al. (1990) found that the survival rate of yearling rainbow trout was 24.5 - 25.5 times greater than for rainbow trout fingerlings. However, the same study detected much lower comparative rates of yearling:fingerling survival in other species of trout (*Salmo trutta* (brown trout) - 2.3 times, *Salvenlinus fontinalis* (brook trout) – 2.1 times, *Salvenlinus namaycush* (lake trout) – 2.4 times). Similarly, Hoff and Newman (1995) found that yearling lake trout had a 3 – 4 times better survival than stocked fingerlings. Further, Hoff and Newman (1995) concluded that the costs of each surviving trout in the fishery differ between the life-stage stocked, with yearlings being cheaper than fingerlings (yearlings: $US 33.90 (October 1991) and $US 61.54 (October 1992); fingerlings: $US 47.28 (October 1991) and $US 113.40(October 1992)). This is despite the higher costs of producing and stocking yearling trout as opposed to fingerlings.

The estimates of producing and stocking fry and yearling rainbow trout at the SWFRAC indicated that yearling trout survival needed to be approximately 17.24 times greater than for fry. From the limited evidence available, this figure is below that quoted by Hansen et al. (1990) (24.5 – 25.5 times). Further, although Hoff and Newman (1995) only found a 3 – 4 times increase in survival of yearling lake trout, as compared to fingerling-stocked lake trout, they still determined a significant costs-benefit obtained by stocking fewer, larger yearlings.

Although encouraging, the confounded terminology between Northern Hemisphere studies and the SWFRAC information must be considered before making radical changes in the production and stocking regimes in WA. Further, scientific evaluations of fry versus yearling stockings are rare in the literature and do not exist for WA. Although it is generally accepted that fry will suffer higher mortality rates than yearling fish, the sheer weight of numbers may still make fry stocking a viable, cost-effective strategy in at least some areas. However, this can only be established after a formal, scientific evaluation of fry and yearling stocking in Western Australia, with an associated risk evaluation for the longer period of rearing yearling trout in an intensive culture situation. An FRDC proposal is being prepared to evaluate such a project.

Literature Cited

Baxter, A.F., S.L. Vallis and D.J. Hume (1985). “The predation of recently released rainbow trout fingerlings (*Salmo gairdneri*) by redfin (*Perca fluviatilis*) in Lake Burrumbeet, October – December 1983”. Arthur Rylah Institute for Environmental Research. Technical Report Series, Number 16.

Cartwright, M.A., D.A. Beauchamp, R.W. Bachmann, J.R. Jones, R.H. Peters and D.M. Soballe (1995). “Investigations of stocked sockeye salmon fry mortality in Margaret Lake, Alaska”. 15th Annual International Symposium of the North American Lake Management Society, Toronto, Canada, 6 –11 November 1995. (summary only).

Chappell, J. (editor) (*in pres*s 2000). “The translocation of brown trout (*Salmo trutta*) and rainbow trout (*Oncorhynchus mykiss*) into and within Western Australia – A discussion paper”. Fisheries WA. Fisheries Management Paper.

Hansen, M.J., P.T. Schultz and B.A. Lasee (1990). “Changes in Wisconsin’s Lake Michigan salmonid sport fishery, 1969-1985”. North American Journal of Fisheries Management. 10. 442-457.

Hoff, M.H. and S.P. Newman (1995). “Comparisons of fingerling and yearling lake trout introductions for establishing an adult population in Pallette Lake, Wisconsin”. North American Journal of Fisheries Management. 15. 871-873.

Jones, M.L., G.W. Eck, D.O. Evans, M.C. Fabrizio, M.H. Hoff, P.L. Hudson, J. Janssen, D. Jude, R. O’Gorman, and J.F. Savino (1995). “Limitations to lake trout (*Salvelinus namaycush*) rehabilitation in the Great Lakes imposed by biotic interactions occurring at early life stages”. Journal of the Great Lakes Research. 21 (suppl. 1). 505-517.

Molony, B.W. and N. Morrissy (2000). “Unusual fishery has an interesting history”. Western Fisheries. Autumn 2000. 38-40.

Morgan, D.L., H.S. Gill and I.C. Potter (1998). “Distribution, identification and biology of freshwater fishes in south-western Australia”. Records of the Western Australian Museum. Supplement 56. 1-97.

Moy, D.R. (1974). “Survival of trout liberated into Barker’s Creek Reservoir, Harcourt”. Fisheries and Wildlife Division, Victoria. Freshwater Fish Newsletter. 6. 19-20.

THEME 5. Questions & Answers

Bob Farragher to Richard Tilzey

Question

You missed out one of the sets of stocking figures in 1995 (another 200,000 rainbow trout). Also, NSW Fisheries is monitoring the Lake Eucumbene fishery (catches) during the Snowy River trout festival, first week of November.

Answer

It's still a hit-and-miss operation. Needs a lot of study to determine differences between natural recruitment and stock enhancement. There needs to be a dedicated scientist monitoring the Lake Eucumbene fishery.

Andrew Sanger (comment)

Question

There are four–five other impoundment fisheries in a similar situation to that of Lake Eucumbene, where a dedicated biologist could be employed. I am curious about whether a large pulse stocking every few years, or a smaller annual stocking is preferable for Eucumbene. I would think that the lake can handle an annual stocking.

Answer

(Richard Tilzey). *Daphnia* selection is privotal to the rainbow trout population, for all age classes. Therefore, [the rainbow trout] population level depends on the *Daphnia* population [level]. So if you have continued stocking, there is too much pressure on the *Daphnia* population and trout condition becomes poor. If you decrease stocking, trout condition and weight improves.

Andrew Sanger to Richard Tilzey

Question

Is there a good predictor of planktonic food supply each year? — as in Tasmanian lakes there was large variability in planktonic food from year to year.

Answer

A fair question. The rise and fall of the lake level is also important. I found that it had more effect on the brown trout populaton in Lake Eucumbene, but not on rainbows which are planktonic feeders.

Charles Todd to Kylie Hall

Question

Some of the issues in Lake Eucumbene may be relevant to Lake Mokoan. For example, could the change in fish growth that you observed in Lake Mokoan be from overstocking?

Answer

Yes, it probably could be a factor — one of the hypotheses we're currently looking at. [I am] hesitant to conclude any one reason until further investigations are completed. Creel study data will enable us to look at this hypothesis further.

Alan Baxter (comment on stocking rates): 8,000 per hectare; 20,000 golden perch per annum.

Paul Brown to Richard Tilzey

Question

Referring to the graphs showing length frequency of trout. Could the variability also be due to growth variability (and not just to recruitment variability)?

Answer

Not really. Whereas there was a continuous decline in brown trout growth over the study period, there was no trend for rainbows. In flood years, the growth of both species improved.

Patrick Coutin to Kylie Hall

Question

Has the stocking of golden perch contributed to the disappearance of redfin perch in Lake Mokoan? And is control of feral species another objective of stocking native species?

Answer

The stocking of golden perch has most likely contributed to the decline of redfin (more by replacement than predation or exclusion), although the redfin virus has surely had a major impact also. [Control of feral species was] not a defined objective. Redfin was a prized angling species prior to the introduction of golden perch but now golden perch are targeted by anglers instead.

Richard Tilzey (comment)

Redfin are more of a sight feeder than golden perch, and golden perch may do better in turbid water.

Paul Brown (comment)

In the early days of the redfin perch dominated fishery, the water in Lake Mokoan was reputed to be much clearer than it now is.

John Koehn to panel

Question

Does anyone have information on stocking success in rivers? All the talks so far have been on stocking into impoundments.

Answer
**[General discussion from the floor. I missed the points]

John Harris (comment)

There are a couple of examples in NSW of assessments of the results from riverine stocking. The first is from 100 km of the Murrumbidgee near Narrandera where there was intensive stocking of native fish but resources for continued monitoring were lacking. The second is from the Manning River which was stocked with locally sourced Australian bass in response to evidence of repeated recruitment failures. The results from this river showed that propagated fish contributed to thye population and there was some stock enhancement.

Alf Hogan (comment)

In Queensland rivers there has been improvement over the last ten years — a lot more recreational fishers stay in Queensland. Greater barramundi numbers from **??..........***

Andrew Sanger (comment)

I agree that there have been improvements in some waterways, but the difficulty in a natural system is in determining the difference between stocked and naturally reproducing recruits.

Wayne Fulton (comment)

[I can give you a] Tasmanian example. A study by Nicholls in the 1950s looked at trout populations in several streams after heavy stocking. The study was repeated in the 1980s by the Inland Fisheries Commission with no stocking in the intervening period. The trout populations were found to be significantly higher in the latter study. Aerial photos showed that the habitat had changed in this period.

Brendon Ebner (comment)

A couple of lakes in the Murray-Darling Basin are quite turbid yet they are dominated by redfin perch. The redfin have been there for some time. Golden perch are also present in the lakes.

Paul Brown (comment)

Yes, I agree with Brendon except that in most of these lakes intensive stock enhancement with a turbid water specialist (golden perch) has not been tried. If it is, we may find that golden perch [will] replace redfin.

John Koehn to Kylie Hall

Question
Are you sure there is no natural recruitment?

Answer
No, I'm not sure yet: our study has not progressed enough. Natural recruitment of Murray cod is evidenced from ageing year classes.

Alf Hogan to Kylie Hall (comment)

Management of put-and-take fisheries is just as important as it is in non-impoundment fisheries. One example is to manage by bag limits.

Alan Baxter (prompted by Andrew Sanger)

Redfin predation on trout: fish size at stocking (trout), and water temperature, are the critical factors. Example of New England trout stocks. Additional comment from ***Brett Moloney*** *on water temperature tolerance of trout.* ***Alan Baxter*** *concludes that "there is no such thing as a temperature tolerant trout".*

John Harris (comment)

We completed a stocking experiment comparing survival over one year of both larvae and juveniles of golden perch and silver perch stocked into a series of impoundments. There was good survival of fish stocked as juveniles, but none from larval stocking. Survival of juveniles was reasonable in redfin perch-dominated waters, especially if there was reasonable cover available.

Steven Eddy to Kylie

Lake Purrumbete in Victoria has a big redfin perch population — introduced in early 1980s. [This population] has led to the decline of the rainbow trout population. Recently, brown trout were introduced to the lake, and creel surveys are suggesting that redfin numbers are declining as brown trout numbers are increasing. Eighthy-three thousand rainbow trout fingerlings were stocked last year as part of a three-year stocking program.

Session 6

MANAGEMENT IMPLICATIONS

Sound Policy And Rules - Central To Any Marine Stock Enhancement Decision Process.

