Project Report QO00003

The Maroochy Estuary Fish-stocking Program 1995 - 99

FINAL REPORT

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1. EXECUTIVE SUMMARY

The pilot stocking program arose from recommendations of the State Government Inquiry into Recreational Fishing (1993). The program was designed to evaluate the success of releasing juvenile dusky flathead (*Platycephalus fuscus*) and sand whiting (*Sillago ciliata*) into the Maroochy River estuary. At the time of its commencement (July 1995), it was the largest of its kind undertaken in Australia. It involved staff and infrastructure from the DPI facilities at Bribie Island Aquaculture Centre (BIARC), Southern Fisheries Centre (SFC), Animal Research Institute (ARI) and the Queensland University of Technology (QUT). The objectives of the program were:

1. To develop technology to undertake large-scale breeding of finfish (sand whiting, dusky flathead) for stocking a south Queensland Estuary.
2. To undertake a large, extended stocking of a south Queensland estuary (the Maroochy River).
3. To develop protocols to monitor the effectiveness of stocking in the Maroochy River estuary.
4. To undertake a full-scale monitoring program in association with the experimental stocking program.

The first three objectives were brought to a successful conclusion. Program management constraints meant that the fourth objective was curtailed before the effect of the stocking program was fully assessed.

1.1. OBJECTIVE 1

An early breakthrough occurred with the successful mass production of fingerlings of both species, without which the project could not have proceeded. The health of all fingerlings was verified using a health assessment index technique similar to that used in stocking programs in the USA.

1.2. OBJECTIVE 2

Pre-stocking surveys of the estuary, using several techniques, yielded estimates of the natural population density of dusky flathead and sand whiting. These estimates were used to calculate an appropriate number of fish to be stocked in order to have a reasonable chance of subsequently detecting a signal in the population. Approximately 100 000 dusky flathead and 335 000 sand whiting fingerlings were released into the estuary by proportional broadcast stocking methods during four major releases between December 1996 and May 1998.

1.3. OBJECTIVE 3

Monitoring the success of the stocking process required a method of identifying hatchery-reared fish and differentiating them from naturally occurring fish. A mass-marking technique was required, because of the small individual size and large numbers of fingerlings to be released. Trials with oxytetracycline baths were unsuccessful because of poor uptake of the marking substance into the fishes' skeletal structure. This technique involved what we consider to be unacceptable personal and environmental risks. An alternative safe procedure, involving analysis of circuli patterns on scales, was highly successful. This method makes use of the fact that fish reared in hatchery conditions are subject to similar environmental conditions at the same time. These conditions create 'hatchery fingerprints' on the early developing scales, which can be analysed by automated computer image-analysis systems and classified statistically into 'hatchery' or 'wild' groups with considerable reliability.

1.4. OBJECTIVE 4

Successful monitoring also required a measure of how the population density of the two fish species changed as a result of the introduction of large numbers of hatchery-reared fingerlings into the estuary. Both fishery-dependent and fishery-independent approaches were adopted. A creel survey and angler diary program was attempted, but discontinued because project resources were limited and unable to deal with the spatial and temporal patchiness of recreational fishing effort. Commercial fisheries data from the CFISH logbook database were also used to try to track changes in population density as reflected by variation in catch rate. These data provided an indication of trends in stock abundance, but the lack of spatial precision reported in fishing locations cast some doubt on their reliability in the context of this study. Indices of the density of dusky flathead and sand whiting populations which we believe to be the best representation of population sizes were derived from regular fishery-independent sampling using beach seines, ring, fence and fyke nets, and beam trawls at a large number of sites throughout the Maroochy River estuary.

Scale pattern analyses revealed that both dusky flathead and sand whiting fingerlings survived well after being released. We found that 47% and 28% respectively of dusky flathead from the recreational and commercial catches were of hatchery origin. Likewise hatchery-reared sand whiting made up 44% and 52% of the recreational and commercial catch samples. The ratio of hatchery to wild sand whiting rose appreciably, following a fish kill that occurred in February 98, between the first and second sand whiting stocking events. This fish kill occurred towards the end of the whiting spawning season. The resultant reduction in the number of wild fish and the timing of the fish kill apparently reduced the opportunity for natural recruitment, thereby opening up a niche that the hatchery whiting appear to have exploited. This is a clear indication of the replenishment potential of a stocking program when natural populations are below normal levels.

Whether or not the stocking events actually resulted in a measurable increase in the population of fish in the river was a more difficult issue to deal with, because of the sampling difficulties and unpredictable changes in fish behaviour, catchability and availability. Although hatchery fish appeared in the commercial and/or recreational catch, this was not evidence *per se* that they have contributed to an increase in the total population. This project was not designed to examine the question of displacement and although we have no direct evidence of its occurring during the project, we presumed that a significant increase in population abundance at an appropriate interval after the stocking event would be the best indicator of its absence.

Catch data from 33 fishery-independent sampling trips between January 1996 and December 1998 were highly variable. Densities of the two stocked species before and after the stocking events were estimated by three statistical models; a general linear model (GLM) based on untransformed data, a GLM using log-transformed data, and a Markov chain Monte Carlo (MCMC) simulation based on untransformed data. All three models suggested that the population density of dusky flathead increased slightly during the first 26 months, but that sand whiting densities remained relatively stable. Populations of both species declined substantially after a major fish kill in the river in February 1998, resulting from hypoxic conditions after an overflow of aquatic weeds from Wappa Dam on the north Maroochy River.

Fourier analysis of long-term catch data highlighted the delay between stocking and observing an effect in the catch data. We believe that the fish kill in February 1998 confounded the effect of the first stocking. We detected a slight increase in the density of both species after stocking, but these changes were not statistically significant. The pilot project was terminated before the effects of the second stocking could be observed.

A conservative economic analysis of this pilot program estimated the cost of each stocked fish captured at between \$17 and \$24. This value is high compared to those from other studies, primarily because the level of economic scrutiny applied to the present study was far greater. Pilot studies such as this are necessarily expensive because of the high research and development component. However, economies of scale and reduced development costs would have a significant effect in reducing costs of future estuarine stocking.

2 INTRODUCTION

A. Butcher and P. Palmer

2.1 STOCKING STRATEGIES

Stocking (hatchery release programs) is one of several management tools designed to enhance fisheries or rebuild depleted stocks (Heppel and Crowder 1998). The history of stocking fish is long and chequered (Rutledge and Matlock 1986). Many earlier stockings occurred without any definition of objectives or evaluation of success (Cowx 1994). This has led to much debate as to the benefits of stocking (Richards and Edwards 1986, Rutledge and Matlock 1986, McGinnis 1994, Kent et al. 1995, Travis et al. 1998, Thorpe 1998, Heppel and Crowder 1998, Hilborn 1998, Masuda and Tsukamoto 1998). Travis et al. (1998) point out that there is no consensus about the success of stocking in all restocked fisheries. Some authors argue that stocking is of doubtful value for improving yields, and in some cases has led to increased exploitation of declining native stocks on the expectation of improved yields (McGinnis 1994, Bannister and Addison 1998, Coronado and Hilborn 1998, Svåsand 1998, Hilborn 1998). However, others have reported cases of increased population densities following stocking (Leber et al. 1995, Leber et al. 1998, Masuda and Tsukamoto 1998, McEacheron et al. 1998). Hilborn (1998) observed that stocking resident species was more likely to be successful than stocking migratory species and that stocking depleted species was more likely to reduce the incidence of displacement. Several authors have raised concerns that stocking may cause inbreeding and shifts in allele frequencies by stocking distant genotypes (Solomon 1988, Garcia De Leániz et al. 1989, Gaffney et al. 1996, Conover 1998, Thorpe 1998). Masuda and Tsukamoto (1998) suggest that the maintenance of genetic diversity is a government responsibility.

Most stockings in Queensland waters prior to 1986 were small, largely research-driven events following the successful development of mass larval rearing techniques for various species (Hamlyn 1998). The Queensland Government established the recreational Fishing Enhancement Program to create recreational fisheries in inland impoundments in 1986. Since then, some 19 million fingerlings of various native species have been released into a range of freshwater impoundments and have created significant inland fisheries (Hamlyn 1998). Most of these are 'put, grow and take' fisheries where stock do not reproduce naturally. There is increased public awareness of the success of these inland fisheries and pressure for marine stocking is increasing. There are several reports of the successful stocking of barramundi into the Johnston River, North Queensland (Russell and Rimmer 1995, Rimmer and Russell 1998). However, while these authors have observed the successful recruitment of hatchery-reared stock into the commercial and recreational catch, they have yet to report on increased abundances of this species in that river system. Palmer (1995), in his review of enhancing non-impounded fisheries, notes the need for discussing important biological, technical, economic and political issues before any major stocking event commences. Several other authors have also evaluated stocking programs and recommended a systematic approach (Rutledge 1989, Wooley et al. 1990, Holt 1993, Blankenship and Leber 1995, Cowx 1994, 1998).

There are at least 10 major components to any stocking strategy (Blankenship and Leber, 1995) and these should form the basis of any stocking program. They are:

- Prioritise and select species
- Develop a species management plan
- Define quantitative measures of success
- Use genetic resource management
- Use disease and health management
- Define enhancement objectives and specify tactics
- Identify hatchery fish and assess effects
- Use empirical processes to define optimum release strategies
- Identify economic and policy objectives
- Use adaptive management.

Many of these points were discussed at a scoping workshop and incorporated into the design of the pilot program. The workshop outcomes are discussed below.

2.2 BACKGROUND

In 1993 the Queensland State Government held an Inquiry into Recreational Fishing (SGIRF). In its concluding report, the SGIRF Consultative Committee recommended 'that research be undertaken to establish hatchery techniques and stocking methods for the purpose of stocking recreational fishing areas with prime angling species and that the Government fund a pilot project in a heavily fished area such as Pumicestone Passage' (p.87 – Recommendation 62).

A technical workshop involving scientists and managers from DPI, CSIRO, QFMA and members of the peak recreational and commercial representative bodies was convened during August 1994 to implement the SGIRF recommendation (see Appendix 13.1 for list of delegates). This workshop covered the following issues:

1) Describing habitats in Pumicestone Passage that support fish and fisheries.
2) Examining biological parameters and estimating population sizes of four fish species that were principal potential stocking candidates at that time (bream, sand whiting, gold lined whiting and flathead).
3) Describing the technology, costs and limiting factors for breeding and releasing significant numbers of juvenile fish into Pumicestone Passage, and determining the most appropriate size at which stocking should occur.
4) Estimating the number of fish that need to be released in order to have a measurable effect upon existing population numbers, and the intensity of sampling needed to detect changes in numbers.
5) Identifying techniques for monitoring changes in numbers of fish and determining which would lead to the most cost-effective and precise estimates of change.
6) Examining the logistics and costs of stocking and monitoring the fish populations in Pumicestone Passage.

The workshop concluded:

1) That a stocking program could be conducted by Departmental staff, using Departmental facilities, subject to the availability of facilities at the Bribie Island Aquaculture Research Centre.

2) That the preferred species for stocking at the time were dusky flathead and sand whiting, subject to appropriate breeding technology being developed. However, these may need to be reconsidered in the light of further information.

3) There would be little point in conducting a stocking program without an associated monitoring program designed to evaluate the effectiveness of the stocking. Such a monitoring program would require released fingerlings to be marked in a way that would identify them as having been hatchery-reared. The most appropriate means of marking were considered to be:

   - A combination of oxytetracycline (OTC) and scale marking techniques
   - Experimental genetic tagging

4) It was agreed that the most appropriate re-sampling techniques would involve:

   - Recreational anglers diary scheme
   - Direct measurement of juvenile abundance
   - Creel census

5) To conduct an effective stocking and monitoring program would take between 5 and 7 years.

At a subsequent Management Team workshop, the DPI Fisheries Senior Management Team reviewed the conclusions of the scoping workshop. They emphasised that populations of juvenile sand whiting and dusky flathead in Pumicestone Passage were probably quite large (at least 0.5 million and 150 000 15–20 mm fish respectively), and that the BIARC facility would be able to produce a maximum of about 150 000 fingerlings of each species annually (provided appropriate rearing methods could be developed). They concluded that stocking in Pumicestone Passage would be unlikely to produce a measurable effect on existing fish populations. Further, there would probably be some leakage of stocked fingerlings from Pumicestone Passage into Moreton Bay, further reducing the ability to detect a significant difference in population size as a result of stocking.

The Management Team workshop recommended that a smaller, more manageable, and less open estuarine system be chosen for the trial site. Such a system should (i) open directly to the ocean to minimise leakage of fish to other areas, and (ii) be close enough to Bribie Island and Deception Bay to allow for ease of transport and monitoring. The most obvious candidate was the Maroochy River estuary. Other estuaries south of Brisbane were considered too distant for such an experiment, and other nearby northern estuaries (Mooloolah and Noosa) were heavily modified by adjacent urban development. A contributing factor to this decision was the fact that in the previous year (August 1993) there had been a major fish-kill in the Maroochy River. In October 1994 a second major fish kill was reported in the Maroochy River system. State Cabinet acted swiftly and in the following month announced that the Maroochy River system would be the site of a large stocking pilot project. DPI was requested to begin full-scale investigations within the river system.

2.3 *THE MAROOCHY RIVER*

The Maroochy River is situated in southeast Queensland, east of the Blackall Range, and is the largest drainage system in the Maroochy Shire (Figure 2.1). It has a north and south arm that join near the tidal limit, about 24 km upstream of the mouth. Three major tributaries (Coolum Ck, Petrie Ck and Eudlo Ck) contribute to a catchment area of some 400 km^2 (Anderson 1993). Its estuary is relatively small compared to other Queensland rivers. The river's surface area, between mouth and bifurcation, is approximately 6.7 km^2 (Anon 1998). Mixed stands of *Avicennia marina, Aegiceras corniculatum* and *Rhizophora stylosa* mangrove communities occur along the river. Modifications to the riverine environment have mainly been through encroachment of urban and agricultural land uses and Anderson (1993) has classified the fisheries habitat disturbance as moderate.