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Abstract

Over recent years, the yield from the world's wild marine fisheries has either remained relatively constant or declined in the face of the continued growth of the human population. Factors such as the associated increase in the demand for fishery products, both as food for human consumption, and as a recreational amenity, and the damage caused to fish habitats as a result of anthropomorphic influences have all contributed to this decline. Many would assert that this situation has occurred because of the failure of "traditional" fisheries management methods. As a consequence "stock enhancement" is now being viewed by some as a worthwhile alternative management tool. If this is the case, how do we decide whether or not to use it? First we need to develop an overriding policy in relation to the use of stock enhancement. Key elements should include very clear and explicit management objectives, and the development of a set of rules to facilitate pre-stocking evaluation. Important issues that need consideration in the development of these guidelines are discussed. The success of such a process is also dependent on sound underlying advice, appropriate risk assessment, cost-benefit analysis and adequate community consultation. If this management tool is to be trialed, then accepted culture and release protocols must be followed, and performance measured and post-stocking outcomes evaluated and where appropriate used to modify the approach.

Introduction

Over recent years, the yield from the world's wild marine fisheries has either remained relatively constant or declined in the face of continued growth of the human population (Larkin 1991; Kent et al. 1995; Fischer et al. 1997; Bartley 1999). Factors such as overfishing related to the increase in the demand for fishery products, both as food for human consumption (NMFS 1995) and as a recreational amenity (McEchron and Daniels 1995), and the damage caused to fish habitats as a result of anthropogenic influences such as water quality and pollution (Hendricks 1995), have all contributed to this decline in yield.

Many would assert that this situation has occurred because in many instances the use of "traditional" fisheries management methods alone have failed (Pitcher et al. 1998) These methods have principally focused on constraining the catch. They are usually classified as either input (include limiting access, spatial and temporal closures, size limits and the like) or output controls (include quotas and bag limits).

Increasingly it seems internationally, hatchery based stock enhancement is being viewed as a potentially worthwhile alternative management tool (Grimes 1998). A similar view is being expressed in Western Australia (WA). Since a major review of the management of recreational fisheries in the early 1990's identified potential problems for many of the State's coastal marine finfish stocks (RFAC 1990; 1991), stock enhancements has been promoted as a management tool with the potential to maintain and/or restore declining recreational catch rates in the face of increasing recreational fishing pressure (Lenanton et al. 1999).

Since about the mid-1990's however, international researchers have increasingly advocated a more responsible approach to the development, evaluation and management of stock enhancement (Blankership and Leber 1995; Hilborn 1999). There are a number of published examples of how stock enhancement programmes have achieved their stated objectives from following this approach (Leber et al. 1998; Leber 1999). It is clear from these examples that we cannot make sensible and defensible decisions in relation to the application of stock enhancement without an overriding policy. The aim of this paper is to briefly review marine stock enhancement initiatives in WA since the recreational reviews of the early 1990's. These outcomes, together with the published information from the international literature, and issues of concern raised during extensive discussions with WA stakeholders will then be used as a basis for the development of a policy and decision rules appropriate for Australian circumstances. However a clear understanding of what is meant by "stock enhancement" is an essential prerequisite.

Origins and status

Marine stock enhancement has been practiced worldwide for more than 100 years (Blaxter 2000). However the idea that marine fisheries cultivation expertise be more closely integrated with traditional management of coastal wild fisheries did not gain real prominence until the late 1980's (Troadec and Lockwood 1991), coinciding with the development of extensive aquaculture (Troadic 1991). Indeed the "science" of marine stock enhancement allegedly began only about 10 years ago (Leber 1999). Stocking has been defined as the "repeated injection of fish (or any organism) into an ecosystem from one external to it" (Coates 1998). It follows that marine stock enhancement is usually thought of as the release of hatchery reared individuals into the wild fishery to increase the harvested biomass of a target species. In the absence of any accepted standard set of terminology for the various forms of "stock enhancement", the following set of definitions proposed by Bannister (1991) have been used in this paper:

Ranching - Identifiable stock released with the intention of being harvested by the releasing agency.

Enhancement - Stock released for the public good; includes:

Restocking - compensation for depletion of natural resources.

Augmentation - compensation for loss of habitat (e.g. salmon breeding sites).

Addition - genuine addition of new stock.

Marine stock enhancement in WA

There have been a number of marine stock enhancement initiatives undertaken in Western Australia (Table 1) since the recreational review of the early 1990's identified stock enhancement as a possible strategy to maintain and enhance the quality of recreational fishing in that state (RFAC 1990; 1991). Throughout this ten year period, our knowledge and understanding of the culture of coastal marine species, such as pink snapper (Pagrus auratus), black bream (Acanthopagrus butcheri) and King George whiting (Sillaginoides punctatus) has been advanced considerably (Jenkins 1999). However, in the absence of a guiding policy, too little has been learnt from the stocking exercises, and considerable resources have also been spent on a consultative process that lacked focus. With one or two exceptions, the approach to date in WA has simply continued the world-wide trend of the last 100 years of a marked lack of evaluation of stock enhancement potential (Leber 1999). This is in stark contrast to the related area of translocation, where the early development of a policy in WA (Table 1) has greatly aided the facilitation of the resolution of issues that have arisen in this area.

Key elements of an overriding policy.

Although Cadwallader (1999) has proposed a decision-making process for the enhancement of marine finfish stocks in Queensland, and trials have already been conducted in Queensland, New South Wales and WA (Butcher et al. 2000; Fielder 1999; Dibden et al. in press), national policy has yet to be developed. The development of a national stock enhancement policy that will enable sensible decisions to be made in relation to the use of such a tool must involve serious consideration of a number of key elements. They include very clear and explicit management objectives (Howell 1998; Welcomme 1998; Cowx 1998), and the development of a set of rules or guidelines to facilitate pre-stocking evaluation (Coates 1998; Hilborn 1999). Many issues must be addressed in the development of this process. The most important ones will be reviewed in more detail below. The success of such a process is also heavily dependent on sound underlying advice, particularly in relation to the underlying biological and ecological processes (Hilborn 1999; Blaxter 2000) and the cost and benefits of using the this management tool (Hilborn 1998; Langton and Wilson 1998). If a decision is made to trial stock enhancement, the exercise should follow accepted culture and release protocols (Blankenship and Leber 1995), performance must be measured, and post-stocking outcomes evaluated (Leber 1999). Where appropriate, development of explicit targets (and limits) for each decision in the evaluation process, together with the determination of the associated level of risk (Gray 1998) must also be an important component of this decision making process.

Table 1. Marine stock enhancement initiatives undertaken in Western Australia since the Recreational Fishing Review of the early 1990's

Year	Initiative	Outcome
1990/1	Recreational Fishing Review	Framework for more comprehensive and broadly representative future management
1994	Translocation Seminar	Translocation Policy
1995	Culture of black bream perfected (Fremantle Maritime Centre)	Stocking of black bream into inland impoundments
1995	Release of cultured silver bream into sea	?
1995	Small scale black bream trial - Swan River	Stocked fish entered the recreational fishery. [Lenanton et al. (1999); Dibden et al. (in press)]
1997	National Fishcare Grant (black bream) Peel Harvey community group	?
1997	Larger release: black bream Swan River and coastal marinas	?
1998/99	Black bream Survival/ Revival Program Swan River (Recfishwest)	?
1999	Pink snapper - Cockburn Sound	Some recoveries from recreational fishers?
2000/01	Black bream - Blackwood River	commenced
2001/02	Shark Bay snapper re-stocking (Eastern Gulf closed 1998) proposed	?
2001/02	King George whiting - Leschenault Estuary being discussed 1	

Management Objectives

In the broadest sense, objectives can be developed as a consequence of one, or some combination of, biological, social, economic or political need (Bartley 1999). Most often, the need is biological i.e. to rebuild a depleted stock, with consequential economic, social and political benefits as an anticipated outcome. Thus, for example, it is unlikely that in the marine environment, the objective would be to create an entirely new stock. However this may be desirable under circumstances where irreversible anthropogenic influences have resulted in habitats being rendered unsuitable for the maintenance of historical ecological processes and associated fish populations (Radouski and Loftus 1995). Here the introduction (addition) of a cultured stock and the establishment of a new ecological balance simply for human benefit is possible. The more likely objective is to produce a permanent increase in the sustainable yield from an existing population. In this situation, there need to be objectives set that specify particular performance from the stock i.e. a target catch and/or effort, linked to a measure of the performance of the fishery communicated by the fishers, such as a catch rate target. Both of the above scenarios could provide new/enhanced investment opportunities for stakeholders (Hale et al. 1995; Bartley 1999), which can generate positive social change (Shafland 1995), and engender economic (Kitada 1999; Liao 1999) and potentially political benefit. At the other end of the spectrum, stock enhancement could be contemplated solely for political reasons i.e. to avoid painful decisions related to wild stock management, or to promote the public profile of an agency (Hilborn 1998).

Issues that need consideration prior to any pre-stocking evaluation

Assessment of the status of the stock, cause of stock decline.

It is important to have a good understanding of the status of the stock prior to enhancement in order to quantify the impact of such an initiative. Ideally, pre-stocking surveys should be aimed at determining values such as the relative abundance of the target species, the essential habitat of juveniles, and the density of juveniles occupying their preferred habitat. Further, are the causes of stock decline clearly understood? Causes can be related to fishing (Stoner and Glazer 1998), or factors independent of fishing such as pollution or habitat destruction, or some combination of the two (Cowx 1998). Many problems experienced with marine fisheries throughout the world are attributed to overfishing. This occurs either because of a genuine lack of understanding of the impacts of fishing (e.g. indirect fishing effects) and thus inappropriate management action, or the deliberate non-compliance with established rules and regulations. Fishing activities can also cause stock decline through damage to essential fish habitats i.e. trawling. Factors independent of fishing comprise a large range of anthropogenic processes. They can also comprise natural environmental process such as long-term climate change (e.g. global warming, El Nino, La Nina), or shorter-term impacts such as variations in ocean current etc.

Capacity to alleviate impacts of threatening processes.

Without the above knowledge, threatening processes cannot be identified, and necessary measures to alleviate impacts cannot be implemented. In the case of fishing, gear may need to be modified or areas closed to fishing to minimize damage to habitat and by-catch. Habitat restoration may also need to be undertaken. However, one process not normally considered as "threatening" is the investment in fishing-dependent business enterprises. Businesses such as holiday resorts and charter fishing companies are often heavily dependent on sustainable fishing opportunities for their survival. In the initial phase of the establishment of such businesses, there are rarely any questions asked about the ability of the yield from the fishery to guarantee the ongoing viability of the business. When such enterprises expand, or stocks and thus yields decline, it is often the proprietors of such businesses that exert political pressure for increased yields from the depleted stocks to at least historical levels, or the creation of alternative fishing opportunities. This problem is likely to increase as the fishing population continues to become more mobile, and thus more willing to travel to remote fishing destinations.