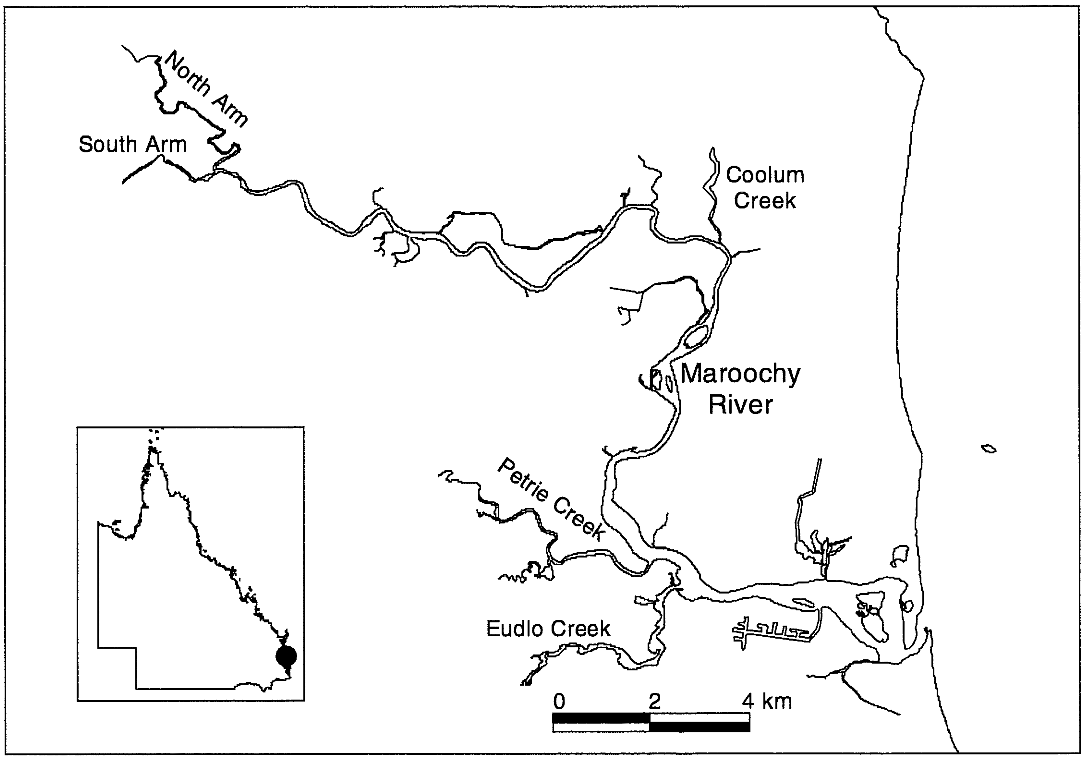


Figure 2.1: Location of the Maroochy River and major tributaries in southeast Queensland. Coastline data in this figure is copyright Commonwealth of Australia, provided by AUSLIG.

2.4 *OBJECTIVES*

The objectives of this program were originally defined by the Fisheries Services Manager, South East Queensland in October 1995. They were:

1. Develop technology to undertake large scale breeding of finfish (sand whiting, dusky flathead) for stocking a south Queensland estuary.
2. Undertake a large, extended stocking of a south Queensland estuary (the Maroochy River).
3. Develop protocols to monitor the effectiveness of stocking in the Maroochy River estuary.

4. Undertake a full scale monitoring program in association with the experimental stocking program.

It was recognised that achieving these objectives would require a multi-disciplinary approach using staff and resources from the Bribie Island Aquaculture Research Centre (BIARC), the Southern Fisheries Centre (SFC), Biometry (ARI) and the Applied Mathematics Department at Queensland University of Technology (QUT). The objectives were considered to be very generalised and a logical progression of tasks was developed to achieve these goals. The tasks were allocated amongst the centres as follows:

Estimate the size of flathead (*Platycephalus fuscus*) and sand whiting (*Sillago ciliata*) populations in the Maroochy River, identifying the habitat preference and seasonal abundance of each species throughout its life-cycle. (SFC, objective 4).

Estimate the number of fingerlings of each species needed for stocking such that there would be a measurable effect on the abundance of existing wild populations. (ARI, QUT and SFC, objective 3).

Develop the necessary expertise and technology to induce flathead and sand whiting to spawn on demand in captivity. (BIARC, objective 1).

Develop marking methods to enable the positive identification of hatchery reared fish after release and subsequent recapture. (BIARC and SFC, objective 3).

Develop culture methods for large-scale fingerling production of the selected species and stock them into the Maroochy River system. (BIARC and SFC, objective 2).

Estimate (quantify/qualify) the effect of stocking the Maroochy River system. (SFC, ARI and QUT, objective 4).

The tasks are discussed in chapters 2 to 7 and achievement of the objectives is assessed in the General Discussion (Chapter 8).

3 PRELIMINARY SURVEYS OF DUSKY FLATHEAD AND SAND WHITING

A. Butcher, D. Smallwood and M. Johnston

3.1 *INTRODUCTION*

There are four main reasons for any stocking program: 1) to mitigate human impacts such as impoundment creation, 2) enhance depleted populations, 3) restore populations after improving carrying capacity, or 4) to create new fisheries (Cowx, 1998). Several authors have highlighted the importance of assessing the status of the stock in the chosen wild habitat prior to stocking an estuarine environment (Cowx 1994, Blankenship and Leber 1995, Palmer 1995). This is important for detecting effectiveness and usually forms part of the justification for any stocking event. The DPI scoping workshop in August 1994 spent a significant amount of time considering stocking of sand whiting and dusky flathead stocks in Pumicestone Passage. However, after the 1993 and 1994 fish kills in the Maroochy River, the site of the pilot program was changed. There was little information available to assess the stocks of dusky flathead and sand whiting in the Maroochy River, or the effect of these recent disturbances on them. In order to establish this baseline, it was necessary to survey the river to quantify the seasonal abundance and habitat preference of each of the chosen species throughout their life-cycles.

3.2 *METHODS*

The preliminary survey was designed to establish baseline information about the seasonal abundance and habitat preference of each of the chosen species throughout their life cycles. It began in January 1996 and continued on a monthly basis until the stocking of dusky flathead in December 1996 and sand whiting in April 1997.

3.2.1 *Field Procedures*

An initial investigation of the various habitats within the Maroochy River system was carried out to identify suitable sampling sites in December 1995. After discussions with recreational and commercial stakeholders and evaluation of the initial visits, the river was divided into nine zones and 15 sites, and a sampling regime was established to examine species diversity and seasonal abundance at each site. During subsequent visits, another 16 sites and 5 zones were added and two sites deleted to give a total of 31 sites in 14 zones (Table 3.1 and Appendix 13.2). Five different sampling techniques were used according to the site topography, as follows:

- ring nets in intertidal flats (sand and mud);
- fence nets on intertidal sloping areas without a defined drainage channel;
- fyke nets on intertidal sloping areas with a defined drainage channel;
- beam trawls on sub-tidal sand and mud bottom and seagrass areas;
- seine nets on sub-tidal sand bottom areas.

Sampling was carried out on the dark of the moon every month during the highest tides of that month. For the first three months, all sites were sampled. However, in the following ten months, the remaining 29 sites were randomly split into two groups of 14 and 15 sites, with each group being sampled in alternative months. Site 25 (Pidnung Island) was discontinued after trip three because of the heavy debris load on the bottom. Site 27 (Twin Waters Canal) was discontinued after six months because of canal development works.

Table 3.1: Sample sites and their relevant data. Note that sites 25 and 27 were dropped after trips 4 and 5 respectively due to sampling difficulties. Refer to Appendix 13.3 for geographical locations of all sites. * denotes local descriptive name – not found on maps.

DPI Site #	Zone	Description	Gear type	Subregion Area (m^2)	Net Area
1	1	Johno's Lagoon*	fyke net	50000	500
2	1	E Channel Is	ring net	75000	625
3	1	SE Channel Is	ring net	318750	625
4	2	SW Channel Is	ring net	243750	625
5	2	NW Channel Is	ring net	187500	625
6	2	W Channel Is	ring net	281250	625
7	9	Cod Hole	beam trawl	56250	1450
8	11	David Low Bridge	ring net	18750	625
9	8	David Low Bridge	beam trawl	462500	1450
10	12	Upstream Is	fence net	12500	1200
11	13	Upstream Is	beam trawl	568750	1450
12	10	Eudlo Ck mouth	fence net	18750	1200
13	1	Spit	fence net	231250	1000
14	1	NE Channel Is	ring net	131250	625
15	3	Black Banks	fyke net	12500	500
16	6	Chambers Is	beam trawl	100000	1450
17	7	Motorway Bridge - ds	beam trawl	431250	725
18	7	Motorway Bridge - us	beam trawl	456250	725
19	7	Eudlo Ck	beam trawl	556250	1450
20	7	Petrie Ck	beam trawl	350000	1450
21	14	Dunethin Rock Lake	beam trawl	93750	725
22	14	Dunethin Rock Lake - ds	beam trawl	625000	725
23	4	Tepequar Canal	beam trawl	212500	725
24	14	Coolum Ck	beam trawl	225000	725
25	14	Pidnug Island	Beam trawl	625000	725
26	5	Black Banks	beam trawl	31250	725
27	5	Twin Waters Canals	seine net	212500	500
28	14	Dunethin Rock Lake - opp	beam trawl	625000	725
29	14	Jungle Bunny Reach*	beam trawl	231250	725
30	1	Sand Fly Byte*	fence net	68750	1200
31	10	Eudlo Ck mouth	beam trawl	9375	725
			Total area	6684375	25925

3.2.1.1 Ring Nets

Ring nets consisted of a net attached to eight wooden stakes (1.8 m x 20 mm^2) set out in a 25 m x 25 m square (Figure 3.1). Areas were determined by number of paces and stakes were driven into the substrate at low tide with a pole rammer. One stake was used in each corner with an additional pole between corner stakes for added net stability. At high tide a multi-filament net (120 m long x 1.2 m deep, 18 mm stretched mesh) was run out around the stakes. To avoid scaring fish, noise and lighting were kept to a minimum. In locations near residential areas, where there was a high level of incidental light, nets were set such that the side that would cast a shadow inside the ring was set last or second last. Signs were attached to corner stakes indicating that research operations were in progress. The catch, net and stakes were retrieved at the next low tide.

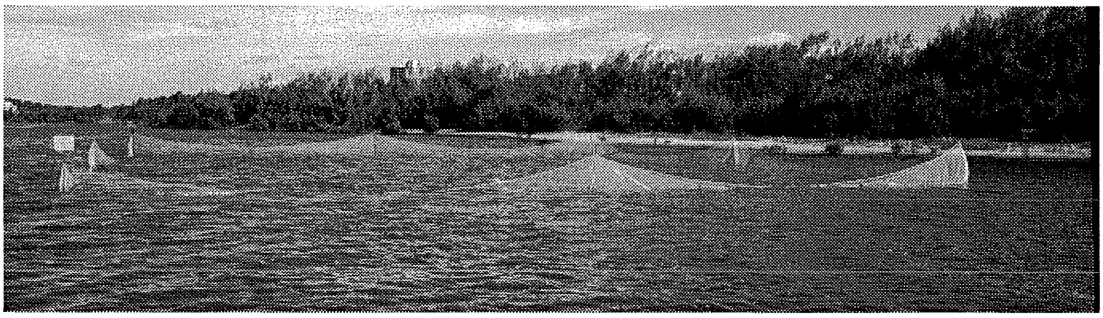


Figure 3.1: Ring net at site 6.

3.2.1.2 Fence Nets

Fence nets were used in intertidal areas which had a boundary above high-water mark (sites 10, 12, 13 and 30). The four fence net sites were topographically different, but the method was essentially the same. From the edge of the high-water mark, stakes were placed to form three sides of a rectangle either 40 m x 30 m or 80 m x 15 m. Stakes were placed approximately 10 m apart (Figure 3.2). Net setting and retrieval was as described for ring nets except that no fourth side was required as it was bounded by dry land.

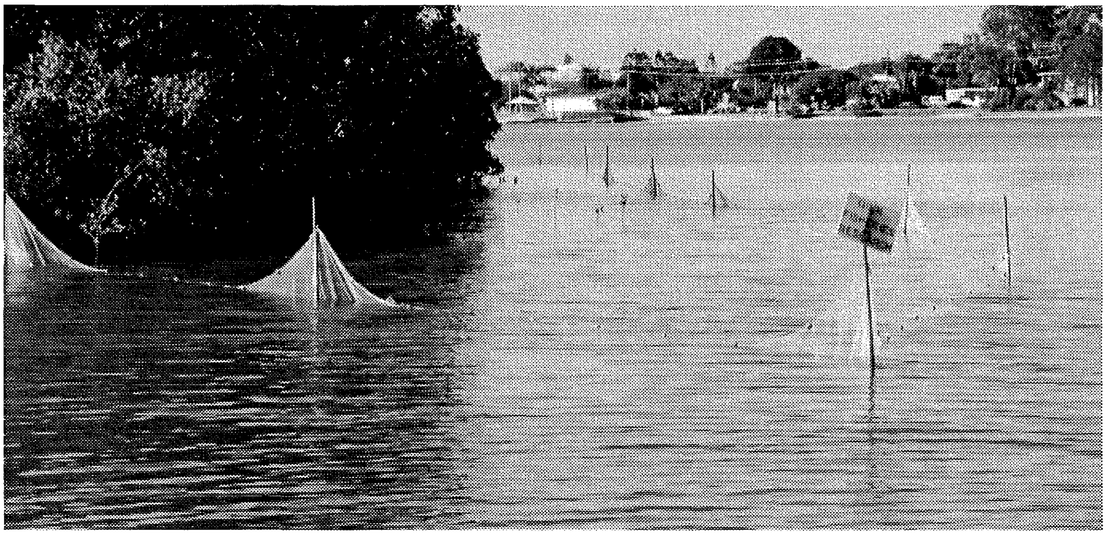


Figure 3.2: Fence net at site 12.

3.2.1.3 Fyke Nets

Fyke nets were used in intertidal areas where there was an obvious drainage channel (Figure 3.3). The fyke net consisted of seven rings of decreasing size surrounded by multi-filament net with mesh sizes decreasing from 26 mm between the first two rings to 18 mm at the bag. Two 15 m lateral wings with a stretched mesh of 18 mm and a drop of 1.2 m extended from the fyke. Each fyke net required seven stakes that were put in place at low tide. Two stakes held each wing in position, two held the front ring of the fyke in position and one at the back held the fyke straight. The net was set at high tide by positioning the fyke between its three stakes and then pulling the wings out. Float-lines were attached to each stake and the lead-line was buried in the substrate to prevent lifting as the tide receded. The apparatus was retrieved and the sample collected at low tide.

Figure 3.3: Typical fyke net in position at site 1.

3.2.1.4 Beam Trawl

Subtidal areas, including seagrass habitat, were sampled at or close to high tide by beam trawl. The beam trawl frame (skids and centre section) was approximately 2.8 m wide and 1.5 m high (Figure 3.4). A two-fathom net, with rollers covering the ground chain, was attached to the frame. At each site the beam trawl was lowered to the substrate opposite a reflective marker placed strategically on the bank, and towed for five minutes at 1000 rpm (approximately 2.5 km^{-1}) behind a vessel (5.2 m aluminium with a 55.2 Kw four-stroke outboard). The beam trawl was towed at approximately 20 m behind the towing vessel. After five minutes the cod-end was retrieved, and (depending on the quantity) the catch was sorted on board or simply dumped straight into plastic bags.

3.2.1.5 Seine net

A seine net was used at site 27. One person held the 'dry' end of the net on the shore with his foot firmly holding the lead line to the substrate and the headline was held at chest height. A second person walked the other end of the net out into 1–1.5 m of water about 20 m offshore. Both then proceeded to drag the net for approximately 100 m parallel to the shoreline with the 'wet' end of the net always being kept ahead of the 'dry' end. To retrieve the net, both people crouched on the shore and slowly dragged the net in by the two lines (head and lead) grasped together. The lead line often dug into the undulating substrate, and was periodically exposed to relieve this weight without losing fish under the lead line. Most of the catch was caught in the cod-end, but some fish meshed in the net wings. The catch was bagged and labelled and stored in a freezer for transport to the laboratory.