Due consideration of "traditional" management options.

In order that depleted or declining fisheries recover, there is a range of "traditional" management strategies that should be considered, either as an alternative to, or for use in conjunction with stock enhancement. They include the conventional input and output controls. In addition, there is scope to redirect targeted effort away from depleted target species. Catch shares of different user groups can be adjusted to favour one or other group. Regional shifts in the relative distribution of fishing effort are also a possibility, as is implementing changes in the mindset of fishers (i.e.promotion and evaluation of catch and release). Nevertheless, however successful the stocking exercise is judged to be in affecting a stock recovery, it is rarely a long-term solution. There must always be a strong underlying management plan that provides the means of guaranteeing ongoing sustainability. Such a plan must also have the capacity to deal with issues such as increased numbers of anglers attracted to enhanced stocks.

Pre-stocking evaluation guidelines

If, as a result of thorough consideration of the above issues, stock enhancement is being contemplated, then there is a need to conduct a thorough pre-stocking evaluation. Issues that need consideration in the development of guidelines include:

Suitability of the candidate species and the "receiving" habitat.

Is the species in question a suitable candidate for stock enhancement. Ideally, in the marine environment, discrete stocks or assemblages with a well-defined and restricted coastal distribution are preferred candidates for restocking. Desirable attributes also include the ability to be readily cultured, physiologically robust and tolerant of the physical characteristics of the receiving water body, and with a high degree of opportunism with respect to habitat and dietary requirements. Further, are the characteristics of the water-body into which the fish are to be stocked suitable? Water quality must be of a high standard. Stocks or assemblages confined to enclosed or semi-enclosed water-bodies with a relatively stable physical environment offer the best opportunity for successful marine stock enhancement. They also provide the best locations for the evaluation of stocking trials.

Limitations of the natural system.

Carrying capacity of the receiving environment is a key issue, especially where habitat destruction or modification is identified (Bowles 1995). Does enhancement result in a net gain in population size and ultimately catch beyond historical levels? For this to happen, the trophic capacity of the habitat utilised by the stock and its competitors must be under-utilised. Most marine fish display strong density-dependent competition, with the consequence that recruitment is largely independent of breeding stock size beyond a certain stock size. Thus the addition of recruits may not result in an increase in overall population size; they may simply displace wild stock, or be out-competed by wild stock.

Other likely ecological consequences.

This is a significant issue that is now beginning to receive the attention it deserves during both pre-, and post-stocking evaluation. Included are threats that are currently major concerns of any stocking proposal. They are issues related to carrying capacity, including the displacement of other local species, and other changes to the biology and ecology of local species, either through predation or competition (Wahl et al. 1995), the spread of disease (Cowx 1998), or through the genetic consequences of the culture and introduction of additional recruits (Bartley et al. 1995; Cross 1999).

Does stocking comply with the provisions of existing legislation?

State Fisheries and relevant Commonwealth legislation provides a legal framework for the administration of numerous management plans, and ESD provisions. International conventions also bind management agencies to prescribed standards in relation to the exploitation of marine fauna; e.g. the Shark Bay World Heritage Area . In this regard how should the introduction of cultured individuals be viewed?

Consequences of stocking for other users.

The users of fishery resources can be broadly classified as extractive and non-extractive. The former comprises commercial and recreational fishers, the latter divers and others who derive pleasure from viewing and interacting with the resource, together with those individuals who like to know that diverse fish communities area are being conserved, but do not necessarily seek to interact with these communities. If introductions by, for example the recreational sector aimed at increasing the population size of a target species, result in a reduction in the abundance of the non-target species, the needs of non-extractive users are clearly being compromised. And what of the broader socio-economic consequences? Successful stock enhancement may attract greater numbers of fishers to a regional centre, boosting tourism revenue, but possibly to the detriment of the lifestyle of residents.

Are costs and benefits well understood?

In very simple economic terms, the "benefit" of enhancement is the value of net production, less the cost of production or some previously agreed cost (Hilborn 1998; Langton and Wilson 1998). A critical factor affecting the value of net production is the ultimate price obtained for the product, while a critical issue in the cost of production is the determination of the optimum size of release and number surviving (Tsukamoto et al. 1999). There have been a number of bio-economic models developed over recent years that have attempted to evaluate the economic benefit derived from the enhancement of a range of species under a variety of harvest strategies (Moksness et al. 1998; Wilson et al. 1998). However, in order to understand the broader community benefit, the "economic" assessment needs to be integrated into a process that also incorporates assessment of social consequences (Hallerstvedt 1999). Further, most such analyses measure the "present-time" benefit. There is far more uncertainty attempting to determine future benefits, because the value of innovation, which is a key outcome of the process of enhancement, is impossible to predict (Hallerstvedt 1999).

Sound underlying advice.

Advice to managers needs to be sound, balanced and independent. Historically scientific advice has always been an essential requirement of any decision-making process. More recently, stakeholder's views have also been sought, as the stakeholders and the wider community are the main beneficiaries of any fisheries management changes. Before the advent of the internet, worthwhile scientific advice was mostly based on material in peer-reviewed journals. With the advent of universal access to the internet has come an alternative source of information, with everyone having access to web-sites that report achievements in a vast array of scientific disciplines, including stock enhancement. Many sites simply contain personal opinions. Thus when accessing this advice, care needs to be taken to ensure the information is still from peer-reviewed sources, and not simply from a topical website.

Stocking protocols and post-stocking evaluation.

Once a decision has been made to embark upon a marine stock enhancement program, sound stocking and evaluation protocols should be observed. A good understanding of the biology of the species is needed to ensure the effectiveness of those protocols.

Culture and release protocols.
There are a number of physiological and behavioral issues related to the culture environment that may affect the survival of cultured fish. Water temperature, stocking density, diet, substratum type and encounters with predators will influence ecophysiological and/or behavioral adaptation (Tanaka et al. 1998; Olla et al. 1998). Modification to growth rates, feeding behavior, sex differentiation (ratio), morphology, developmental endocrinology and predator avoidance behavior have also been observed as a consequence of the culture and rearing process.

Release strategies are also important in determining survival of stocked fish. Size at release, release habitat and release season are all important determinants of survival. Leber (1999) advocates an experimental approach to evaluate pilot hatchery releases, where adaptive management methodology can provide feedback to improve release strategies, while the risk of failure is restricted to sub-populations. Ideally, both experimental design and evaluation of such experiments should incorporate a high degree of statistical rigour, and should be conducted over a finite time-frame.

Genetic issues.
The major issue here is to ensure the "genetic health" of the wildstock is maintained, even though following release, there is likely to have been genetic interaction between reared and wild conspecifics (Cross 1999). Depending on the specific application, there are a range of protocols to follow during the maintenance of broodstock (Cross 1999; 2000). They include the choice of broodstock, adequate pair-mating during breeding, and trying to ensure mortality occurs equally across families, thereby maximising family contribution to each release. It is also worthwhile if both the broodstock, the reared juveniles, and the recipient wild population are monitored both prior to, and subsequent to stocking (Carvalho and Cross 1998).

Disease control.
Juveniles being raised in captivity for release in stock enhancement programs must be as healthy as possible, to maximise survival in the hatchery and in the wild following release, and to prevent disease transmission to wild stock (Coates 1998). In this regard, a range of hatchery and release procedures have been developed to help achieve this objective for warm water marine finfish being grown for stocking purposes (Kennedy et al. 1998).

Benefits to users.
It is vitally important to measure the success of a stock enhancement experiment, not just in terms of the sustainability of the stock and dependent habitat demanded by the broad spectrum of users, but also in terms of the expectations of the extractive user groups. Post-release survival rates of stocked juveniles are clearly linked to their return rate in catch surveys which, if high enough, have the potential to improve the overall catch rates achieved by fishers. The return rates need to be high enough to deliver ongoing and desirable increases in catch rates for these users, that in turn justify the costs. Recent improvements in tagging technology have greatly enhanced the ability of scientists to measure survival. This is no longer restricted to post-settled life history stages. There are recent examples in the literature of the successful marking of both eggs (Jones et al. 1999) and larvae (Palumbi 1999).

Targets, limits and risk assessment.

The ultimate decision about how to proceed needs the approval of management. In this regard, there is a very clear need for all decisions to be defensible. Where appropriate, there should be agreed targets in relation to each decision taken in the pre-stocking evaluation process. As outlined above, it is these targets that also form the basis for the evaluation of post-stocking performance. However there is also a need to undertake some risk assessment in order to determine the effect of implementing a range of alternative management options, while acknowledging the uncertainty associated with each of the options. Further, as a result of implementation and post-stocking evaluation, if the risk profile changes (e.g. survival is much higher than anticipated), there needs to be scope to change the approach accordingly. This can best be achieved using "adaptive management" - a continuing assessment process whereby new ideas for refining enhancement are constantly considered and integrated into the management process (Blankenship and Leber 1995).

Conclusions.

Various marine stocking initiatives have been undertaken in WA since marine stock enhancement was identified as a possible management strategy some ten years ago. From both the WA experience, and those in other states, without the development of a national policy and decision guidelines, marine stock enhancement in this country is likely to continue in an unplanned, and largely unevaluated manner, as has been the case for a great many years worldwide. As a consequence, we will learn little from ongoing initiatives, and the "science" of stock enhancement will remain under-developed, able to contribute little to the development and refinement of this potentially valuable management tool. And unlike the more "traditional" management tools, once "enhancement" is well established, it can be stopped, but the impact is essentially irreversible.

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References

Bannister, R.C.A. (1991). Stock enhancement (Workshop Report) ICES Marine Science Symposia 192, 191-192.

Bartley, D.M. (1999). Marine ranching: a global perspective In B.R. Howell, E. Moksness and T. Svasand, (Eds) Stock Enhancement and Sea Ranching (pp. 79 - 89). Fishing News Books, Oxford.

Blankenship, H.L. and K.M. Leber (1995). A responsible approach to marine stock enhancement. American Fisheries Society Symposium 15, 167-175.

Blaxter, J.H.S. (2000). The enhancement of marine fish stocks. Advances in Marine Biology 38, 1-53.

Bowles, E. (1995). Supplementation: Panacea or curse for the recovery of declining fish stocks. American Fisheries Society Symposium 15, 277-283

Butcher, A., J. Bourke and I. Brown (Eds) (2000). The Maroochy Estuary fish stocking program, 1995 - 99. Final Report. Project Report QO 000003. 103 pp. Department of Primary Industries, Queensland.