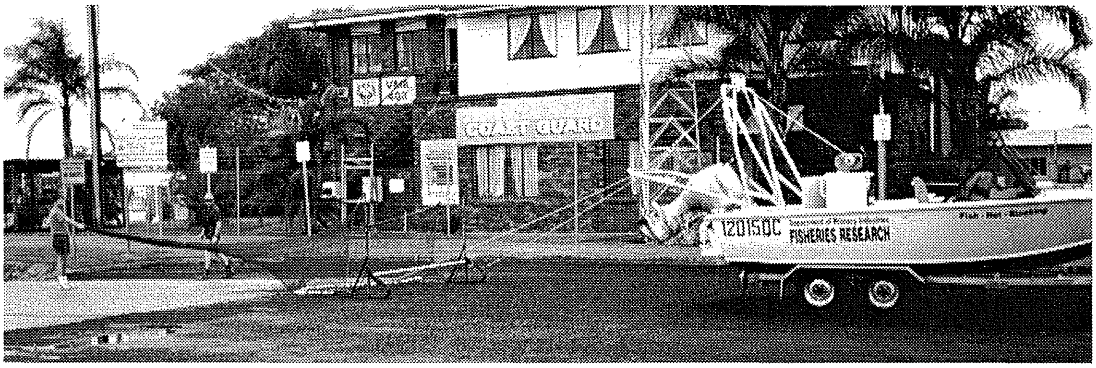


Figure 3.4: Layout of beam trawl apparatus.

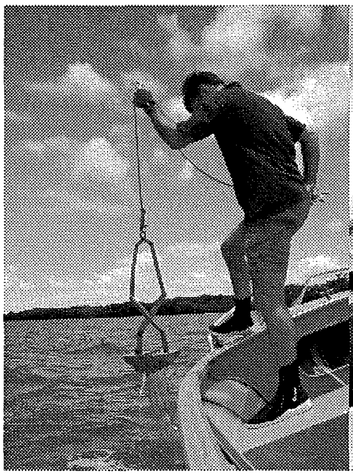
3.2.2 *Laboratory Procedures*

All samples were frozen in appropriately labelled plastic bags as soon as possible after capture. In the laboratory, fish samples were thawed in water then sorted into separate species. Standard length and weight measurements of fish species were taken using a measuring board and an electronic balance. Individual lengths and weights were recorded for all commercial fish species, and numerically abundant non-commercial species (>100) were counted and a total weight recorded. Length was measured to within 1 mm and weight to within 0.1 g, except for very small fish (< 1 g) which were weighed to the nearest 0.01 g. Crabs were individually identified to species, sexed, weighed and measured across the carapace. Prawns were sorted into species and a total weight and number recorded.

Information was transcribed from the raw data sheets and saved to a spreadsheet (Microsoft Excel) for later analysis. The chosen species were analysed both as a total population, for input into the relative abundance estimates, and as a juvenile sub-population for input into developing the stocking protocol (Section 6.2.1).

3.2.2.1 Sediment Sampling

Sediment analysis was conducted according to the technique of Aziz and Greenwood (1982). A sediment sample (approximately 150 cc) was collected from each of the 31 sites in the Maroochy River using a Van Veen grab (Figure 3.5) and placed in plastic bags, labelled and frozen the same day as collection. In the laboratory sediment samples were thawed to room temperature and fed through a series of Endecott vibrating test sieves with decreasing mesh size (2 mm, 1 mm, 500 µm, 250 µm, 125 µm, 63 µm). The remaining sediment in solution was gravity fed through a Whatman number 4 qualitative filter paper (Figure 3.6). All test sieves and the filter paper were then dried in an oven for 24 hours at 60°C. The contents of the test sieves and filter paper were weighed and recorded and the net weights of each fraction calculated by subtraction.



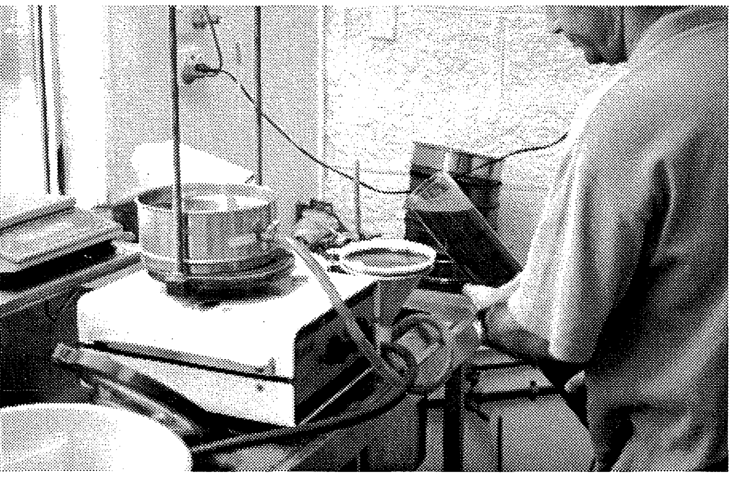


Figure 3.5: Sampling sediment. **Figure 3.6**: Filtering sediment residual in the laboratory.

During the first 12 months of the preliminary survey a total of 108 net samples and 73 beam trawl samples were collected. Each site was sampled on at least six occasions, except those that were discontinued (Sites 25 and 27) and those that were added much later (sites 28,29, 30 and 31) to add replication to the sampling regime. Sites with muddy substrata were most commonly sampled by beam trawling, whereas ring nets were most commonly deployed at sites with sandy substrates. Sites with a mixture of sandy-mud substrates were mostly sampled using fence nets (Figure 3.7).

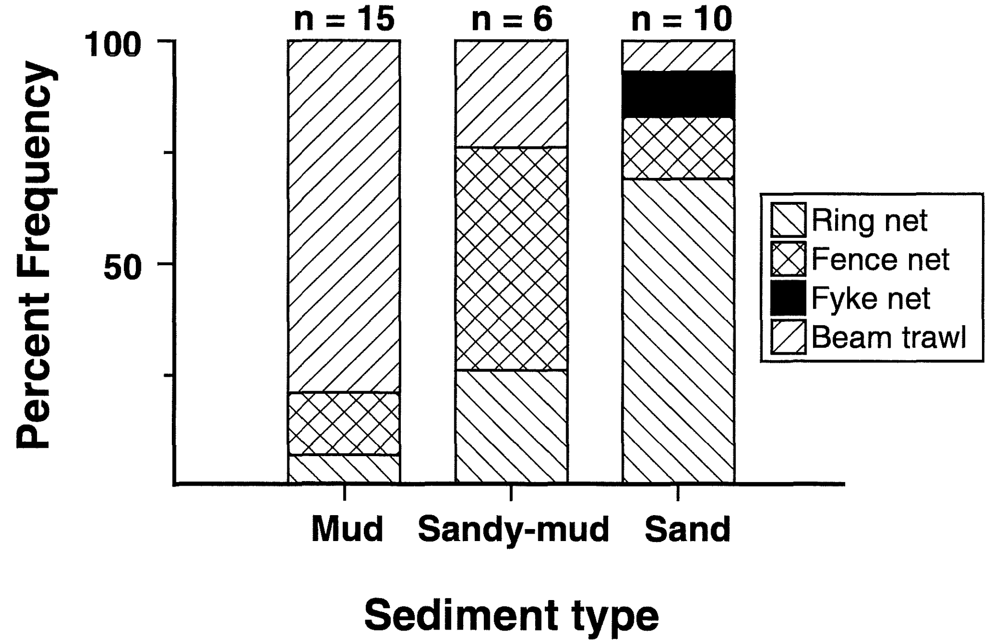


Figure 3.7: Frequency of gear types used on each substrate class.

Relative catches were used to contrast seasonal abundance and habitats preferences of the different stages of each species life-history. Relative catches were derived by converting the raw data to densities/1000 m^2. This was achieved by dividing catches by area sampled and adjusting for net efficiencies. These were transformed (ln (raw catch + 0.001)), fitted to a general linear model with the main effects of site and month, and then back transformed to give a standardised catch/1000 m^2. Confidence intervals of the relative density estimates were derived from ± 1 SE about the mean. These were back-transformed to give a standardised error estimate.

3.3 *RESULTS*

3.3.1 *Dusky flathead*

A total of 222 dusky flathead were caught during preliminary surveys from January to November 1996, prior to the first dusky flathead stocking event in December 1996. They ranged in size from 6.0 to 53.5 cm SL (Figure 3.8) with a mean of 17.1 cm. Their length-frequency distribution was positively skewed (B_1 = 1.47) and leptokurtic (B_2 = 5.82). The majority of dusky flathead were caught in fence and ring nets (Table 3.2) Half of the dusky flathead caught were taken on mud-sand substrates with a further 34% being taken on mud substrata (Table 3.3). Nearly 60% were caught upstream of the Motorway Bridge, primarily from sites 8, 10 and 12.

Catches of dusky flathead varied considerably during the first two months sampling (Figure 3.9). This reflects the sampling intensity during trip one when only 13 downstream sites were sampled, compared to trip two when 23 sites were sampled (refer to Appendix 13.4). Relative catches stabilised for the remaining eight months. There was a small decline in catches over the cooler months of late winter and into spring. However, by summer, the catch rate had begun to increase. The catch results (Table 3.4) were compiled for use in estimating the relative abundance of dusky flathead in the Maroochy River (Section 4.3) and developing the stocking protocol (Section 5.2.1).

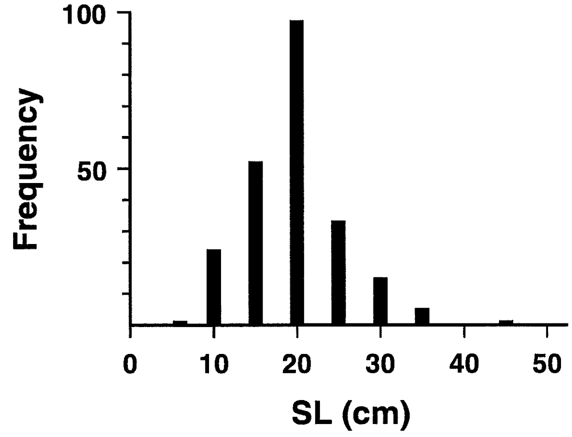


Figure 3.8: Length-frequency of all dusky flathead caught during preliminary surveys (January to November 1996).

Table 3.2: Relative abundance of dusky flathead/1000 m^2 caught in each gear type during the preliminary surveys (January to November 1996).

Gear Type	relative catch (%)
Fence net	35
Ring net	34
Fyke net	6
Beam trawl	25

Table 3.3: Relative abundance of dusky flathead/1000 m^2 caught over each substrate class during the preliminary surveys (January to November 1996).

Substrate Type	relative catch (%)
Mud	35
Mud/sand	6
Beam trawl	25

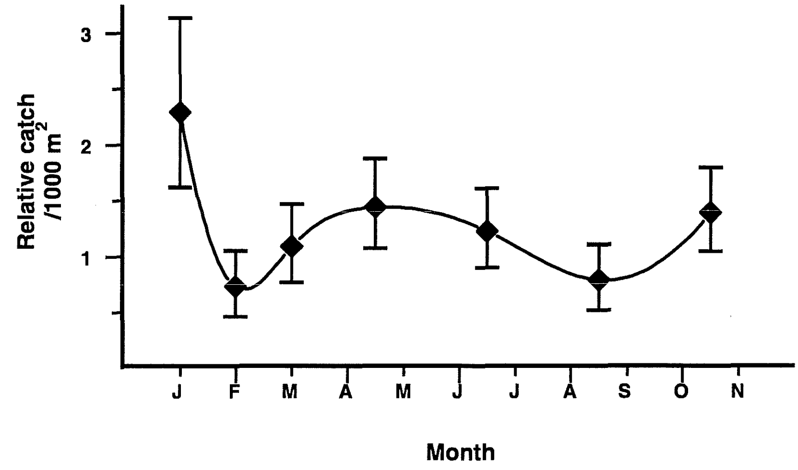


Figure 3.9: Relative abundance of dusky flathead (standardised by gear type and net area)/1000 m^2 each trip during preliminary surveys (Jan 1996 to Nov 1996).

Table 3.4: Total catch of dusky flathead (in numbers) each sampling trip between January and November 1996.

Trip #	Month	# dusky flathead caught
1	January	31
2	February	24
3	March	48
4	April	4
5	May	27
6	June	14
7	July	15
8	August	5
9	September	19
10	October	6
11	November	29

The smallest dusky flathead taken during preliminary surveys was 6.0 cm (SL). We needed to investigate the seasonal abundance and habitat preferences of juveniles of a small size, given that BIARC was expecting to produce 30 to 50 mm SL dusky flathead fingerlings for stocking. Examining a size-frequency plot of estimated <1year old dusky flathead[1] caught during the first 12 months (Figure 3.10) indicated that we would need to examine fish <12 cm SL to maintain a meaningful sample size (ie n> 30). Analysing where these were caught during the preliminary surveys indicated that more juvenile dusky flathead were taken from sites sampled by fence nets (Table 3.5) and that juvenile dusky flathead preferred intertidal mud-sand and mud flats (Table 3.6), similar to larger dusky flathead (>12 cm SL) (Figure 3.10). Most juvenile dusky flathead (77%) were caught at sites between the Motorway Bridge and Dunethin Rock (refer to Appendix 13.2).

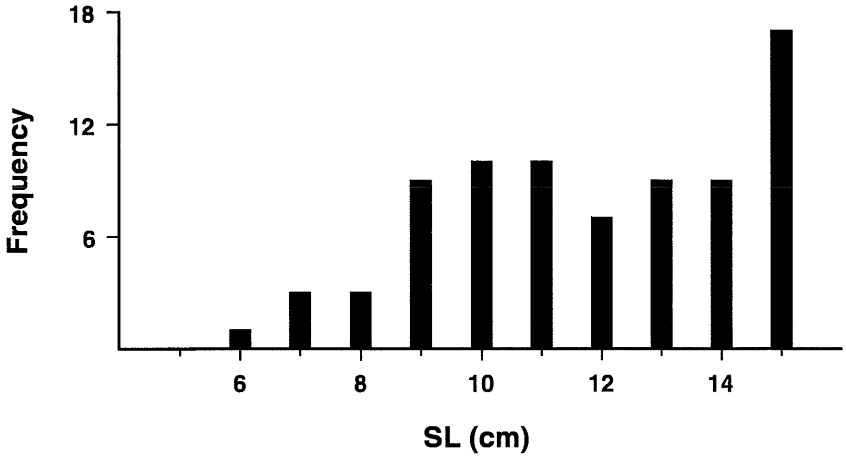
Table 3.5: Relative abundance of juvenile dusky flathead/1000 m^2 caught in each gear type during the preliminary surveys (January to November 1996).

Gear Type	relative catch (%)
Fence net	18
Ring net	21
Fyke net	0
Beam trawl	61

Table 3.6: Relative abundance of juvenile dusky flathead/1000 m^2 caught over each substrate class during the preliminary surveys (January to November 1996).

Substrate Type	relative catch (%)
Mud	34
Mud/sand	47
Beam trawl	19

Figure 3.10: Size frequency of dusky flathead <15 cm SL (estimated <1 year old) caught during the preliminary survey.



3.3.2 *Sand whiting*

A total of 3502 sand whiting were taken during preliminary surveys (January 1996 – March 1997). They ranged in size from 3.8 –34.4 cm SL with a mean of 10.19 cm (Figure 3.11). Their distribution was positively skewed (B = 2.35) and very leptokurtic (9.86). The majority of sand whiting were caught in the clearer waters

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[1] Size at age was determined from unpublished wild flathead growth data supplied by D. Cameron, DPI

downstream of the Motorway Bridge using ring nets (Table 3.7), where they appeared to prefer intertidal muddy-sand substrates (Table 3.8).

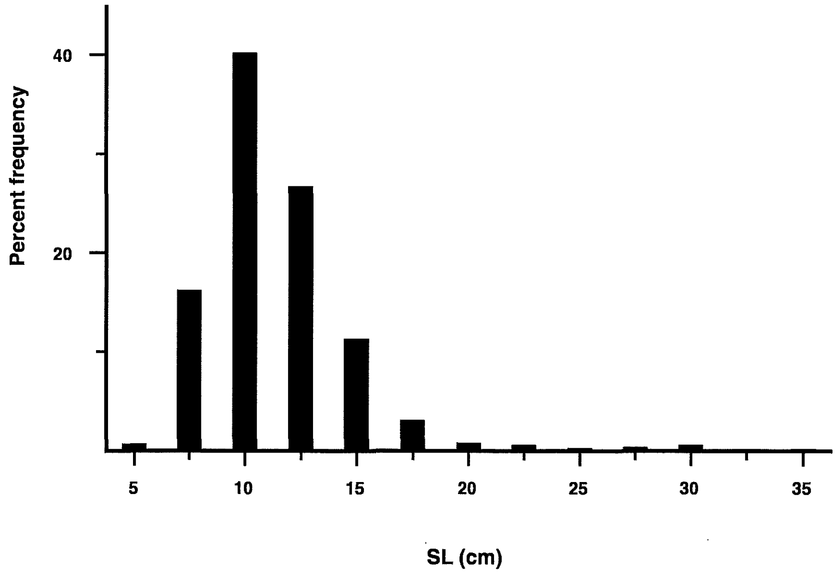

Figure 3.11: Length-frequency of all sand whiting caught during preliminary surveys (January 1996 to March 1997).

Table 3.7: Relative abundance of sand whiting/1000m^2 caught in each gear type during the preliminary surveys (January 1996 to March 1997).

Gear Type	relative catch (%)
Fence net	28
Ring net	55
Fyke net	11
Beam trawl	6

Table 3.8: Relative abundance of sand whiting/1000m^2 caught over each substrate class during the preliminary surveys (January 1996 to March 1997).

Substrate Type	relative catch (%)
Mud	34
Mud/sand	50
Beam trawl	16

Catches of sand whiting during the first sampling trip, in January 1996, were high (average of 33/site), but for the rest of the preliminary surveys they were less than 20/site (Figure 3.12). The large catch in the first survey was attributed to the fact that sites sampled in the first trip (1-11 and 13-14) were primarily downstream of the Motorway Bridge with sandy or mud/sandy sediments, whereas subsequent sample trips investigated sites with a wider variety of substrate types. The catch data (Table 3.9) were used to estimate the abundance of sand whiting in the Maroochy River.

Table 3.9: Total catch of sand whiting (in numbers) each sampling trip.

Trip #	Month	# sand whiting caught
1	January	467
2	February	230
3	March	286
4	April	220
5	May	268
6	June	219
7	July	116
8	August	250
9	September	146
10	October	126
11	November	277
12	December	131
13	January	98
14	February	456
15	March	212

The smallest sand whiting taken during preliminary surveys was 3.8 cm (SL). We needed to investigate the seasonal abundance and habitat preferences of juveniles in an appropriate size range, given that BIARC staff were expecting to produce 30 – 50 mm SL sand whiting fingerlings for stocking. A size-frequency plot of estimated <1 year old sand whiting[2] caught during the first 15 months (Figure 3.13) indicated that we would need to examine fish at least up to 10 cm SL to obtain an adequate sample size for analysing juvenile habitat preferences during the first 15 months.

Most juvenile sand whiting were caught in fence and ring nets (Table 3.10). Juvenile sand whiting (<10 cm SL) were more common on intertidal mud-sand flats (Table 3.11) than larger sand whiting (>10 cm SL) which were caught predominantly over sand substrates. Interestingly, juvenile sand whiting were taken in relatively equal proportions in all zones between the river mouth up to the islands upstream of the David Low Bridge, whereas the larger fish (>10 cm SL) were taken primarily below the Motorway Bridge.

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[2] age data was supplied from ISAMP sand whiting age-length key (Hoyle et al. 2000)

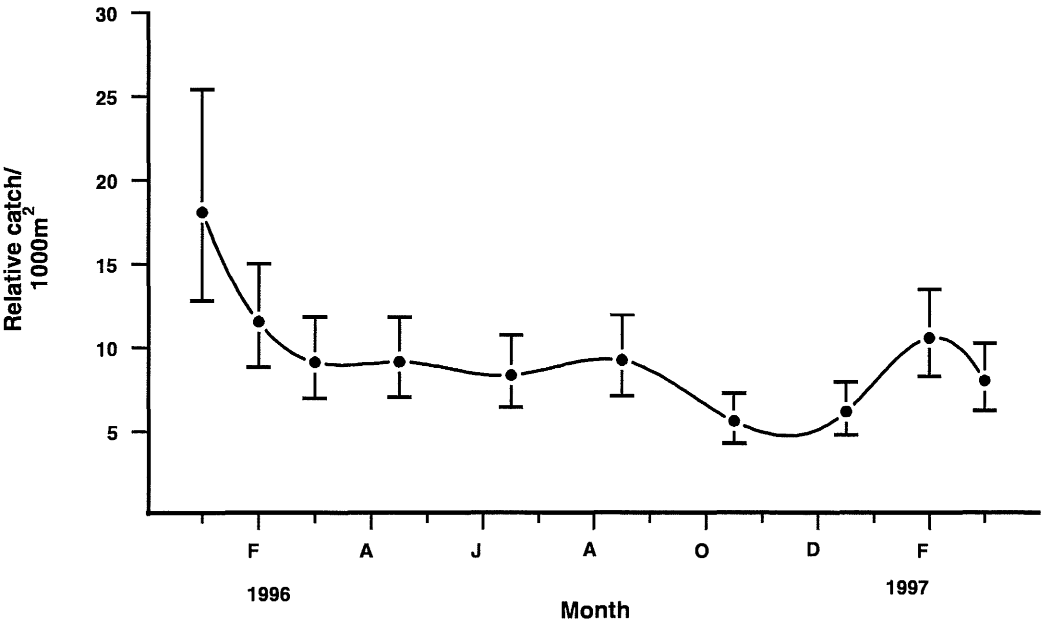


Figure 3.12: Relative catch of sand whiting each sampling trip (standardised by gear type and net area) during the preliminary survey (Jan 1996 to Mar 1997).

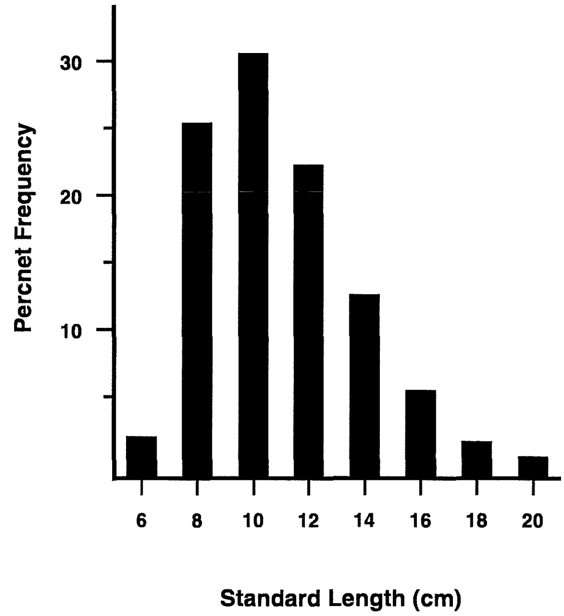


Figure 3.13: Relative size-frequency of sand whiting (estimated to be <1 yr old) taken during the preliminary surveys.

Table 3.10: Relative abundance of juvenile sand whiting/1000m^2 caught in each gear type during the preliminary surveys (January 1996 to March 1997).

Gear Type	relative catch (%)
Fence net	28
Ring net	55
Fyke net	11
Beam trawl	6

Table 3.11: Relative abundance of juvenile sand whiting/1000m^2 caught over each substrate class during the preliminary surveys (January 1996 to March 1997).

Substrate Type	relative catch (%)
Mud	34
Mud/sand	50
Beam trawl	16

3.4 DISCUSSION

During the pre-stocking surveys, detailed information was collected on the habitat preferences of juvenile and adult dusky flathead and sand whiting. The four main gear types used for sampling were fence, ring, fyke nets and beam trawling, although several seines nets and traps were also trialed. The deployment of each gear type was habitat and substrate dependent and together they consistently produced catches of the chosen species during each survey.

Dusky flathead were not as abundant as sand whiting in the Maroochy River. This probably reflects their higher trophic order. They displayed a strong preference for mud or mud-sand substrates, being far more abundant in the more turbid waters upstream of the Motorway Bridge than below. Fewer were caught in the river during the winter months, a time when they are commonly found in waters adjacent to the more protected ocean beaches (D. Cameron, personal communication 1995). There were large numbers of dusky flathead below minimum legal size (30 cm TL) in the catches. This was a direct consequence of the smaller mesh size used in the fishery-independent gear (13 mm for set nets and 25 mm for the beam trawl net) than commercial mesh sizes. The decision to define juvenile dusky flathead as being <12 cm SL was based on the need to have a sufficiently large sample to analyse for habitat preferences. Juveniles favoured intertidal muddy-sand flats between Coolum Creek and the Motorway Bridge. Juvenile numbers were low during the summer months of 1995/96 and increased over the year to late spring. Given that peak spawning occurs in spring to early summer, the fish appeared to take 10 to 12 months to grow to the minimum size that was caught in the research samples.

Sand whiting numbers were surprisingly high within the river system given the two major fish kills in the preceding years (1993 and 1994). This may have been due to large-scale migrations by sand whiting in and out of the river during and just after periods of large run-off. However, sampling during pre-stocking surveys failed to detect any trend in sand whiting numbers, suggesting a fairly stable resident population. The large numbers of juvenile sand whiting captured, by comparison to those of legal size (>23 cm TL), was a direct effect of the mesh size used in all gears. The decision to define juvenile sand whiting as those that were <10 cm SL was justified on the basis of providing adequate numbers of small sand whiting to examine their habitat preferences when developing a stocking protocol. Juvenile sand whiting occurred in a wider variety of habitat classes than adults and sub-adults did, apparently being restricted more by depth than substrate type, although few of either size category were found on muddy substrates. The failure to discern any trend in juvenile sand whiting abundance may result from the fact that this species has been reported to have a protracted spawning season (September to March) in southern Queensland waters (Morton 1985). We suspect they have a extended "trickle" recruitment pattern over nearly half of the year. This pattern could prove useful as the stocking was expected to supply a large recruitment pulse that should overshadow a natural "trickle" recruitment pattern.

In general, numbers of both flathead and sand whiting were variable during the pre-stocking surveys because of the large catches in one or two trips. This can be partially attributed to the sampling regime. After trip three, when the number of sites increased beyond 20, a decision was made to sample only half the sites each month to ensure that all nets would be set at high water. However, given the degree of variability of catches observed during the preliminary survey, the sampling regime was changed so all sites in the river were sampled each trip from January 1997 regardless of the state of the tide.

4 ESTIMATION OF DENSITY.

S. Knight, D. Mayer and A. Butcher

4.1 INTRODUCTION

If the aim of stocking is to increase the population size, then the population size must be estimated before and after to quantify success of the stocking operation (Solomon, 1988). More importantly, prior estimates of density are needed to determine appropriate stocking levels. The August 1994 scoping workshop, convened to preview the stocking program, estimated the density of the both species in the Pumicestone Passage, southern Queensland. However, these estimates became irrelevant when the target estuary for stocking was changed to the Maroochy River, on the recommendation of senior Fisheries managers. Estimates of the density of dusky flathead and sand whiting in the Maroochy River, as well as the expected levels of stocking and the post-stocking mortality (between stocking and recapture) were needed to give the BIARC production team an indicative target production level for supplying the stocking events. It was anticipated that the process would be repeated for each cycle of stocking, using the most up-to-date data available.

Following discussions with mathematicians, it was decided to use a Baysian approach to develop a Markov chain Monte Carlo simulation model (MCMC) to estimate the pre-stocking densities of the chosen species in the Maroochy River. This involved collaboration between DPI and staff and students from the Queensland University of Technology, Applied Mathematics Department. The model would also be used later to estimate whether stocking had any positive effect on post-stocking densities of the chosen species in the Maroochy River (Section 8.2).

4.2 METHODS

4.2.1 Markov chain Monte Carlo modelling

A multi-tiered model was developed to estimate densities of the chosen species using standard catch and auxiliary site data. The model used catch data from the 14 predefined habitat zones in the estuarine reaches of the river. Each zone was divided into several regions containing one or more sampling sites (see Appendix 13.2). The first tier of the model assumed a Poisson distribution of fish within each zone, for each time period. Within these sampling events, the fish were assumed to be randomly distributed, ie. no major schooling effect. However, within each region it was also assumed that there was a localised spatially-dependant variability, or 'neighbourliness', influenced by the number of fish in an adjacent region or zone. In each zone, the influence of neighbourliness increased with the length of the common boundary between adjacent zones/regions. The intensities of the Poisson distributions from each sample site were collectively modelled by a conditional autoregressive Gaussian process (Weir and Pettitt 1996).

The second tier of the model described the observed catch at each site as a binomial distribution with a known catch rate but unknown number (density) of fish that each gear-type had attempted to catch. The efficiencies of the four different types of sampling gear used were estimated from observational data and were to be refined later by independent net efficiency experiments.

The above two tiers required the estimation of six parameters (Table 4.1), and because the model used prior information, it also required specific prior distributions associated with each observation. The third tier of the model employed Markov chain Monte-Carlo (MCMC) methods to systematically simulate the population size from the full prior distribution. It updated all the variables, one at a time, to achieve the best estimate of each. The resulting estimates of abundance were then integrated and presented as fish numbers in a time × site matrix.

Table 4.1: Parameters used in the hierarchical model

Parameter	Description
x	set of "ideal" fish catch numbers
z	set of Poisson distribution intensities
c	set of catch rates for each gear type
α	the overall intensity of each region
β	the overall intensity for each trip
H	the neighbourliness intensity

4.2.2 General Methods

The MCMC model required a comma-delimited ascii file compiled from the catch data matrix of sites by trips across the maximum length of time available prior to the commencement of stocking, in order to estimate fish numbers in the whole river through time. The input file also required a table of neighbourliness, net area, region surface area, gear type and habitat code number (refer to Appendix 13.3). In addition, the model required 'seed' estimates for the prior distributions of gear efficiency. The gear type was a predetermined numerical code given to each net-type used. Net efficiencies were seeded with estimated percentage values of chosen species that were captured by the individual sampling gear: 95% for ring and fence nets, 92% for fyke nets and 25% for beam trawls. The catch data used are presented in Table 4.2.