Cadwallader, P. L. (1999). The decision-making process in relation to the enhancement of catadromous fish stocks in Queensalnd, Australia. In Howell, B. R., Moksness E. and Svasand, T. (Eds) Stock Enhancement and Sea Ranching (pp. 526-536). Fishing News Books, Oxford.

Carvalho, G.R. and T.F. Cross (1998). Enhancing fish production through introductions and stocking: a genetic perspective. In Cowx, T.G. (Ed.) Stocking and Introduction of Fish (pp.338-354), Fishing News Books, Oxford.

Coates, D. (1998). Codes of practice for the stocking and introduction of fish. In Cowx. I. G. (Ed.) Stocking and Introduction of Fish (pp. 383-396), Fishing News Books, Oxford.

Cowx, I.G. (1998). Stocking strategies: Issues and options for future enhancement programs. In Cowx. I.G. (Ed.) Stocking and Introduction of Fish (pp. 1 - 13), Fishing News Books, Oxford.

Cross, T.F. (1999). Genetic considerations in enhancement and ranching of marine and anadromous species. In Howell, B.R., E. Moksness and T. Svasand (Eds) Stock Enahncement and Sea Ranching (pp. 37-48), Fishing News Books, Oxford.

Cross, T.F. (2000). Genetic implications of translocation and stocking of fish species, with particular reference to Western Australia. Aquaculture Research 31, 83-94.

Dibden, C.J., G. Jenkins, G.A. Sarre, R.C.J. Lenanton, and S.G. Ayvazian (In press). The evaluation of a recreational fishing stock enhancement trial of black bream (Acanthopagrus butcheri) in the Swan River, Western Australia. Fisheries Research Report, Fisheries Western Australia.

Fielder, S. (1999). Mulloway tamed. Fisheries NSW Magazine. Spring 1999, 21.

Fischer, J., R.L. Haedrich and P. Sinclair (1997). Inter-ecosystem impacts of forage-fish fisheries. In Forage Fishes In Marine Ecosystems (pp.311-321). Proceedings of the International Symposium on the Role of Forage Fishes in Marine Ecosystems. Alaska Sea Grant College Program Report No. 97-01, University of Alaska Fairbanks.

Gray, J.S. (1998). Risk assessment and management in the exploitation of the seas. In Calow, P. (Ed.) Handbook of Environmental Risk Assessment and Management (pp. 453-474). Blackwell Science, Oxford.

Grimes, C.B. (1998). Marine stock enhancement: sound management or techno-arrogance? Fisheries 23(9), 18-23.

Hale, M.M., J.E. Crumpton and R.J. Schuler (Jr) (1995). From sportfishery bust to commercial fishing boon: A history of the blue tilapia in Florida. American Fisheries Society Symposium 15, 425 - 430.

Hallerstvedt, A. (1999). Management of enhanced stocks: Social, economic and access issues. In Howell, B.R., E. Moksness and T. Svasand (Eds) Stock Enahncement and Sea Ranching (pp. 493-508), Fishing News Books, Oxford.

Hendricks M. (1995). The contribution of hatchery fish to the restoration of American Shad in the Susquehanna River. American Fisheries Society Symposium 15, 329-336.

Hilborn, R. (1998). The economic performance of marine stock enhancement projects. Bulletin of Marine Science 62(2), 661-674.

Hilborn, R. (1999). Confessions of a reformed hatchery-basher. Fisheries 24(5), 30-31.

Howell, B. (1998). Marine fisheries. In Cowx. I.G. (Ed.) Stocking and Introduction of Fish (pp. 289-293), Fishing News Books, Oxford.

Jenkins, G. (1999). Temperate Marine Finfish Aquaculture Development in WA - Useful Lessons for Kimberley Aquaculture? In Lee , C.L. and Harvey D.C. (Eds) Proceedings of the WA Conference on Tropical

Aquaculture in the Kimberley, May 27-29, 1999, Broome, WA. Tropical Aquaculture Association, Broome, Western Australia.

Jones, G.P., M.J. Milicen, M.J. Emsile, and C. Lunow (1999). Self recruitment in a coral reef fish population. Nature 402, 802-804.

Kennedy, S.B., J.W. Tucker (Jr), C.L. Neidig, G.V. Vemeer, V.R. Couper, J.L. Jarrett, and D.G. Sennett. (1998). Bacterial management strategies for stock enhancement of warm water marine fish: A case study with common snook (Centropomus undecimalis). Bulletin of Marine Science 62(2), 573-588.

Kent, D.B., M.A. Drawbridge and R.F. Ford (1995). Accomplishments and roadblocks of a marine stock enhancement program for white seabass in California. American Fisheries Society Symposium 15, 492 - 498.

Lenanton, R.C.J., S.G. Ayvazian, C. Dibden, G. Jenkins and G. Sarre (1999). The use of stock enhancement to improve the catch rates of black bream (Acanthopagrus butcheri Munro) for Western Australian recreational fishers. In Howell, B.R., E. Moksness and T. Svasand (Eds) Stock Enahncement and Sea Ranching (pp. 219-230), Fishing News Books, Oxford.

Moksness, E., R. Stofe and G. van der Meeren (1998). Profitability analysis of sea ranching with atlantic salmon (Salmo salar), arctic charr (Salvelinus alpinus) and european lobster (Homarus gammarus) in Norway. Bulletin of Marine Science 62(2), 689-699.

Kitada, S. (1999). Effectiveness of Japan's stock enhancement programmes. In Howell, B.R., E. Moksness and T. Svasand (Eds) Stock Enahncement and Sea Ranching (pp. 103-131), Fishing News Books, Oxford.

Langton, R.W. and J.A. Wilson (1998). Economic considerations for fish stocking and enhancement In Cowx, I. G. (Ed.) Stocking and Introduction of Fish (pp. 414-421), Fishing News Books, Oxford.

Larkin P.A. (1991). Mariculture and fisheries: future prospects and partnerships. ICES Marine Science Symposium 192, 6-14.

Leber, K.M. (1999). Rationale for an experimental approach to stock enhancement. In Howell, B.R., E. Moksness and T. Svasand (Eds) Stock Enahncement and Sea Ranching (pp. 63-75), Fishing News Books, Oxford.

Liao, T.C. (1999). How can stock enhancement and sea ranching help sustain and increase coastal fisheries? In Howell, B.R., E. Moksness and T. Svasand (Eds) Stock Enahncement and Sea Ranching (pp. 132-150), Fishing News Books, Oxford.

Leber, K.M., N.P. Brennen and S.M. Arce (1998). Recruitment patterns of cultured juvenile Pacific threadfin, Polydactylus sexfilis (Polynemidae), release along sandy marine shores in Hawaii. Bulletin of Marine Science 62(2), 389-408.

McEachron, L.W. and K. Daniels (1995). Red Drum in Texas: a success story in partnership and commitment. Fisheries 20, 6-8.

NMFS (National Marine Fisheries Service) (1995). Status of fishery resources of the northeastern United States. NOAA Tech. Mem. NMFS - NE 108, 140pp.

Olla , B.L., M.W. Davis, and C.H. Ryer (1998). Understanding how the hatchery environment represses or promotes the development of behavioral survival skills. Bulletin of Marine Science 62(2), 531-550.

Palumbi, S.R. (1999). The prodigal fish. Nature 402, 733-735.

Pitcher, T.J., J.B. Hart and D. Pauly (1998). (Eds) Reinventing Fisheries Management, Preface (xxv-xxvi). Kluwer Academic Publishers, Dordrecht.

Radonski, G.C. and A.J. Loftus (1995). Fish genetics, fish hatcheries, wild fish and other fables. American Fisheries Society Symposium 15, 1-4.

Recreational Fisheries Advisory Committee, Western Australia (1990). The future for recreational fishing - issues for community discussion. Fisheries Management Paper 34, 104 pp.

Recreational Fisheries Advisory Committee, Western Australia (1991). The future for recreational fishing - the final report. Fisheries Management Paper 41, 73 pp.

Shafhand, P.L. (1995). Introduction and establishment of a successful butterfly peacock fishery in south-east Florida canals. American Fisheries Society Symposium 15, 443-451.

Stoner, A.W. and R.A. Glazer (1998). Variation in natural mortality: Implications for queen conch stock enhancement. Bulletin of Marine Science 62(2), 427-441.

Tanaka, M., T. Seikai, E. Yamamoto, and S. Furuta (1998). Significance of larval and juvenile ecophysiology for stock enhancement of the Japanese flounder, Paralichthys olivaceus. Bulletin of Marine Science 62(2), 551-571.

Troadec, J.P. (1991). Extensive aquaculture: a future opportunity for increasing fish production and a new field for fishery investigation. ICES Marine Science Symposium 192, 2-5.

Troadec, J.P., and S.J. Lockwood (1991). The Ecology and Management Aspects of Extensive Mariculture: Introduction. ICES Marine Science Symposium 192, 1.

Tsukamoto, K., H. Kuwada, K. Uchida, R. Masuda and Y. Sakakura (1999). Fish quality and stocking effectiveness: behavioural approaches. In Howell, B.R., E. Moksness and T. Svasand (Eds) Stock Enahncement and Sea Ranching (pp. 205-218), Fishing News Books, Oxford.

Wahl, D.H., R.A. Stein and R.D. DeVries (1995). An ecological framework for evaluating the success and effects of stocked fish. American Fisheries Society Symposium 15, 176-192.

Welcomme, R.L. (1998). Evaluation of stocking and introductions as management tools. In Cowx. I. G. (Ed.) Stocking and Introduction of Fish (pp. 397-413), Fishing News Books, Oxford.

Wilson, J.A., R.W. Langton and C. Van Orsdel (1998). A model for the preliminary analysis of the economic feasibility of Atlantic cod enhancement in the Gulf of Maine (USA). Bulletin of Marine Science 62(2), 675-688.

Conservation Stockings – A Manager's Perspective

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Absract only

NSW Fisheries is engaged in two large conservation stocking programs for the endangered species trout cod (Maccullochella macquariensis) and eastern cod (Maccullochella ikei). These programs are quite different in nature. The trout cod program being a long standing joint NSW/Victorian government initiative, with associated research and monitoring components. In contrast, the eastern cod program was initiated by NSW Fisheries but then fairly quickly discontinued. An eastern cod stocking program then commenced as an initiative of a private hatchery with ongoing funding provided by community groups.

The two conservation stocking programs have yielded some valuable lessons for the managers involved. These lessons include:

- *the value of resourcing research and monitoring programs, • a need to think in an evolutionary framework and timescale, while working in a climate of short term corporate imperatives,*
- *the complexities of maintaining appropriate conservation genetic protocols when faced with rudimentary knowledge of both the species biology and the required breeding technologies,*
- *some of the difficulties in delivering the appropriate environmental conditions to assist the successful establishment of new populations or protect remaining wild fish,*
- *the need to recognise and harness the strong community support for the conservation of large charismatic fish, and if possible temper the widely held view that stocking fish is the best answer to most fishery problems,*
- *the pressing need to effectively deal with pressures from uninformed but powerful interest groups.*

A recreational fisheries manager's guide to stock enhancement

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Abstract

Stock enhancement is one of a number of categories of fisheries management tools. It can be used to help solve problems or to create opportunities, but it can present a real challenge for managers. The immediate and tangible nature of measures such as fish stocking and artificial reef programs makes them attractive to many recreational fishers, water and catchment managers, politicians, industry and media stakeholders. The urgency, expectations and passion of proponents often produce an atmosphere in which it can be extremely difficult for all parties to engage in objective discussions with some prospect of satisfactory agreed outcomes. What makes the task even more difficult is the wide range of values that different stakeholders bring to the discussion and must be reconciled if there is to be a universally agreed outcome.

The adoption of a structured approach to analysing the problem to be solved or the opportunity to be created is essential for proposals that are of potentially high cost or other impact on the fisheries and their environment (biological, social and economic). Such an approach must specify the goal, objectives, performance measurement and the manner in which success will be determined. Agreement to proceed must include the allocation of resources required for monitoring and evaluation. The literature offers several guides to problem analysis and protocols for planning and evaluating stock enhancement programs.

What these objective guides and protocols do not address is the crucial initial step of examining the values of the key stakeholders and participants in the process, as well as their expectations and their aspirations for the fishery under consideration. Managers can make their own lives easier, assist those who engage in enhancement discussions and maximise the chance of reaching productive outcomes by:

- *sharing their information (eg on scientific studies, survey results, management policies and principles, previous decisions and rationales);*
- *basing decisions such as stocking numbers on scientific evaluations;*
- *taking the time, initially, to clarify what each party really wants in terms of fishing outcomes (as distinct from inputs or controls);*
- *specifying desired outcomes in more precise terms than "quality", "improved", "restored" etc; and*
- *given the arbitrary nature of many enhancement actions, knowing where and when to compromise, how much to give – and being prepared to do so.*

Introduction

The management of recreational stock enhancements is generally about manipulation of biological systems, in a politicised atmosphere, to meet social goals, according to scientific and economic principles that different participants endorse and observe to varying degrees. Given the challenge that this represents to managers, it should come as no surprise that the same tool that makes it possible for them to deliver great benefits to recreational fishers also provides numerous major and ongoing problems. It is frequently said that the most common fault of fisheries enhancement programs is the failure to properly define management objectives. For example, Cowx (1998a) refers to stocking as "*a much used, but all too often abused, tool in fisheries management*", stemming from the assumption that stocking invariably increases yields. Fuzzy issue definition, poor planning and evaluation, inadequate resourcing and failure to consider "*the wider political, social and economic issues associated with fisheries management*" commonly account for the failure of stocking programs.

On the related subject of monitoring and evaluation, Hilborn (1999) points to the failure of marine stocking programs to demonstrate whether natural production is enhanced or replaced by stocking. A similar observation can be made about the success of artificial reef programs aimed at enhancing production of wild fish populations in marine waters. Reviews of the reported performance of artificial reefs have repeatedly concluded that clear evidence of increased fish production is lacking. One such review (Grossman *et al.* 1997) found that reef construction may harm reef fish populations and that there is little evidence that insufficient reef habitat is limiting reef fish populations. The key point to emerge from these examples is the need to first examine "the problem" – in these cases, limited fish populations – before accepting what are proposed as obvious solutions and leaping into costly programs impacting on natural systems.

Management considerations

Stock enhancement is one of a number of categories of fisheries management tools. It can be used to help address a range of issues that fall into two broad categories of solving problems creating opportunities. Previous papers have outlined and provided many examples of this range which include:

- introduction of new species to create new fisheries, as food for target species or as predators of unwanted species;
- stocking to enhance, maintain or restore populations targeted by recreational fishers;
- habitat enhancement to restore or improve natural habitat, enhance fish production or attract fish;
- removal of pest species and unwanted predators;
- enhancement, reduction or overall control of recruitment from self-sustaining stocks.

While perhaps not strictly stock enhancement methods:

- the advances in mass rearing of native fish since the 1980s have contributed significantly towards the productivity of Australia's inland recreational fisheries, and
- during the last decade, the strong and growing angler-led trend towards catch-and-release and tight harvest restrictions help to balance the impacts of increasing angling pressure.

Many of the observations below apply to enhancement by stocking fish or by general habitat enhancement and restoration programs. However, some forms of stock enhancement generally pose fewer difficulties for managers, for example:

- construction of artificial redds in Great Lake feeder streams to increase trout recruitment;
- carp eradication strategies in Lake Crescent and Lake Sorell;
- control of numbers of spawning trout in Lake Leake to limit recruitment;
- controlled harvest of pre-spawning brown trout in the Eucumbene River.

The key distinction for most of these measures is their foundation upon research that has identified problems and enhancement opportunities.

Some stock enhancement tools are extremely popular with anglers for obvious reasons. For instance, anglers fishing near artificial reefs often experience higher and more consistent catches than when they fish elsewhere. In the many instances where fish introductions followed by maintenance stocking programs have resulted in popular and productive fisheries, there is a widespread belief that releasing more fish will always result in higher catches. So popular are these forms of enhancement that the establishment of an artificial reef or the release of fish often becomes an end in itself for many stakeholders. Seen from the viewpoint of the angler, fishing media, tackle retailer, tourism operator, catchment manager and other stakeholders, this is understandable. The "quick fix" aspects of stocking are also hard to contain. For example, Hilborn (1999) points out that *"Fish stocking is much more popular with landowners than habitat protection because it doesn't require them to do anything* ..[and].. *with politicians because dumping fish in waterways is more tangible and "easier" to the public than habitat protection."* He points out that, once started, stocking can rapidly become highly political and move beyond the manager's control. A strong demand by anglers and tourism businesses, plus the ability to make a popular response immediately often makes a decision to order a release of fish politically irresistible. These political stocking decisions are justified as a means of boosting angling participation, harvest rates and regional economic benefits. However, the hallmark of political stockings is that, where their impacts have been studied, they continue even when proven to have failed to produce tangible benefits (Epifanio and Lindloff 1999).

In itself, the widening range of stakeholders adds complexity to consideration of stock enhancements. For example, where the primary stakeholders in inland fish stocking proposals were once the fisheries and conservation agencies and angler groups, today fishing guides, tackle and bait retailers, tourism interests, fishing media, regional economic development interests and water and catchment managers are commonly involved. While there will be some overlap in outcomes desired by these groups, their motivations and measures of success usually differ, often significantly. For example, for local tourism businesses needing to boost flagging visitor levels, success may comes the instant fish are released into a nearby drought-stricken water, providing them with the opportunity to promote "action" that carries the prospect of fishing success.

Working through the shared and separate objectives of all stakeholders, the focus must be on producing good fisheries management outcomes. Traditionally, the fisher's interests and satisfaction have been paramount in this process. This is based partly on the obvious central role of the fisher in the fishery and, often, on the fact that the fisher is the only non-agency stakeholder contributing directly to the cost of managing the fishery. However, in some policy settings regional economic development or other interests are elevated to an equal or even a pre-eminent position.

Working within the boundaries of sustainable use of natural resources and protection of biodiversity, the manager's challenge is to get all of the interested parties to focus initially on their desired outcomes and to relate these to fisher's aspirations for the fishery – what it is that the fisher really wants from the fishery - not on the management strategies that might be used. The manager must lead the process of working through the perceived problem or opportunity to see that it is identified realistically and defined properly. Once a common understanding is reached, the feasibility and options for addressing it can be examined. The response should include monitoring, assessment and evaluation measures commensurate with the scale and impact of the proposal, indicating the roles and responsibilities of the parties involved. Only with a clear picture of what fishers really want from their fishery – as the starting point - can this process of defining the solution or opportunity and setting objectives be linked to performance indicators that deliver – and be measured in terms of – fisher satisfaction.

In leading the discussion of detailed objectives, monitoring and evaluation of enhancement proposals, the manager must ensure that the whole fishery is considered, including its biological and human dimensions. While other stakeholders may take a narrow view of an issue and how it should be addressed, the manager must ensure that, for example, all species in the fishery are considered and that responses do not repeat approaches shown previously to be unlikely to succeed.

What is the solution?

In a technical sense, the great danger for recreational fisheries managers is to be drawn into considering "solutions" before a problem has been properly defined and analysed the precise outcomes sought by fishers (and other stakeholders) has been identified. Often, an analysis of stocking proposals will show that the appropriate management intervention is removal of a constraint on a fish population, such as through habitat restoration or stricter harvest controls (Cowx 1998a). There are many proven problem analysis and decision-making tools, ranging from the simple and generic (eg Kepner and Tregoe 1965) to the more complex protocols developed for natural resource management (eg Brindell 1995).

There are several excellent tools that can assist managers to lead the process of evaluating stock enhancement proposals. For example, Cowx (1998a & 1999b) provides schematic decision protocols for planning and evaluating stocking programs, to assist stocking decisions and to minimise adverse impacts, maximise benefits and evaluate success. An example of a more specific recreational fisheries decision tool is the decision key for brown trout management in south eastern Minnesota streams, emphasising habitat restoration, described by Thorn *et al.* (1997).

These tools work best where there is good background knowledge of the fish population in question and the system in which it lives and is fished, plus the capability to undertake research aimed at answering critical questions. These conditions are often satisfied only partially, in fact in many instances the scale of proposals is such that the cost of determining the biological inputs cannot be justified. This may be overcome by a combination of extrapolation from other similar fisheries, use of anecdotal information and scientific best-guesses, and clearly stated assumptions. Fulton and Sanger (1995) describe the futility of trying to manipulate wild lake trout fisheries to produce larger fish by using harvest regulations when what is needed is a substantial increase in fishing pressure, harvesting of adults or recruitment control – based on knowledge of the population biology of the trout and the ecology of the lake.

Where it is not possible to use such decision tools confidently, recreational stock enhancements are ideal candidates for adaptive management approaches. Hilborn (1999) proposes that responsible fisheries enhancement should:

- start from a clear statement of ecological assumptions, including a "*testable hypothesis about habitat and density dependence, and how enhancement will integrate with harvesting, habitat, and enforcement";*
- indicate clearly the manager's objectives and how they are to be evaluated;
- specify a monitoring program to measure success, including the net increase in production;
- set clear rules specifying what types of results will lead to termination, continuation, expansion or other outcomes for the enhancement.