A review of the available literature indicated that stocking mortality was variable and would probably be quite high (Inoue 1976, Tsukamoto et al. 1989, Kristiansen and Svåsand 1990). Coupled with this unknown was the lack of available information about expected mortality between stocking and recapture. Nor were we able to determine the density of fish smaller than our survey size range for dusky flathead (6.9 – 40.5 cm SL) or sand whiting (4.0 – 34.4 cm SL). Given this degree of uncertainty, and recognising that our density estimates would be less than the total numbers of all sizes of both species in the river, we used power analysis to examine our ability to detect any increase associated with the stocking. We used a technique similar to that of Gerrodette (1987) to model our ability to detect the effect of different stocking levels, given a range of predicted mortality rates. The model had several assumptions: 1) Stocking did not cause any displacement of natural stock, i.e. releases augmented the natural population, 2) there was no recruitment during the post-stocking sampling period, and 3) there were no other major effects on the population (such as fish kills or migration) during the course of the stocking program. The input parameters are given below in Table 4.3.

Table 4.2: Dusky flathead and sand whiting catch data from the preliminary surveys for input into the density estimating models. '-1' indicates no sampling was carried out at that site during that trip.

	Dusky Flathead						Sand whiting					
Site	Trip 1	Trip 2	Trip 3	Trip 4&5	Trip 6&7	Trip 8&9	Trip 1	Trip 2	Trip 3	Trip 4&5	Trip 6&7	Trip 8&9
1	3	0	1	3	0	2	35	24	29	22	24	16
2	1	0	7	2	1	0	65	12	85	18	43	12
3	0	2	0	0	1	0	19	20	13	10	10	15
4	5	0	0	1	0	2	25	4	24	61	14	69
5	1	0	0	1	2	1	43	3	3	5	15	33
6	1	0	2	2	2	1	21	20	4	61	27	44
7	2	1	1	0	6	0	51	9	10	23	71	47
8	2	2	0	0	2	0	21	17	16	50	66	12
9	-1	1	1	0	0	0	-1	6	2	9	9	30
10	-1	-1	0	0	0	0	-1	-1	0	0	1	0
11	-1	0	0	0	0	-1	-1	1	4	0	0	-1
12	-1	0	0	0	1	0	-1	1	1	1	6	0
13	-1	0	0	1	3	0	-1	6	5	1	0	3
14	-1	0	0	3	3	0	-1	5	0	0	0	0
15	-1	1	0	0	1	0	-1	1	0	0	0	0
16	-1	0	0	0	4	0	-1	0	0	0	0	0
17	0	1	-1	1	0	2	18	13	-1	4	7	21
18	2	0	1	2	2	4	3	2	6	2	1	1
19	-1	6	15	2	0	6	-1	0	22	11	11	4
20	7	5	4	1	1	3	22	56	15	96	19	29
21	7	5	15	5	0	2	136	23	43	113	7	59
22	0	0	1	3	0	0	7	7	4	0	4	1
23	-1	-1	0	4	0	0	-1	-1	0	1	0	0
24	-1	0	0	0	0	1	-1	0	0	0	0	0
26	-1	0	0	0	0	0	-1	0	0	0	0	0
28	-1	-1	-1	-1	0	0	-1	-1	-1	-1	0	0
29	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
30	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
31	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1

Table 4.3: Input parameters for power analysis

Parameter	Dusky flathead value	Sand whiting value
Population size (N)	60 000	350 000
Number of samples collected prior to stocking	6	6
Number of samples between stocking and average recapture	5	7
Coefficient of variation	0.2	0.03
Mortality ($m_{stocking}$ and $m_{recapture}$)	0.50 $\pm$ 0.25	0.50 $\pm$ 0.25
Significance level (α)	0.05	0.05

Mortality values used in the model refer to the relative proportion of fingerlings that suffered mortality associated with each time segment of the stocking process. The parameter "$m_{stocking}$" was associated with harvest, transport and stocking in the river. The parameter "$m_{recapture}$" referred to the expected natural mortality between stocking and the time that an average fingerling might expect to be recaptured by fishery-independent sampling. These values ranged from 0.06 ($m_{stocking} = 0.25$ x $m_{recapture} = 0.25$) to 0.56 ($m_{stocking} = 0.75$ x $m_{recapture} = 0.75$), with the average being 0.25 ($m_{stocking} = 0.5$ x $m_{recapture} = 0.5$).

4.3 RESULTS

4.3.1 Markov chain Monte Carlo

There was a 1–2 month time delay between field sampling and data processing for analysis in the model. The production team required an indication of numbers of fry needed for stocking some six weeks prior to the first dusky flathead stocking event planned in December 1996. This meant that only the data from the first nine trips were available for inclusion in the initial density estimates models. During the first 9 months of the preliminary survey, some 149 dusky flathead and 2163 sand whiting were caught. The average catch was 25 dusky flathead and 351 sand whiting. However, these catches were highly variable (15–43 dusky flathead and 224–484 sand whiting).

The MCMC model was run for 11 000 iterations. The model systematically changed each parameter by a value between zero and one, then produced an estimate of fish density. The results from the first 1000–1500 iterations were deleted from the analysis because the model often took this long to converge into an acceptable estimate area (parameter change values between 0.3 to 0.7). The neighbourliness parameter (H) was not significantly different from zero, but was retained in the model. The MCMC estimates of fish numbers, in the entire river, integrated from the posterior distributions of all parameters, are presented in Table 4.4. These estimates are for all the size-ranges observed in the fishery-independent survey and would have been larger if we had been able to sample the total population.

Table 4.4: Pre-stocking estimates of density of dusky flathead (>6 cm SL) and sand whiting (> 4 cm SL), along with their SD from Markov chain Monte Carlo models.

Month	Dusky Flathead	SD	Sand whiting	SD
Jan	29 067	2 018	354 144	3 615
Feb	55 894	10 684	179 003	10 680
Mar	35 163	13 346	230 734	10 614
Apr/May	42 110	15 492	346 485	9 051
Jun/Jul	53 652	11 625	237 117	10 839
Aug/Sep	61 955	13 915	285 489	10 231
Av.	46 307	11 180	272 162	9 172

A total population estimate of each species was obtained by multiplying the average fishery-independent survey derived density estimate (Table 4.4) by a factor of 1.25, and rounding to the nearest 1000. The multiplication factor was a conservative estimate of additional numbers of fish below the fishery-independent surveys size-range. The total population estimates were 60–70,000 dusky flathead and 340–350,000 summer whiting.

4.3.2 Power Analysis

The coefficient of variation for dusky flathead (0.2) was much larger than that of sand whiting (0.03) which reflects the difference in the density estimates between both species. If we assumed average survival for dusky flathead (50% stocking mortality and 50% post-stocking mortality), then reasonable power to correctly identify an effect from stocking is achieved at a stocking level around 75 000 fingerlings (Figure 4.1). Similarly, for sand whiting a stocking level of around 80 000 fingerlings would be adequate (Figure 4.2). However, if mortality rates were higher, then stocking levels greater than 100 000 (dusky flathead) and 350 000 (sand whiting) would be required. Alternatively, if mortality rates were low, then only 30 000 dusky flathead and 50 000 sand whiting fingerlings would be required to achieve a measurable change in population levels.

Given that this was the first time such a large stocking had been undertaken in Queensland, we set target stocking figures based on two major assumptions: 1) Within reason, overstocking would be better than understocking for detecting a change in density, and 2) Mortality rates would probably be in the higher end of conceivable possibilities. However, we considered that stocking with levels that were higher than our estimated natural population estimates would have a major impact on natural genetic diversity. Thus we set the target stocking levels equivalent to our fishery-independent estimates of dusky flathead (60–65 000) and summer whiting (250–350 000) densities.

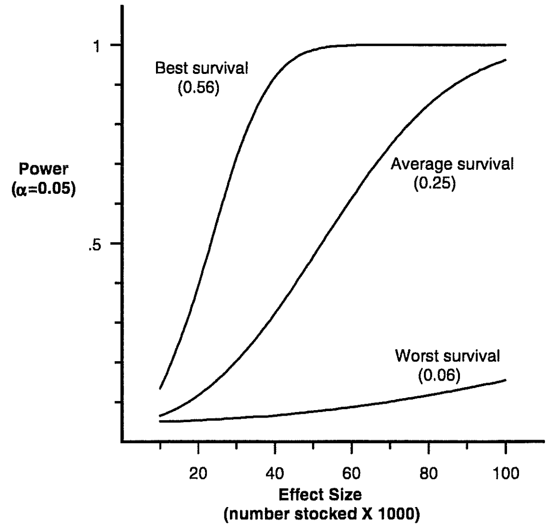


Figure 4.1: Power Analysis of various dusky flathead stocking rates given variable stocking and post-stocking mortalities.

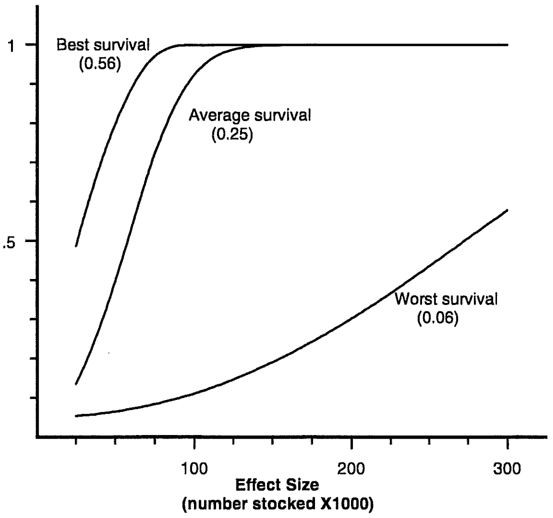


Figure 4.2: Power Analysis of various sand whiting stocking rates given variable stocking and post-stocking mortalities.

4.4 DISCUSSION

Estimating the densities of dusky flathead and sand whiting in the Maroochy River using an MCMC model involved several major assumptions (Knight 1996). The first of these was that gear efficiency remained constant. This implied that variation in sample catches was therefore attributable to natural phenomena, relating to natural fluctuations in the population size of each species, rather than variation in sampling effectiveness. Great care was taken to ensure that sampling procedures were applied consistently over successive surveys, but factors such as water turbidity and cloud cover (increasing urban light reflection) may have influenced gear efficiency.

The second assumption was that our estimates of gear efficiency were accurate. The size selectivity of the gear is an important issue to which the model proved very sensitive. It was not possible to run a gear standardisation experiment during the preliminary surveys with the level of resources available at the time. This was accepted as a shortcoming of the estimation process that would be rectified at a later date (see Section 8.2.1.1). It was assumed that if we used a conservative guess of net efficiency, then the resulting density estimates would be acceptable, or at worst, over-estimates. This would influence the stocking rate by requiring a higher than necessary number of fry for the stocking. However, in an experiment aimed at determining whether an effect of stocking could be detected, it was deemed preferable to overstock (within reason) rather than understock.

Power analysis of our ability to detect a change following stocking was strongly influenced by two factors: 1) total population estimates and 2) estimates of stocked fingerling mortality.

Model derived density estimates were restricted to the survey size-range for each species and it was difficult to accurately extrapolate these out to total river population estimates. There were no data available in the literature and discussions with population dynamicists and fisheries biologists provided no clear direction. We concluded that a multiplication factor of 1.25 would provide a conservative estimate of the total population. This was a complex problem and will require further examination in future stocking programs.

Previous stocking work had demonstrated that mortality associated with stocking was highly variable (Inoue 1976, Tsukamoto et al. 1989, Kristiansen and Svåsand 1990). For this experiment, we examined the effect of a range of mortalities (0.5 ± 0.25) and found that power to detect a change was very sensitive to mortality. Again, erring on the side of caution, we used the most pessimistic mortality estimates when setting our target production figures.

We recognised the concerns raised by several authors about inbreeding and the concept of applying conservation genetics to stocking operations (McGinnis 1994, Blankenship and Leber 1995, Cottrell et al. 1995, Kincaid 1995, Radonski and Loftus 1995, Gaffney et al. 1996, Travis et al. 1998).

Taking the above issues into account, we set target stocking levels to maximise our chance of detecting a change in the population density of each species.

The modelling process was not updated with additional catch data prior to the first sand whiting stocking, planned for April 1997, because of the unavailability of QUT staff. The model has since been converted to PC format and was applied to the complete data set from 31 sampling exercises to determine whether the effect of stocking could be measured. This is described and discussed later in Section 8.

5 DEVELOP THE EXPERTISE AND TECHNOLOGY TO INDUCE CAPTIVE DUSKY FLATHEAD AND SAND WHITING TO SPAWN ON DEMAND.

P.Palmer, J. Burke, M.Burke, K.Cowden, J. McGuren and A. Butcher

5.1 INTRODUCTION

Two general problems have restricted the development of marine stock enhancement technology this century—a lack of evaluation capability and the inability to culture marine fishes beyond early larval stages (Blankenship and Leber 1995). However, advances in aquaculture of marine fish have recently resulted in profitable ventures (Richards and Edwards 1986). This success has led to a resurgence of community support, in particular from the recreational sector, for the concept of stocking in marine environments. Researchers at the Bribie Island Aquaculture Research Centre (BIARC) have pioneered the development of culture technology for several fish in subtropical environments including Australian bass (Burke 1994) and barramundi (Palmer et al. 1992).

At the 1994 scoping workshop, there was much debate on the selection of suitable species for stocking. The preferred species at that time were dusky flathead (*Platycephalus fuscus*) and sand whiting, (*Sillago ciliata*). There was no evidence in the literature that dusky flathead had been bred and reared under aquaculture conditions. Sand whiting had been reared successfully in the laboratory, on a small scale (Battaglene et al. 1994). It was recognised, at the workshop, that the choice of species might have to be reviewed in light of further culture research.

The task of the hatchery team at BIARC was to establish reliable mass hatching and rearing techniques for the two chosen species. The initial approach taken was to explore the application of hormone-induced spawning methods in conjunction with "green-water culture" (GWC) rearing methods previously developed and proven for barramundi (*Lates calcarifer*) (Palmer et al. 1994). It was expected that some variations in procedures would be required to take into account the biological differences of the nominated species.

5.2 METHODS

The development of appropriate breeding technology involved the following components:

- collection and domestication of broodstock (from the general area to be stocked, to alleviate any genetic translocation concerns),
- conditioning of broodstock (appropriate nutrition, water quality and photoperiod control),
- induced spawning of broodstock with hormone injection, LHRHa,
- stripping of eggs, semen and artificial insemination (alternatively collect fertilised eggs from the spawning tank),
- incubation and hatching of fertilised eggs,

- culture of larvae (intensive hatchery-based green-water cultures),
- culture of fry (semi-intensive outdoor nursery-pond cultures),
- harvest of fingerlings from culture ponds, and
- development of Health Assessment Index (HAI),

5.2.1 Broodstock

Broodstock collection for the program began in 1995 and spanned the coastal regions between the Maroochy River and Jumpinpin Bar in southeast Queensland. Mature specimens of both species were obtained from local recreational and commercial fishers. New broodstock were subjected to a two-week quarantine period prior to placement in tanks with existing broodstock. A broodstock rotation system was adopted so that 50% of the broodstock that contributed to stocked fingerlings in any particular year were replaced with wild fish.