What most objective guides, protocols and decision tools do not address properly are supporting strategies to help managers maximise their chances of reaching satisfactory outcomes as smoothly as possible. Firstly, as a general rule stocking policies, biodiversity and other recreational fishery constraints should be developed in conjunction with fishers wherever possible, and ongoing efforts made to publicise and explain them to all stakeholder groups. In addition, results of research, surveys and assessments should be shared with stakeholders, including clear explanations of the management questions addressed and the management implications of the results. As far as possible, enhancement policies and protocols should be based on the results of such studies. For example, Petr (1998) describes how stocking Queensland impoundments with several species has been evaluated in terms of fishing outcomes (measured by creel surveys) and economic benefits, leading to objective guidelines for development and maintenance stocking rates and optimum release sizes. Considering the long history and extent of recreational fish stocking programs in eastern Australia, there are few examples of such approaches in the southern states. This situation is certainly not confined to Australia (Welcomme and Bartley 1998).

Before engaging in detailed discussions of stock enhancements, a crucial step for managers is to examine the values, perceptions and assumptions of the participants. Not only do their values and assumptions influence their perspectives on goals and objectives (Barber and Taylor (1990), but they may lead to differing interpretations of the language and terminology used. The need for precise definitions of terms such as "quality", "improved" and "restored" is obvious, particularly where they form part of the desired outcomes of the enhancement program. Stakeholders' values and perceptions can be closely linked. Many anglers feel that stocking is a good and necessary management response to declining catch rates where fisheries and habitats are severely affected by drought. This can lead to the perception that an agency which refuses to meet their stocking requests is uncaring. As Barber and Taylor (1990) state, *"The more incongruent the participants' values are, the more conflict and the more difficult the process"*.

Through understanding and responding to stakeholders' values, perceptions and assumptions, the manager is in a much stronger position to lead them through the vital process of clarifying what each party really wants in terms of fishing outcomes and developing shared goals and objectives.

Finally, given the arbitrary nature of many enhancement actions, the manager must know where and when to compromise, how much to give – and be prepared to do so. Clinging rigidly to the view that "*professionalism is a heroic individual effort of pursuing truth, testing it with data and peer review, and gaining immediate acceptance and approval*" (Barber and Taylor 1990) can lead to decisions on stock enhancements shifting into the political arena where the chances of good fisheries management outcomes are far less certain.

References

Barber, W.E., and J.N.Taylor (1990). The importance of goals, objectives and values in the fisheries management process and organisation: a review. *North American Journal of Fisheries Management* **10(4)**, 365-373.

Brindell, J R (1995). A natural resource policy protocol. *Journal of Coastal Research* **11(4)**, iii-ix.

Cowx, I.G. (1998a). Stocking strategies: issues and options for future enhancement programmes. *In* Stocking and Introduction of Fish, Ed. I G Cowx, Fishing News Books, London, 3-13.

Cowx, I.G. (1998b). An appraisal of stocking strategies in the light of developing country constraints. *In* Inland Fisheries Enhancements, FAO Fisheries Technical Paper 374, Rome, 119-132.

Epifanio, J., and S.Lindloff (1999). Status and trends for inland trout management in Wisconsin. Trout Unlimited Technical Report, 52pp.

Fulton, W., and A.Sanger 1995. Quality trout management. *On the Rise*, Inland Fisheries Commission (Tasmania) **24(2)**.

Grossman, G.D., G.P.Jones, and W.J.Seaman (1997). Do artificial reefs increase regional fish production? A review of existing data. *Fisheries* **24(4)**, 17-23.

Hilborn, R. (1999). Confessions of a reformed hatchery basher. *Fisheries* **24(5)**, 30-31.

Kepner, C.H., and B.B.Tregoe (1965). The rational manager – a systematic approach to problem solving and decision making. Tata McGraw-Hill Publishing Co Ltd, Bombay-New Delhi.

Petr, T. (1998). Review of administration and of benefits from fishery enhancements in Australia. *In* Inland Fisheries Enhancements, FAO Fisheries Technical Paper 374, Rome, 65-78.

Thorne, C.T., C.S.Anderson, W.E.Lorenzen, D.L.Hendrickson, and J.W.Wagner (1997). A review of southeast Minnesota streams. *North American Journal of Fisheries Management* **17**, 860-872.

Welcomme, R.L. (1998). Evaluation of stocking and introductions as management tools. *In* Stocking and Introduction of Fish, Ed. I G Cowx, Fishing News Books, London,397-413.

Welcomme, R.L., and D.M.Bartley 1998. An evaluation of present techniques for the enhancement of fisheries. *In* Inland Fisheries Enhancements, FAO Fisheries Technical Paper 374, Rome, 1-35.

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THEME 6 Questions & Answers

John Koehn to Ross Winstanley

Question

You mentioned accountability, but it was interesting that you didn't comment about environmental accountability. What about ESD and other factors?

Answer

I referred to our need to communicate policies on translocation, stocking, biodiversity and so on. Certainly, in Victoria, all nof us who are involved in recreational fisheries stock enhancement are as committed to the Flora and Fauna Quarantee Act as we are to the Fisheries Act.

Paul Brown to Bill Talbot

Question

I was interested in your phrase "pays as you says". Can you comment on anglers being identified as a key threatening process? Who do you think should pay for endangered species recovery and stock enhancement?

Answer

Anglers are currently paying for the stocking of eastern cod and for other actions in the recovery plan, and they seem happy to pay. They are obviously keen to see these species recover to the point where they once again become part of the fishery. I also think that we should not underestimate their support for conservation in general

Andrew Sanger (comment)

When there is a lot of decline, it is often factors other than overfishing — such as land degradation, habitat alteration ... Usually anglers are prepared to contribute to recovery programs.

Richard Tilzey (comment)

All three speakers have said there is a clear need for management objectives. But you need to incorporate all stake holders. However, I acknowledge that this is a MASSIVE task — there are always hidden agendas. It strikes me that this is one of the greatest management issues. Education of stakeholders is part of it.

Ross Winstanley (comment)

You have to go even further than that. You need to get to know the values, assumptions adn perceptions of the stake-holders you are working with. People often want to 'go back' 30–40 years to when a lake was such and such, and they want it to be holding fish like it was then. [You] have to go back in time. Otherwise you can believe you are talking about the same problem and the same solutions when actually your stake-holder needs a time machine to transport him back to Lake Purrumbete in the 1960s before redfin were introduced and impacted the rainbow trout fishery. Stocking six-figure numbers of rainbow trout fingerlings won't achieve what he wants.

Dave Pollard (comment)

On who pays. It is a continuum from highly protected species such as the eastern cod to a fish that is open to a large fishing effort. [We] should look at the potential for recovery of the first through to the latter. Anglers could thus be asked to contribute towards the recovery of currently endangered species which could be exploited for fishing in the future.

Rob Day (comment)

ESD objectives, general community conservation objectives and funded research[: they all] have to be integrated. At the moment I do not see representation of the ESD principles by conservation representatives at management discussions, nor in funding decision making.

(**Ross Winstanley**). This is partly because much research is funded by anglers themselves. We have conservation representatives on our statutory Fisheries Co-Management Council and Inland Fisheries Committee but no equivalent source for funding [the] non-fishery impacts of recreational stock enhancements.

Rob Day (comment)

You can still gain community support to push for funding ESD-principled research.

Richard Tilzey (comment)

I see that as ESD principles gain increasing federal support, they will filter into other areas — [become] more local. People will have to demonstrate that fishing is not adversely affecting fish stocks. This is a major strength.

Rob Day to Richard Tilzey

But this is 'top down', and not originating from the bottom.

Overview of the ASFB Working Group on Stock Enhancement – June 2003

At the AGM of the 2000 ASFB Workshop/Conference, a proposal was put forward to develop recommendations from the ASFB workshop on stock enhancement. The President directed the establishment of a working group to develop this document. The working group, listed below, is comprised of members from all states;

Working Group Membership

Adam Butcher - DPI, Queensland

Wayne Fulton - MAFRI, Victoria

Peter Gehrke - Fisheries, New South Wales

Dean Gilligan - Fisheries, New South Wales

Roland Griffin - DPIF, Northern Territory

Gary Jackson - Department of Fisheries, Western Australia

Keith Jones - SARDI, South Australia

Rod Lenanton - Department of Fisheries, Western Australia

Brett Molony - Department of Fisheries, Western Australia

Tony Moore - SCU, New South Wales

David Mills - DPIWE, Tasmania

Mike Rimmer - DPI, Queensland

Ron West – University of Wollongong, New South Wales

Ross Winstanley - Fisheries, Victoria

The following document summarises the wide-views of the working group members, plus input from ASFB members and Executive. It is not intended as a definitive statement but as an overview of the critical issue of stock enhancement as discussed at the 2000 ASFB Workshop. Thus, the following document does not necessarily represent the views of any individual agency, research group or researcher.

Background

Most aquatic resources worldwide are fully or overexploited, and Australian aquatic resources are no exception. Even well-managed stocks are unlikely to yield increased harvests in the immediate future. It is likely that future demands on aquatic resources will intensify public pressure to augment natural systems by means of aquaculture or stock enhancement. Stock enhancement is generally defined as the hatchery production of a species of fish to a particular size or stage, that are released within a certain area or stock to increase an aspect of fishing quality (e.g. catch rates, total catch, biomass, abundance etc). Stock enhancement covers a range of activities such as; establishing new fisheries (eg. in freshwater impoundments), rebuilding endangered populations, re-establishing missing or over-exploited cohorts and commercial aquaculture (i.e. sea-ranching).

There are vast differences in the complexities between stocking a freshwater impoundment, an estuarine embayment or a marine environment. In particular, ecosystem complexity and natural environmental variability will dictate fish productivity cycles, influencing the impact of stock enhancement. Thus what may work in a freshwater impoundment, may not translate successfully to the marine or estuarine environment. Also, the time-scale for successful stock enhancement is species-specific, depending on the life-history of the target species and size and age of recruitment into a fishery. These factors, among others, will have a major impact on economic viability of any stock enhancement program.

Stock enhancement has been attempted for a large number of species throughout the world. Historically, stock enhancement was viewed as a simple and immediate solution to all fishery problems and most early attempts involved little more than the production and release of egg-stage and larval fishes. As a result, many early stock enhancement attempts failed for a number of reasons, including insufficient recognition of the complex biology and ecology of species (e.g. high natural mortality rates), environmental complexities and variations (e.g. carrying capacity), inadequate duration of stock input and numbers stocked, or lack or evaluation. However, there have been some recent successes, most of which have been carried out in inshore or freshwater areas. These successes have highlighted the potential of stock enhancement as a fisheries management tool.