Specimens of each species were maintained in covered tanks with dim (<20%) natural light and flow-through seawater at ambient temperatures. Even though both species are known to bury into benthic substrates in the wild, no substrates were used. This was done to facilitate monitoring of broodstock condition, tank cleaning and long-term hygiene. Dusky flathead were housed in 10,000 litre fibreglass tanks (up to 25 fish between 0.5 kg and 5.0 kg fish/tank) with a ratio of 2:1 females to males, and fed chopped pilchards with vitamin supplements every second day (Figure 5.1). Sand whiting broodstock were housed in 5,000 litre fibreglass tanks at an approximately even sex ratio (up to 50 x 600 g fish/tank). They were alternately fed chopped prawn, chopped squid, or barramundi grower-pellets previously soaked with vitamin supplements every second day (Figure 5.2). Broodstock adapted well to these captive conditions and there were no disease outbreaks.

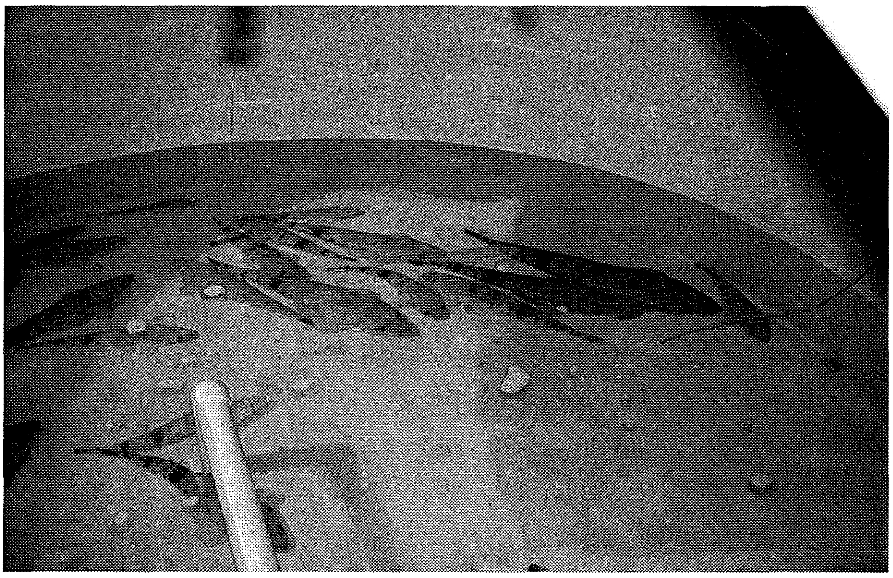


Figure 5.1: Dusky flathead broodstock kept in a barren tank at BIARC.

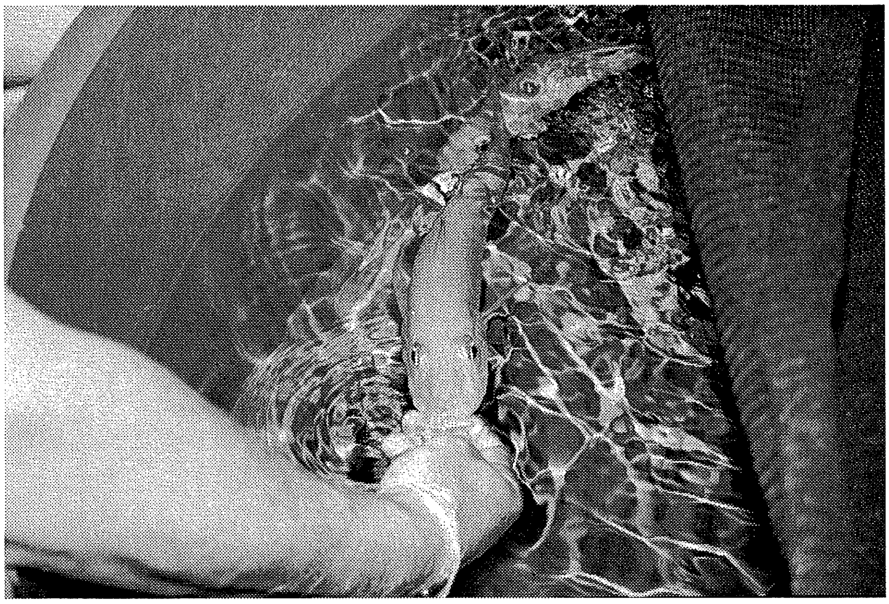


Figure 5.2: Sand whiting broodstock were kept in barren tanks at BIARC.

5.2.2 Spawning

During the course of this exercise, fish were only spawned during times when peak reproductive activity would naturally be occurring in wild local stocks of the particular species. This enabled augmentation of broodstock contributions (to enhance genetic diversity) when required. A single injection of LHRHa (25–30 µg/kg body weight) was used to stimulate ovulation in both species (Figure 5.3). Utilising group or mass spawning techniques ensured maximum genetic diversity in sand whiting progeny. With dusky flathead, this was achieved by artificially combining eggs and sperm from several donors of each sex.

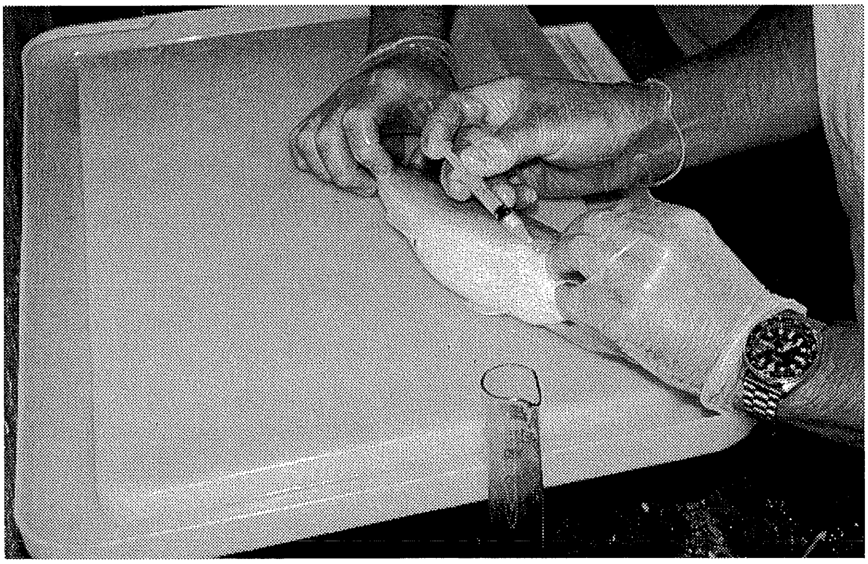


Figure 5.3: Injecting sand whiting broodstock with LHRHa to stimulate ovulation.

5.2.3 Larval rearing and nursery pond culture

The larval culture methods, first described by Palmer et al. (1992) for barramundi, were adapted at BIARC to grow sand whiting and dusky flathead larvae to a length of 9-10 mm. The closely managed larval culture process can generally be described as follows:

Fertilised eggs/embryos were incubated in 1000 litre tanks with filtered seawater until the larvae hatched. As the larvae depleted their egg yolk and began to open their mouths, they were transferred (prior to first feed — day 3) into static aerated greenwater (*Nannochloropsis oculata*) cultures (GWC's) (Figure 5.4), with ongoing maintenance of plankton feed densities (rotifers and brine shrimp) and water qualities (salinity of $30^{0}/_{00}$, pH 7.8-8.4, total ammonia <1ppm).

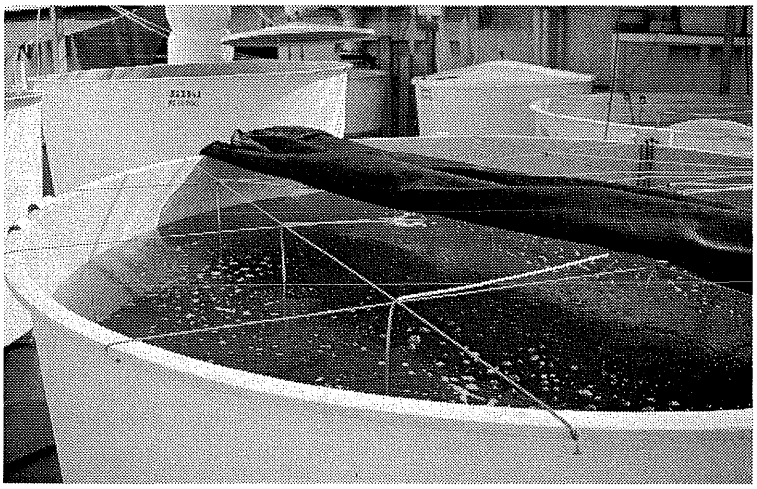


Figure 5.4: Outdoor GWC nursery tanks containing dusky flathead fry.

Fish cultures were augmented daily with algae and with 10 g Frippack™ Booster (2.5–20μ). Fry of both species were harvested from green-water cultures between days 18 and 22. At harvest they were concentrated in black 500 l hemispherical tanks for estimation of numbers prior to distribution into previously prepared outdoor saltwater nursery ponds.

Fingerling production ponds were necessary for the enhancement program, both because of the large numbers of fingerlings required and the preferred size of the fingerlings at release. These nursery pond cultures used a similar approach to that previously used successfully for barramundi at BIARC (Palmer et al. 1992, 1994), and were managed according to the methods recently described by McGuren and Palmer (1997). Considerable effort was directed towards improving pond management strategies to maximise growth and survival of stocked fry in plastic lined rather than earthen ponds.

Two sequential plankton pond phases were necessary to produce fingerlings in the 40 to 50 mm total-length range. As dusky flathead did not wean onto artificial diets easily, a live zooplankton diet was needed for producing fingerlings. By way of contrast, sand whiting weaned easily onto a variety of artificial feeds in ponds when live-feed sources (planktonic and benthic organisms) were exhausted. Supplementation of existing zooplankton, by stocking *Artemia sp.* into the ponds several days prior to the introduction of fry, was unsuccessful because of the high variability in survival of *Artemia sp.*.

5.2.4 Enumeration

Stocking and harvest density estimates were undertaken in several ways, depending on the size of fish. Numbers of larvae stocked into greenwater cultures, and numbers of 9–10 mm fry harvested, were estimated by taking volumetric samples of water from well-mixed conical or hemispherical tanks, respectively. Harvest estimates for nursery ponds were undertaken by tallying the number of volumetric vessels of fingerlings with similar densities (visually adjusted) to a standard volumetric vessel of known density (Figure 5.5). However, achieving precision was difficult, especially when counting larvae at the end of the GWC period. At that stage larvae were still only 11–15mm long and in a very rudimentary stage of development. Accurate enumeration of such fragile larvae was impossible, even when using a series of ten sub-samples/tank. However, the estimates were a necessary guide to final pond stocking densities and should be viewed as such rather than an attempt to achieve mathematical precision.

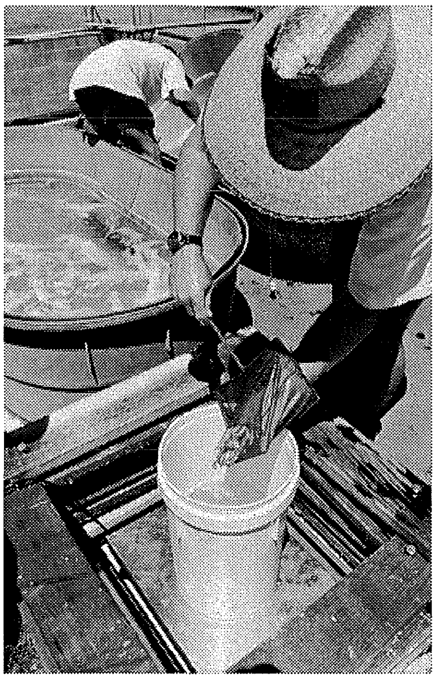


Figure 5.5: Counting fingerlings into a known volume of water.

5.2.5 Harvest

The floors of the BIARC ponds gradually slope towards the exit monk (a sunken concrete-lined pit external to and below the pond floor) and fish are collected externally in a harvest pit (Figure 5.6). Standard harvest procedures were applied and no major losses were incurred apart from some entanglement of dusky flathead in filamentous algae on the pond bottom when appropriate turbidity levels could not be maintained. Sub-samples of harvested fingerlings were rated with a Health Assessment Index (HAI) modified from a method published by Adams et al. (1993). The method involved examining a sub-sample of fingerlings macroscopically to assess the overall health of the population. A score (0–3) was assigned according to the normality or otherwise of: fins, eyes, gills, liver, spleen, kidney, gall and presence of mesenteric fat according to the list in Table 5.1. A score was also assigned according to the level of gill and whitespot infection. A minimum sample of 10–20 individuals was taken from each batch of fish. To calculate an HAI for each fish within a sample, numerical values for all parameters are summed. Using the ten separate criteria nominated, the worst possible score was 30 while the best score was zero. The population HAI was the mean (with a standard deviation) of the individual scores. The HAI was not designed to be diagnostic but rather to provide a simple health profile of the sampled population without the use of specialised laboratory facilities.

Figure 5.6: Draining a growout pond into the sunken concrete-lined monk. Fingerlings are captured in large tanks placed under the white drainpipe.

Table 5.1: Parameters and scoring system used in the HAI.

FINS	All fins & other extremities intact	0	KIDNEY	Firm, dark red, flat	0
	Previous damage – healed over	1		Swollen, wholly or in part	1
	Mild damage &/or slight haemorrhage	2		Mottled, grey discolouration	2
	Sever erosion & haemorrhage/infection	3		Granular &/or inclusions	3
EYES	Good clean eyes	0	BILE	Straw colour, part full/empty	0
	One or both eyes opaque	1		Light to grass green, full	1
	One or both eyes protruding	2		Yellow, full	2
	One or both eyes bleeding	3		Dark green/blue, full	3
GILLS	Normal	0	FAT	>50% coverage	0
	Ragged tips	1		25 to 50% coverage	1
	Clubbed	2		<25% coverage	2
	Pale	3		No fat deposits present	3
LIVER	Normal red	0	WHITESPOT	No observed parasites	0
	Pale red	1		Few observed fungal spots	1
	Nodules	2		Moderate fungal infestation	2
	Coffe coloured (fatty)	3		Heavy fungal infestation	3
SPLEEN	Black, dark red, red	0	TREMATODES	No observed parasites	0
	Enlarged	1		Few observed parasites	1
	Nodules	2		Moderate parasite infestation	2
	Gross aberrations	3		Heavy parasite infestation	3

5.3 RESULTS

5.3.1 Broodstock

Broodstock were successfully held in captivity for the duration of the project. There were no mortalities recorded, and spent fish were returned to the wild as new animals were introduced.

5.3.2 Spawning

Spontaneous spawning was observed once with sand whiting, but on every other occasion both species required hormone therapies to initiate final maturation. A single injection of LHRHa (25–30 µg/kg body weight) was sufficient to stimulate ovulation in both species. Sand whiting readily released and fertilised their eggs without further manipulation. However, being a group spawner they did require the presence of several fish to initiate spawning behaviour. Dusky flathead broodstock did not release eggs following ovulation, and therefore required stripping. Captive dusky flathead males yielded adequate quantities of milt for fertilisation, and were successfully stripped more than once in a season. Females were assessed hourly close to ovulation and stripping commenced when the eggs were visually assessed to be at the point of ovulation.

5.3.3 Larval rearing

Green-water larval cultures regularly produced high quality fingerlings after a culture period of approximately three weeks. Survival rates in these cultures were routinely high (Tables 5.2–5.6) but the estimates of survival suffered from the imprecision of sub-sampling from non-homogenous populations.

Table 5.2: Estimated survival of dusky flathead and sand whiting larvae from GWC's during 1995 production run.

Species	Tank number	Estimated number stocked [a]±s.e.	Estimated number harvested [b]±s.e.	Estimated survival (%)
Flathead	1	74 067 ± 4000	11 9620 ± 4000	161
	2	49 980 ± 3000	48 160 ± 2000	96
	3	99 733 ± 6000	11 4720 ± 2000	115
Whiting	1	84 493 ± 15 000	92 236 ± 4000	109
	2	84 493 ± 15 000	79 012 ± 16 000	94
	3	84 493 ± 15 000	68 384 ± 8000	81

[a] = #'s based on volumetric allocation (n=3), [b] = #'s based on Palmer et al., 1992. GWC methods (n=10)

Table 5.3: Estimated survival of dusky flathead and sand whiting larvae from GWC's during 1996 production run.

Species	Tank number	Estimated number stocked [a]±s.e.	Estimated number harvested [b]±s.e.	Estimated survival (%)
Flathead	1	58 400 ± 2000	43 650 ± 3000	75
	2	82 800 ± 6000	55 500 ± 2000	67
	3	58 400 ± 2000	50 925 ± 2000	87
Whiting	1	110 203 ± 4000	120 975 ± 22 000	100
	2	76 428 ± 8000	74 700 ± 8000	98
	3	281 875 ± 18 000	267 750 ± 6000	95

[a] = #'s based on volumetric allocation (n=3), [b] = #'s based on Palmer et al., 1992. GWC methods (n=10)

Table 5.4: Estimated survival of dusky flathead and sand whiting larvae from GWC's during 1997 production run.

Species	Tank number	Estimated number stocked [a]±s.e.	Estimated number harvested [b]±s.e.	Estimated survival (%)
Flathead	1	108 650 ± 18 000	132 800 ± 2000	122
	2	108 650 ± 18 000	114 500 ± 7000	105
	3	108 650 ± 18 000	108 200 ± 7000	100
Whiting	1	215 160 ± 36 000	267 750 ± 13 000	125
	2	215 160 ± 36 000	267 750 ± 13 000	125
	3	215 160 ± 36 000	267 750 ± 13 000	125

[a] = #'s based on volumetric allocation (n=3), [b] = #'s based on Palmer et al., 1992. GWC methods (n=10)

Table 5.5: Estimated survival of sand whiting larvae from GWC's during 1998 production run.

Species	Tank number	Estimated number stocked [a]	Estimated number harvested [b]±s.e.	Estimated survival (%)
Whiting	1	150 000	88 000 ± 15 000	59
	2	150 000	126 000 ± 50 000	84
	3	150 000	137 000 ± 26 000	91

[a] = #'s based on volumetric allocation (n=3), [b] = #'s based on Palmer et al., 1992. GWC methods (n=10)

5.3.4 Nursery pond culture

Up to 80 000 fry/0.04 ha nursery pond was found to be a manageable stocking density for a 3—week growth period following the hatchery based green-water culture phase of growout. However, the irregular development of copepod and zooplankton assemblages using standard pond fertilisation regimes resulted in widely variable survival during these outdoor-pond stages (Tables 5.6–5.9).

Table 5.6: Estimated survival of dusky flathead and sand whiting fry in nursery ponds during 1995 production run.

Species	Pond #	1st Nursery Stocking [a]	Harvest [b]	Estimated Survival (%) [c]	2nd Nursery Stocking [a]	Harvest [b]	Estimated Survival (%) [c]
Flathead	1	112 000	22 000	19	22 000	13 000	58[d]
	2	117 000	45 000	39	45 000	9000	20[d]
	3	2600	2000	69			
Whiting	1	85 000 ± 4000	66 000[e]	77			

[a] = numbers based on volumetric allocation, [b] = as per pond harvest methods, [c] = assumed 100% is maximum possible, [d] = poor survival due to benthic algal material, [e] = ministerial release of 12,000 fry.

Table 5.7: Estimated survival of dusky flathead and sand whiting fry in nursery ponds during 1996 production run.

Species	Pond #	1st Nursery Stocking [a]	Harvest [b]	Estimated Survival (%) [c]	2nd Nursery Stocking [a]	Harvest [b]	Estimated Survival (%) [c]
Flathead	1	43 000 ± 3000	51 000	100	51 000	30 000 ± 2000[d]	60
	2	55 000 ± 2000	40 000	72	40 000	17 000 ± 1000[d]	44
	3	51 000 ± 2000	50 000	99	50 000	34 000 ± 1000[e]	67
Whiting	1	96 000 ± 19000	37 000	39	24 000	19 000[f]	79
	2	65 000 ± 8000	35 000	54	33 000	17 000[f]	50
	3	268 000 ± 6000	150 000	56	50 000	30 000[f]	61
	4	14 000± 3000	12 000	85	12 000	5000[f]	42

[a] = numbers based on volumetric allocation, [b] = as per pond harvest methods, [c] = assumed 100% is maximum possible, [d] = fish released at Cod Hole, Maroochy River, [e] = fish released at David Low Bridge, Maroochy River, [f] = fish not released (kept for further research).

Table 5.8: Estimated survival of dusky flathead and sand whiting fry in nursery ponds during 1997 production run

Species	Pond #	1st Nursery Stocking [a]	Harvest [b]	Estimated Survival (%) [c]	2nd Nursery Stocking [a]	Harvest [b]	Estimated Survival (%) [c]
Flathead	1	190 000	29 000	15[d]	29 000	18 000[e]	63
	2	165 000	19 000[e]	12[d]			
Whiting	1	268 000	170 000	63	166 000	101 000	61
	2	268 000	161 000[f]	60			
	3	268 000	150 000[f]	56			

. [a] = numbers based on volumetric allocation, [b] = as per pond harvest methods, [c] = assumed 100% is maximum possible, [d] = poor survival due to benthic algal material, [e] = fish released at Picnic Point, Maroochy River, [e] = fish released in Maroochy River.

Table 5.9: Estimated survival of sand whiting fry in nursery ponds during 1998 production run.

Pond #	1st Nursery		Estimated	2nd Nursery		Estimated
	Stocking[a]	Harvest[b]	Survival (%)[c]	Stocking[a]	Harvest[b]	Survival (%)[c]
1	55 000 ± 16 000	25000	45	25 000	20 000	79
2	100 000 ± 47 000	55000	55	55 000	56 000	102
3	94 000 ± 27 000	40000	42	40 000	38 000	94

[a] = numbers based on volumetric allocation, [b] = as per pond harvest methods, [c] = assumed 100% is maximum possible.

5.3.5 Harvest

A total of 137 500 dusky flathead fingerlings and 499 500 sand whiting fingerlings were produced for stocking during this program, although not all of these were released in the Maroochy River. More sand whiting than dusky flathead were produced because of the anticipated need for greater numbers of sand whiting to detect a 'pulse' of hatchery-reared fish in follow-up surveys.

Over a series of six different harvests, sand whiting fingerlings consistently scored a HAI in the range of 4 to 5, while dusky flathead fingerlings scored in the range of 6 to 7. These sub-sample scores are an indication of the overall health of the fish produced.

5.4 DISCUSSION

The early success of attempts at mass production of both species reflected the choice of appropriate methodology (green-water culture), the availability of appropriate facilities (hatchery and ponds) and the presence of skilled staff based at BIARC. Production was further facilitated by the relative ease of access to broodstock, provided by both commercial and recreational fishers. Suitable stocking quantities of fingerlings were produced very early in the Maroochy River Pilot Stocking Program. In fact some 23 500 dusky flathead and nearly 150 000 sand whiting were produced prior to the pre-stocking surveys being completed. Many of these fingerlings were used in a number of experimental applications including university research projects, commercial recirculating systems and grow-out trials in commercial aquaculture farms. The supply of adequate numbers of fingerlings was never a constraint during the pilot study, even though neither of the chosen species had been the subject of serious production efforts previously.

Accurate enumeration of production numbers was difficult. However, to obtain precise counts would have involved subjecting fingerlings to unnecessary stress. This led to some implausible survival estimates (>100%), which, while obviously inaccurate, were indicative of the high survival rates achieved in GWC and other growout phases.

A major constraint to production of fingerlings was the variability of pond plankton performance. Results in terms of growth and survival appeared to be closely related to the amounts of zooplankton available in the ponds, in conjunction with stocking rates. A number of pond fertilisation and seeding procedures was attempted but the unpredictability of pond dynamics was always in evidence. Variable intake water quality and the use of plastic lined ponds were probably the main contributors to the lack of long-term productivity in the ponds. The practise of seeding nursery ponds with newly hatched *Artemia sp.* several days before stocking with fry proved a useful way of ensuring an initial adequate food source, but the survival of the *Artemia sp.* was too variable to rely on this strategy alone. Considerable effort was directed towards improving pond management, but the small number of available ponds, combined with the large number of fingerlings required, precluded any statistical evaluation of pond performance.

A further constraint to production was the delay in the development of the statistical model on which the survey was based. This meant that target figures for release were not available until well into the production runs. Efforts to maximise production may have contributed to over-stocking and consequently poor survival. It appears that lower stocking rates may have resulted in higher survival, particularly during the first dusky flathead nursery pond stage. The best survival of dusky flathead fingerlings (71–99%) was in 1996 (Table 5.6) when the nursery ponds were stocked at 40–50 000/0.04 ha pond. The poorest survival of dusky flathead fingerlings (11–15%) was in 1997 (Table 5.8) when they were stocked at between 160–190,000/0.04 ha pond. Sand whiting fingerlings did not show such a clear trend, with stocking rates of 80 000 fingerlings/0.04 ha nursery pond deemed a manageable stocking density, but only when copepods or *Artemia sp.* supplements bloomed successfully. The density of planktonic food remaining in the pond largely determined the timing of the transfer from nursery ponds to the larger grow-out ponds.

An alternative strategy could be to sequentially fertilise a number of ponds in excess to requirements so that those developing the most productive blooms could be used. This would depend on the availability of suitable ponds and prior knowledge of the numbers of fingerlings required.

Qualitative weaning schedules revealed a persistent reluctance by dusky flathead to accept artificial diets. In contrast, sand whiting weaned readily in the pond. As a consequence of this behaviour, it was possible to supplement sand whiting ponds when the plankton crop failed. This procedure was of no benefit to the dusky flathead. Observations of cannibalism in juvenile dusky flathead suggested that lower survival rates may have been attributable to the failure of plankton blooms in the ponds and subsequent predation by the larger juvenile individuals. Over-stocking would exacerbate this situation.

A further complication arising from the variability of pond performance was the development of filamentous algae on the pond bottom during the growout phase. This occurred when the bloom diminished and the water cleared. Once it became established, this type of alga was difficult to control, and it was a major entanglement hazard for juvenile dusky flathead (a benthic species) during harvest.

To quantify the physical/physiological condition of the fingerlings, a health assessment index was developed along the lines of routine procedures used in stocking programs in the USA (Adams et al. 1993). Provided the health assessment is based on a statistically robust sampling regime, it should be applied generally to all future stocking programs. Suitably trained staff can quickly perform the examination using a low power compound microscope. Consistent application of a health assessment would introduce a high level of quality assurance into the supply of fingerlings.

6 DEVELOP MONITORING PROTOCOLS

P.Palmer, D. Willett, J. Burke, M. Burke, J. McGuren, A. Butcher, M. Johnston, D. Smallwood and D. Mayer

6.1 INTRODUCTION

Monitoring the effectiveness of stocking requires a method to easily identify hatchery-bred fish after their release and subsequent capture. The method has to be easy to apply to large numbers of fish simultaneously, should not affect survival or growth, should be retained on the fish for the duration of their life and be relatively inexpensive. During the scoping workshop (August 1994) four methods were considered;

- genetic markers
- micro-wire tags
- scale-pattern analysis
- chemical marking to stain otoliths.

The workshop participants concluded that logistic constraints in collecting and maintaining broodstock with a suitably large genetic diversity negated the use of genetic markers as a method for the initial stocking program. Similarly, micro-wire tagging was also rejected as too expensive and laborious, given the large number of animals to be marked. However, the use of both chemical marking and scale recognition techniques was considered to be suitable for this research. Scale pattern analysis has a successful history in freshwater stocking programs in Queensland. The selected methods included (i) chemically marking otoliths with oxytetracycline (OTC) and (ii) scale pattern analysis (SPA).

6.1.1 Oxytetracycline Marking

Tetracycline is an antibiotic drug that is incorporated into growing calcified structures and fluoresces when viewed under UV light (Brothers 1990). There is considerable information about this technique in the scientific literature (Conover and Sheehan 1996, Ukenholtz et al. 1997, Reinert et al. 1998). A range of chemical and physiological factors can mediate the rate of OTC uptake, which in turn affects the quality of resulting marks in otoliths (Brothers 1990). It has proven very successful for marking freshwater species such as golden perch, *Macquaria ambigua*, (Anderson 1988). However, some authors (Drawbridge et al. 1993, Blom et al. 1994) have questioned the retention rate of OTC marks in otoliths. Blom et al. (1994) suggested that UV light degrades the quality of OTC mark on otoliths. This is particularly relevant to marked fry that have little pigmentation. Other authors (Palmer 1995) have questioned the environmental safety aspect of widespread use of this antibiotic for immersion marking.

6.1.2 Scale Pattern Analysis

Scale pattern analysis (SPA) has been successfully used to differentiate the origins of high-seas wild salmonid stocks (Cook and Lord 1978, Major et al. 1978). It has also been used to differentiate between wild and hatchery bred native fish stocked into freshwater impoundments in Queensland. Willett (1996) was able to differentiate between wild and hatchery bred stocks of golden perch, *Macquaria ambigua*, silver perch *Bidyanus bidyanus* and Australian bass *Macquaria novemaculeata* with up to 99% certainty (88% average). Such results are equal to or better than those obtained from other tagging methods.

This technique is able to differentiate between wild and hatchery fish because differences in growth rates, resulting from environmental factors, are reflected in the inter-circulus spacing on scales. Hatchery production at BIARC involves a cycle of transferring fish from tanks/ponds that have been cleared of food organisms into new tanks/ponds with abundant food resources. This series of transfers cause checks to form on the scales of fish, corresponding to periods of slow growth caused as ponds are depleted of food, followed by periods of fast growth in the new food-rich ponds. Wild stocks, on the other hand, have a relatively constant growth rate. As a result, most wild fish display a very even pattern of circuli on the inner portion of their scales. These differences can be utilised to differentiate between wild and hatchery reared populations. The inter-circulus distances are compared between stocks, using standardised discriminant function coefficients, to highlight significant differences. Willett (1996) gives a more detailed description of this technique.