Stock enhancement should only be applied when the reasons why a fishery is under-performing have been identified and mitigated (e.g. control of over-fishing). Further, stock enhancement will only generally be potentially feasible under two ecological circumstances; 1) if habitat is under-utilised, and 2) if trophic resources are available. Both factors are a function of the carrying capacity of an ecosystem and vary temporally. Therefore, the fundamental point relating to stock enhancement success concerns the degree of available resources in an ecosystem. While this is often addressed at a species-specific level, at an ecosystem level species interactions determine that other, non-exploited species are likely to depend on the same resources. For example, non-target species may be exploiting resources left available by reduced numbers of the target species. Thus any successful stock enhancement of the target species will result in a reduction of numbers of non-target species.

Therefore, successful stock enhancement will have ecological consequences, some that may be unforseen or unintentional, especially in complex estuarine or marine environments. Secondary effects (i.e. those beyond changes in the abundance of target species) are rarely considered in stock enhancement programs.

Stock enhancement has historically been technology-driven: that is, the ability to produce large numbers of fish of a range of species has often driven decisions on whether to apply stock enhancement. Further, there is a broad misconception that stock enhancement is a simple, straightforward technique. Recently, however, there have been calls to develop stock enhancement as a science and a true fisheries management tool.

Regardless of the scientific debate, growing population pressures in Australia are likely to impact on policy and the demand for increased production will escalate the pressure to undertake stock enhancement for a range of species, particularly in the recreational fishing sector. Fishery and natural resource managers require a set of objective guidelines to assist in determining the feasibility and appropriateness of stock enhancement proposals. One strategy is to provide a framework that promotes the general principles involved in stock enhancement, at a national level, that can be adapted to meet individual requirements at a state level. The recent ASFB workshop (Albury 2000) discussed stock enhancement in detail and a proposal was put forward to develop an ASFB overview on stock enhancement for further debate (Figure 1). However, it is stressed that stock enhancement is not a substitute for good fisheries management.

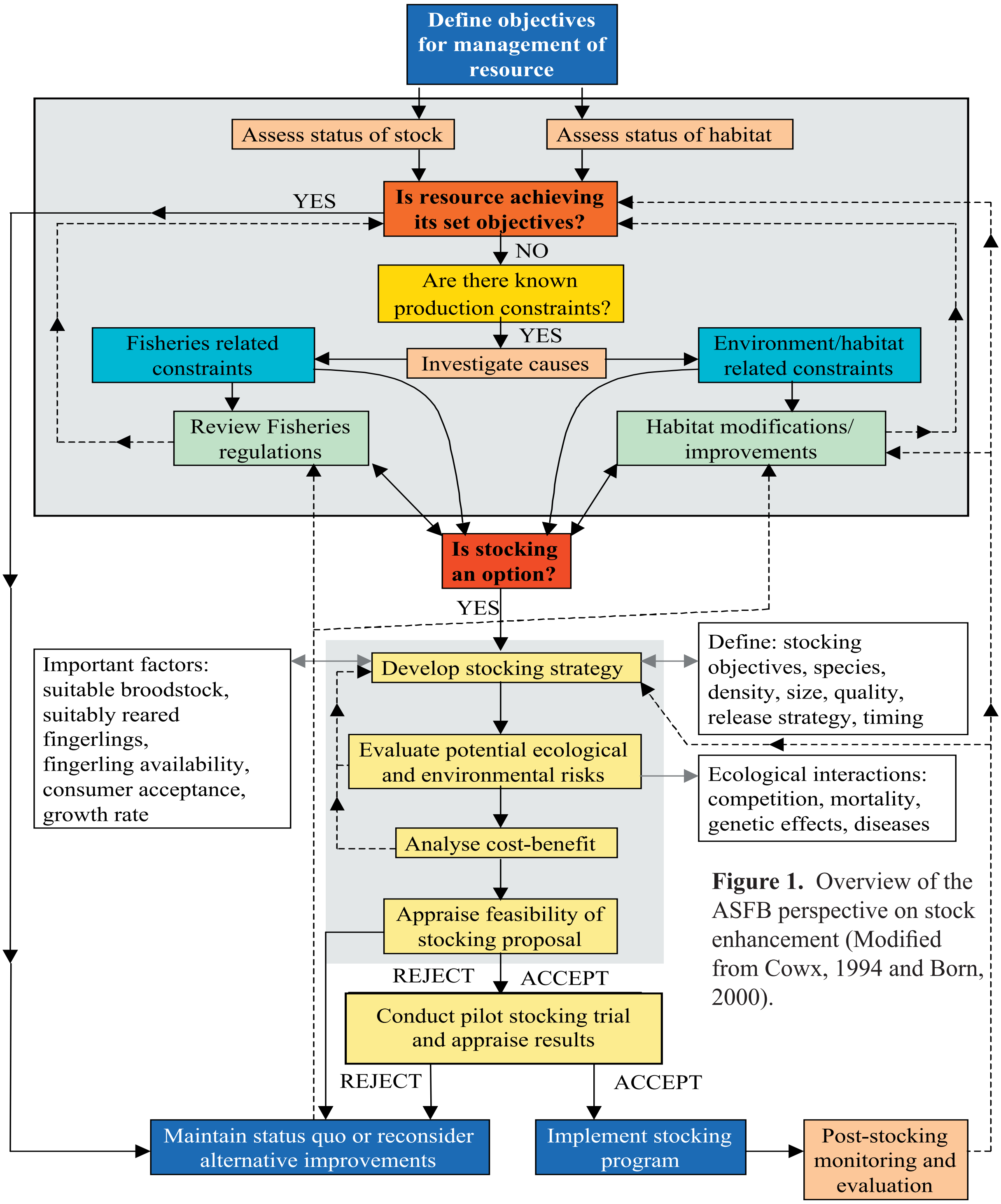

Figure 1. Overview of the ASFB perspective on stock enhancement (Modified from Cowx, 1994 and Born, 2000).

The ASFB overview of stock enhancement is comprised of many steps, each of which forms an integral part of a holistic approach to reaching an impartial, scientifically-based conclusion on how best to manage aquatic resources, using the information available. Each step progresses logically down the page (solid line) with appropriate feed back mechanisms (dotted lines). Each step is discussed in more detail below.

ASFB Statement on Stock Enhancement

Define objectives for management of resource

Sound management of aquatic resources requires precise, quantifiable objectives, allied to achievable performance targets. Objectives may stem from social, economic or biological expectations ranging from threatened species restoration to commercial exploitation. While fishery objectives may be framed around single species or defined fisheries production, there is a growing imperative under Ecologically Sustainable Development policies for management objectives to include broader issues of non-target species and ecosystem processes (i.e. ecosystem-based management). Thus it is imperative the process of defining management objectives is undertaken via a consultative process involving all stakeholders. Performance targets can be defined through any of the prime management tools of input and output controls that are governed by legislative mechanisms. However, all management tools have a cost in both the short and long term that need to be considered when setting performance targets. Some of the more important questions that need to be addressed include:

- What is the status of the resource?
- What is its current performance compared to historical performance?
- What are the reasons the resource is under-performing?
- What management methods can be employed to mitigate these, and at what cost?

These questions require clear and concise answers and may require further investigation of the resource and habitat before any particular combination of management tools are applied.

Resource and stock assessment

A primary requirement for the management of any resource is knowledge of its status. What are its biological requirements and interactions with coexisting species? Is there an expectation or scope for increased productivity? The difference between expectation/perception and reality, if any, needs to be emphasised so that a sound scientific judgement on the best approach is taken, rather than what is politically expedient. For example, high historical recreational catches many no longer be possible, simply as a result of increased population (fishing effort).

Habitat assessment

What is the status of the habitat? What is the estimated carrying capacity, remembering that carrying capacity is not a constant value, but dependant on the prevailing environmental and ecological conditions? Can it be improved? Habitat restoration may be possible at smaller scales, especially in riverine and estuarine areas where barriers (eg. small dams, culverts) can be removed or modified to restore river flow or access to essential fish habitats. In some cases, artificial habitats may be installed to replace structure that has been historically removed (eg. artificial or natural snags into clear-bottomed dams, artificial reefs into areas that have structure removed). Short-term pollution effects (eg. accidental release of pollutants) may be managed by short-term investments in clean up and habitat rehabilitation exercises.

Is the resource achieving its set objectives?

Armed with knowledge of both the resource and its habitat requirements, it is possible to review the performance targets and assess how well they meet the resource objectives. The outcome of this review will dictate what further action, if any, is necessary. An assessment of whether the resource is adequate to meet the current objectives, or if intervention is necessary, is fundamental to identifying the most appropriate suite of management tools. In many cases, legislative intervention and enforcement will be sufficient to achieve performance targets. However, in some cases, habitat management or stock enhancement may be necessary to promote the resource towards achieving the set performance targets. Stock enhancement will not be successful if reasons for the fishery under-performing can not be identified and controlled. Stock enhancement is not a substitute for good fisheries management.

Are There Production Constraints? Can these constraints be mitigated?

Productivity constraints such as overfishing, habitat loss/modification, change in fishing effort, point source pollution and changes in conservation status need to be investigated to assess possible impacts on achieving performance targets. Are wild fish prevented from spawning and/or recruiting effectively? Can environmental conditions be improved to restore habitat or food resources, in appropriate locations? Do social or economic impacts (eg. current fishing practices) require modification for the resource to achieve its performance targets? If the constraints cannot be identified or mitigated, then stock enhancement will not be effective.

Is stocking an option?

It must be accepted that the stocking of fish will not solve all fishery problems. For example, stock enhancement alone will not solve problems related to over-fishing or over-exploitation. Once resource status, habitat assessment and production constraints are identified, a management plan can be developed to mitigate them. A management plan will typically incorporate the use of several management tools such as reduced catch, closures, habitat improvement, and/or stock enhancement. These will require consultation with community and stakeholders, and perhaps changes to legislation and adequate enforcement. If stock enhancement is to be considered as an appropriate and complimentary management tool, then managers should be made aware that the five applications of stock enhancement with the most potential are:

1. Stocking for mitigation by man made perturbations (e.g. dams)
2. Stocking for enhancement where natural productivity is less than historical carrying capacity
3. Stocking for restoration after a limiting factor (such as water quality) has been controlled.
4. Creating new fisheries in areas that had not previously held stock (e.g. stocking fish into new dams).
5. Stocking to restore a threatened population.

Stocking for any other purpose will not achieve a beneficial environmental outcome and will probably have negligible or a negative effects on existing stocks. Thus, before undertaking any stocking programs, it is imperative that a thorough evaluation of the rationale is undertaken and a risk analysis of potential impacts are undertaken. These assessments should consider the impacts of alternative management strategies such as legislative reform, habitat or fishing effort remediation, or doing nothing. Prior evaluation is best achieved through a review mechanism by an independent or at least impartial panel that incorporates as wide a range of expertise as possible. The evaluation process does not necessarily determine an outcome, but does provide impartial advice to the appropriate legislative authority.

Develop stocking strategy

If stock enhancement is identified as an appropriate method to assist in meeting performance targets, a stocking strategy should be developed. Essentially, a stocking strategy is a process that defines stocking objectives, assesses options to achieve them and leads to the development of a stocking plan. The plan must include appropriate monitoring and evaluation to determine whether the objectives are being met and clearly define starting and terminating time frames of stocking. [The continual stocking of fish is not stock enhancement but the maintenance of a put-and-take fishery].

To have any realistic appraisal capability, stocking programs require precise goals with quantified measures of success. The definition of these goals should include review procedures aligned with decision rules and escape clauses to allow for adaptive management of the stocking program. Any proposal must include methods for assessing whether the stock enhancement program has achieved the defined goals (i.e. the success of the intervention). The methods employed will be dependent on the defined goals. The plan needs to be based on the precautionary principle to minimise the possibility of large-scale and irreversible ecosystem damage.

Monitoring and evaluation is critical to determining the outcomes and impacts of stock enhancement and other adaptive management strategies and to formally evaluate stock enhancement against pre-set objectives. Full evaluation, although often expensive, is critical to be able to assess stock enhancement proposals. To partially overcome this expense it may be possible to monitor and evaluate fully during pilot releases, with reduced monitoring during full-scale production releases. A strategic approach to developing a stocking strategy involves iterative refinement in an adaptive management context, that determines whether the program should continue as planned, continue with modifications or discontinue because it has either failed or achieved its objectives. At least in the pilot stage, all fish stocked must be tagged or marked in some way to allow differentiation of wild and stocked fish.

Species to be Stocked.
Local stocks of endemic species should be the only species considered for stock enhancement. In general the practise of translocation is discouraged because it is recognised as both ecologically and genetically negligent. Although viable fisheries have been established by translocating adult broodstock outside their natural distribution in the past, a national policy covering the translocation of live aquatic organisms now exists. This Bureau of Rural Sciences document is available generally and should be consulted if translocation is to be considered. Other documents discussing translocation and stock enhancement also exist and should be consulted (e.g. Phillips 2003).

It is important to adopt a precautionary approach to resource management to avoid irreversible or slowly reversible changes through inappropriate stocking. Fishery managers should not attempt to enhance a single population by means of stock enhancement, but should focus on improving the functioning of a particular ecosystem to increase the productivity of the ecosystem and species. None-the-less, stocking can be a powerful management tool if it is developed within an ecological context, using ecological, community-based perspectives that quantify important components. These components include biotic factors such as feeding guild structures, resource use, competition, genetic diversity, and pathogenic interactions, as well as abiotic factors such as water quality and habitat utilisation. The possible impacts on native species other than fishery-target species should be given due recognition when the selection process is being carried out. These interactions may be positive or negative. Thus stocking, as a management practice, should be considered within an ecosystem context, linking species management with ecological considerations. Employing strategies that minimise negative and maximise positive interactions between stocked fish and wild communities can reduce ecological risks.

Evaluate potential ecological and environmental risks

A formal risk assessment of the outcomes of stocking on an ecosystem is recommended. The potential adverse impacts of stocking, in terms of environmental, genetic and ecological interactions should be considered fully and the 'precautionary principle' applied if any adverse impacts are foreseen. This may take the form of an environmental assessment or formal risk assessment, depending on the levels of uncertainty potential risks. The is a marked difference in stocking man-made impoundments as opposed to natural marine environments and the risks/problems associated with each environment will also differ. This is an important fact to consider as many successful put-and-take fisheries exist in freshwater impoundments throughout Australia whereas the same technology has little historical credibility in estuarine or marine ecosystems.

It is essential to consider genetic risks as an integral part of any stock enhancement code of practice. If enhancement is to be used as a tool to manage wild fisheries and to produce increased, predictable harvests on a reliable basis, then hatcheries must find ways to produce fish with negligible genetic differences from the wild stock. This requirement is at odds with the aim of much of the world's conventional aquaculture, which strives to select, or genetically modify, organisms in order to maximise production for a given cost. Therefore hatchery practices for aquaculture programs must be maintained as distinct to hatchery programs aimed at supplying fish for stock enhancement. Techniques required to maintain genetic integrity of wild populations are not vastly different than current hatchery practices, but do require implementation from the outset if they are to be effective. Attention should also be given to processes that reduce or minimise the risks of inadvertent transmission of diseases or parasites. These are quality control issues and can be best handled at certified hatchery and rearing facilities.

Cost-Benefit Analyses & Tagging

A cost-benefit analysis should accompany any proposed stock enhancement proposal to demonstrate the apparent value. This may be difficult to demonstrate when social and conservation values are being quantified. Also, when assessing the economic cost-benefit it is important to remember that alternatives, such as regulating a fishery, are not a trivial matter, nor without economic impact.

Stocking can be appraised by a variety of methods, but under pure market criteria, there are three basic factors that need quantifying. In order to quantify the rate-of-recovery, all fish produced and stocked must be marked in some way in order to differentiate stocked from wild fish during subsequent sampling. A variety of marking techniques now exist from external tags to genetic marks and the marking strategy must be determined prior to the production of fish within a hatchery.

The rate of recovery, cost of production and the unit value of each harvested animal must be estimated. These variables are necessary for economists to assess the value of a stocking program against the future rate of return. Methods such as the net present value provide a comparative analysis of financial investment. However, there are intrinsic socioeconomic benefits and risks associated with stocking. These should be recognised and included, where possible, in any economic assessment, but only if they can be assessed in quantitative terms. This can only be achieved with a sound comprehension of how natural resources integrate in the socioeconomic well being of local communities.

Appraise feasibility of stocking proposal

Once a stocking plan has been developed, taking into account the ecological and environmental risks, evaluation procedures and a cost-benefit analysis, it is important to have the proposal independently appraised prior to producing and stocking fish. The appraisal process should canvass opinion from as wide variety of expertise as possible to evaluate all aspects of the proposal. The appraisal process may require additional information. The outcome from the appraisal process is to provide the appropriate legislative authority with a sound defensible argument for accepting, modifying or refusing the proposal.

Conduct pilot stocking trial and appraise results

Regardless of the depth of the stock enhancement appraisal process, it is imperative to recognise that at best this is a theoretical exercise that still carries a risk in its practical application. To minimise this risk it is recommended that stocking programs initially undertake a pilot-scale stock enhancement trials. Although recognised as an added expense, the pilot program can be evaluated prior to full-scale stock enhancement to determine if production, identification and monitoring techniques are adequate for the task of determining a cost-benefit of the exercise, before a full commitment of funds is made. Further, pilot-scale releases allow the evaluation of a range of stocking strategies (e.g. numbers, size, locations, time-of-year), to identify the optimal and most cost-effective stocking regime for the release of fish, while minimising unforseen negative impacts.

General Discussion

The steps in the flow-chart are designed to put stock enhancement in the broader perspective of ecosystem-based fisheries management The flow-chart also recognises stock enhancement as one of several tools available to fishery managers. As such, stock enhancement should not be viewed separately from other more traditional tools and should be applied in conjunction with other fishery management tools. The above approach attempts to minimise the risk of stock enhancement being technologically- driven (ie. driven by the ability of hatcheries to produce fish) and promotes a scientific basis to decision made around stock enhancement activities. Stock enhancement risks should not be underestimated as the technology to produce a large range of fish species is readily available and public pressure for stock enhancement programs exists and is increasing. This is despite few demonstrated successes of stock enhancement worldwide over a period of more than 100 years.

The process indicated above has the benefits of following a logical progression, taking into account a wide range of factors that will affect an aquatic resource and any stock enhancement program. Further, the code allows newly proposed stock enhancement initiatives and existing stock enhancement fisheries to be evaluated in a similar way. It recognises the critical differences between commercial aquaculture, stock enhancement and endangered species recovery programs. Finally, it allows input by all stakeholders throughout the decision and design process.

Supporting Literature

Blankenship, H.L. and Leber, K.M. 1995. A responsible approach to marine stock enhancement. In: *Uses and effects of cultured fishes in aquatic ecosystems*. (ed's. Schramm, H.L. and Piper R.G.). American Fisheries Society Symposium 15:167-175.

Blaxter, J.H.S. 2000. The enhancement of marine fish stocks. *Advances in Marine Biology* 38:1-54

Born, A.F. 2000. Stock enhancement. P.133-144 In: Sustainable fish production in Lake Nasser: ecological basis and management policy. (ed. J.F. Craig). ICLARM Conf. Proc. 61, 184p.

Cowx, I.G. 1994. Stocking strategies. *Fisheries Management and Ecology* 1:15-30.

Cowx, I.G. 1998. Stocking strategies: issues and options for future enhancement programs. In: *Stocking and Introduction of Fish*. (ed. I.G. Cowx). Fishing News Books. pp. 1-13.

Coates, D. 1998. Codes of practise for the stocking and introduction of fish. In: *Stocking and Introduction of Fish*. (ed. I.G. Cowx). Fishing News Books. pp. 383-396.

Hilborn, R. 1988. The economic performance of marine stock enhancement projects. *Bulletin of Marine Science* 62(2):661-674.

Howell, B. 1998. Marine fishes In: *Stocking and Introduction of Fish.* (ed. I.G. Cowx). Fishing News Books. pp. 289-293.

Langton, R.W. and Wilson, J.A. 1998. Economic considerations for fish stocking and enhancement. In: *Stocking and Introduction of Fish*. (ed. I.G. Cowx). Fishing News Books. pp. 414-421.

Munro, J.L. and Bell, J.D. 1997. Enhancement of Marine Fisheries Resources. *Reviews in Fisheries Science*. 5(2):185-222.

Phillips, B. (Compiler). 2003. *Managing Fish Translocation and Stocking in the Murray-Darling Basin.* Workshop held in Canberra, 26-26 September, 2002. Statement, Recommendations and supporting papers. WWF Australia Report: 02/03. 110 p.

Wahl, D.H., Stein,R.A. and DeVries,D.R. 1995. An ecological framework for evaluating the success and effects of stocked fishes. In: *Uses and effects of cultured fishes in aquatic ecosystems*. (ed's. Schramm, H.L. and Piper R.G.). American Fisheries Society Symposium 15:176-189.

Welcomme, R.L. 1998. Evaluation of stocking and introductions as management tools. In: *Stocking and introduction of fish*. (ed. I.G. Cowx). Fishing News Books pp.397-413.

Welcomme, R.L. and Bartley, D.M. 1998. Current approaches to the enhancement of fisheries. *Fisheries Management and Ecology*. 5:351-382.