6.2 METHODS

All trials directed towards marking fingerlings with OTC were conducted at BIARC. All otolith and scale assessments were undertaken at SFC.

6.2.1 Oxytetracycline marking of otoliths

Considerable effort was directed towards the development of an optimal marking system. Fourteen separate trials were conducted on flathead and whiting, between September 1995 and September 1997, to establish the best method of marking the otolith. Attempts were made to create multiple marks by exposing the fish at several of their developmental stages to a range of OTC concentrations.

Fish of various ages were immersed in a range of concentrations (up to 1000 mg/l) of oxtetracycline hydrochloride BP both experimentally in 31 hemispherical bowls and *en masse* in 500 to 2000 litre tanks. The addition of TRIS buffer was necessary to avoid excessive pH depression of the immersion solution, particularly at high OTC concentrations.

In an attempt to produce the strongest and most consistent otolith marks possible in fingerlings being produced for release in the program, the bulk of fish harvested from each culture phase was exposed *en masse* to the maximum OTC concentration tolerated in experimental exposures. Experimental exposures preceded harvest dates by one day to provide prior information on OTC tolerance at that particular size, so that bulk-exposure concentrations used the following day could be adjusted to avoid the possibility of unacceptable mortalities occurring.

The long-term survival and growth of fry and fingerlings exposed experimentally to OTC was assessed by growing fish in cages floating in the nursery ponds for a period of 2 to 3 weeks. The following strategies were adopted:

1. broodstock injected with OTC
2. juveniles exposed @ late embryo stage,
   @ 10-12mm length
   @ 20-25mm length
   @ 35-45mm length

Larvae and juveniles were exposed to concentrations of 1000 ppm OTC for up to twelve hours. When a number of trial exposures did not result in reliable marks, the concentrations and exposure times were increased. Marking methods were also modified to eliminate the suspected chelating effect of competing metallic ions by exposing fish at low salinities (Brothers 1990). All trials were validated by examination of otoliths using UV microscopy.

6.2.2 Scale Pattern Analysis

The SPA technique utilises circulus spacing measurements taken from the scales of the chosen species from a known source to establish a discrete classification function. This can then be used to differentiate between groups in subsequent mixed-stock analyses. Reference samples of sand whiting (n = 75) and dusky flathead (n = 100) were collected from hatchery and wild populations. The reference hatchery collection was taken from juveniles and adults during the production run. The reference wild collection was taken from fish caught in the Maroochy River prior to the first major release of either species (see Table 7.1 for release data).

Scales taken from the dorsal fin region of dusky flathead (Figure 6.1) and pectoral fin region of sand whiting (Figure 6.2) were mounted between paired slides (Figure 6.3) and examined microscopically. Inter-circulus measurements were taken from the scale focus to beyond the 16th circulus (Figure 6.4) using computer-imaging (Optimas 6.1©). The measurement data from scales of known origin fish were used to build up reference hatchery and wild collections using discriminant classification functions (Genstat 5©). The technique was validated for both species by reintroducing the reference sample scale data as "unknowns" and observing how the classification functions re-assessed the data. Once the accuracy of the discrete classification function was examined and an estimate of error obtained, scales from fish of unknown origin could be assessed by the discriminant classification functions to discern their probable origin.

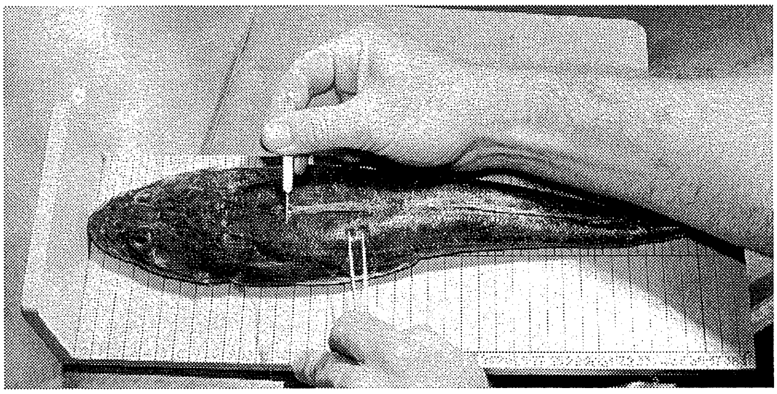


Figure 6.1: Removing scales from the dorsal surface of dusky flathead.

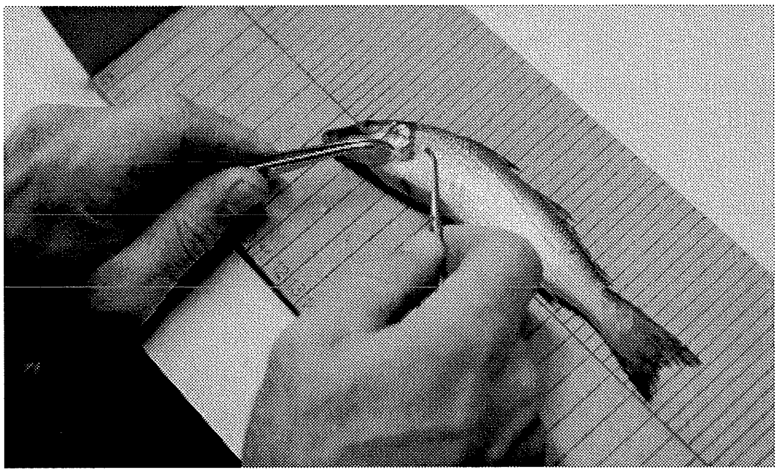


Figure 6.2: Removing scales from behind the pectoral fin of a sand whiting.

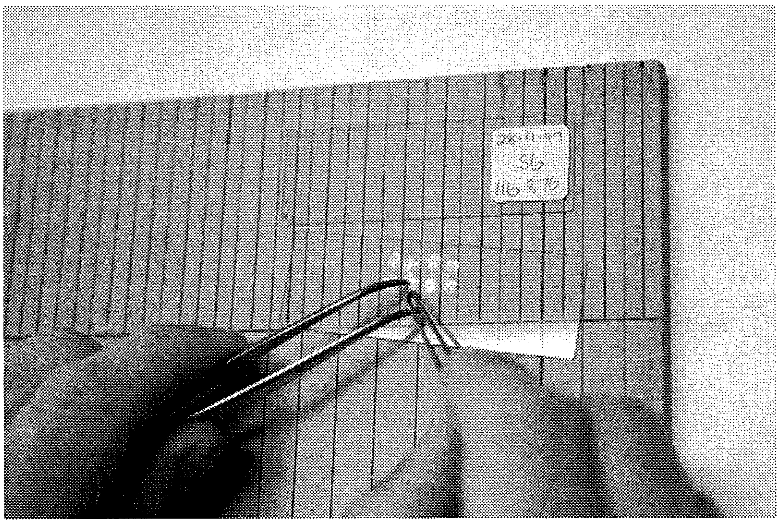


Figure 6.3: Loading scales onto slides.

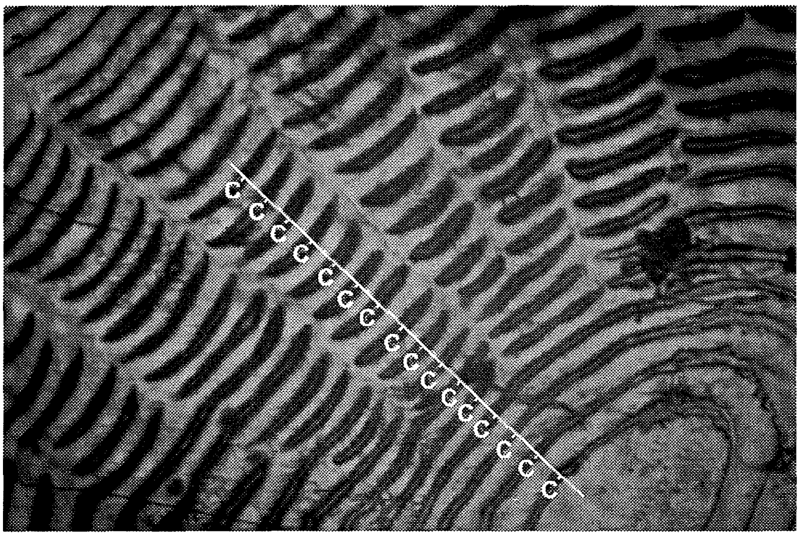


Figure 6.4: Computer image of the inner circuli of a wild sand whiting scale, showing the measuring radius and measurement points. Magnification x 100.

6.3 RESULTS

6.3.1 Oxytetracycline marking trials

We found that exposure to OTC concentrations of 1000 mg.l^{-1} at low salinities (<10 $^{0}/_{00}$) produced the best marks, but mortalities under these conditions were unacceptably high. Table 6.1 summarises the results of these trials.

Table 6.1: Summary of methods and results of OTC marking trials undertaken over the course of the study.

Date	species	Length (mm)	OTC conc. (mg.l^{-1})	exposure period	Sal. ($^{0}/_{00}$)	General result
9/95	flathead	egg	500	4 h	35	No marks produced
10/95	flathead	8	300	4 h	36	A few weak marks produced
11/95	flathead	24	300	4 h	36	A few weak marks produced
12/95	flathead	38	500	4 h	36	No marks produced
2/96	whiting	egg	1000	4 h	34	No marks produced
2/96	whiting	10*	200^{+}	13 h^{+}	30	No marks produced
2/96	whiting	10	500	12 h	34	A few acceptable marks produced but mainly poor results
3/96	whiting	18	1000	12 h	35	No marks produced
4/96	whiting	50	500 & 1000	12 h	9,18 & 36	Lowest salinity & highest OTC conc. gave best marks but high mortalities
11/96	flathead	21	1000	12 h	8-9	Intermediate, weak or no marks produced
11/96	flathead	30	1000	12 h	8-9	Intermediate, weak or no marks produced
12/96	flathead	24	1000	12 h	8-9	Weak or no marks produced
1/97	flathead	53	1000	12 h	5$^{\#}$	Using NaCl or distilled water improved marks
5/97	whiting	51	500	12 h	5$^{\#}$	Using NaCl or distilled water improved marks

* Fish were exposed to OTC whilst still in the hatchery-based green water culture.

$^{+}$ Residual OTC after water exchanges resulted in longer exposure at lowered concentrations.

. $^{\#}$ seawater or NaCl solutions diluted with tap water or distilled water were investigated

6.3.2 Scale Pattern Analysis

6.3.2.1 Flathead

Reference scales from 101 flathead was collected during breeding trials at BIARC in 1997. In the same year, 71 wild flathead were taken from the Maroochy River to establish the wild fish reference library. The highest discriminant function coefficients of the inter-circulus distances (and therefore the most useful) were between circulus-pairs 14 and 15, 4 and 5, 10 and 11 and 2 and 3 respectively. However, all inter-circulus distances were used to develop the discriminant function. The standard deviation of all inter-circulus distances was also used in this function. Table 6.2 summarises the accuracy of the flathead discriminant function, in the form of an error matrix.

Table 6.2: Error matrix of flathead scale classification

Original Stock source	Natural estimate Hatchery	 Wild	% misclassification
Hatchery (n=101)	79	22	22
Wild (n=79)	18	53	23

The flathead discriminant function misclassified hatchery fish as wild in 22% of all cases and misclassified wild fish as hatchery fish in 23% of all cases. The fact that the misclassification rate is almost equal for both populations implies a consistent level of accuracy to the dusky flathead discriminant function.

6.3.2.2 Whiting

Reference scales from 181 hatchery-reared whiting were collected from BIARC during breeding trials in 1996. In the same year, 99 wild whiting were taken from the Maroochy River to establish the wild reference library. The inter-circulus distances between circulus-pairs 15 and 14, 14 and 13, 13 and 12 and 11 and 10 had the highest coefficients and were thus the best discriminators between stocks. All the inter-circulus distances and their standard deviations were used to standardise the accuracy of the discriminant function. Table 6.3 summarises the accuracy of the whiting discriminant function in the form of an error matrix.

Table 6.3: Error matrix of whiting scale classification

Original Stock source	Natural estimate Hatchery	 Wild	% missclassification
Hatchery (n=181)	139	42	23
Wild (n=99)	11	88	11

The whiting discriminant function misclassified hatchery fish as wild in 23% of all cases, and misclassified wild fish as hatchery fish in 11% of all cases. The fact that the hatchery to wild misclassification rate is more than twice the wild to hatchery misclassification rate implies that the sand whiting discriminant function will give conservative estimates, i.e. more true hatchery fish will be classified as wild stock than *vice-versa.* This error can be corrected mathematically to achieve a nearly unbiased estimate (Cook and Lord 1978).

6.4 DISCUSSION

Despite attempts to establish reliable OTC marks in sand whiting and dusky flathead, a consistent result was not achieved. Exposures at reduced salinities (5 ppt), designed to reduce the suspected effect of Ca^{++} and Mg^{++} ions, did produce acceptable marks, but at the expense of high mortality. The poor OTC marking results are not consistent with other reported literature (Anderson 1988, McEacheron et al. 1995, Reinert et al. 1998). There are several reasons given in the literature for poor quality OTC marks. Unkenholz et al. (1997) recorded a time lag of nearly two months (56 days) after immersion before adequate OTC marks were discernible in the otoliths of juvenile yellow perch (*Perca flavescens*). Harrison and Heidinger (1996) observed that fish growth rate immediately surrounding the time of OTC immersion affected the quality of OTC marks and that fish fed to satiation possessed a better quality mark than those starved or fed small meals. In our trials, it is unlikely that the trial fish were examined before an adequate OTC mark was established on the otoliths. Nor were the fingerlings lacking in food. A more probable explanation rests with laboratory evidence of immersion-solution salinity having an effect on the uptake of OTC by fingerlings. Marking trials conducted at lower salinities did produce comparatively better marks, but had unacceptably higher mortality levels.

Scale Pattern Analysis is a proven technique for identifying the different origins of a mixed stock (Anas and Murai 1969, Major et al. 1978). This makes it particularly suited to large stocking programs, especially when the numbers of introduced fish are large and resources available prohibit the use of alternative and more invasive tagging techniques. However, care must be taken to adhere to accepted standards to ensure the best "quality of mark" is induced (Buckley and Blankenship 1990). Of the 16 inter-circulus distances examined by SPA in this study, several of the inner and outer pairs contributed most to the flathead discriminant function, while the outer pairs of inter-circulus distances contributed most to the whiting discriminant function.

Overall, the flathead and whiting discriminant functions developed from the wild and hatchery reference collections were 78% and 77% accurate in differentiating hatchery-origin stock from an unknown source. The discriminant function developed for dusky flathead erroneously classified hatchery produced flathead as being of wild origin, with almost the same error rate in classifying wild fish as being of hatchery origin. Thus, although the function was inaccurate, there was an implied lack of bias because the error rates were almost equal. The sand whiting discriminant function erroneously classified BIARC produced sand whiting as being of wild origin with twice the error rate as erroneously classifying a wild fish as being of hatchery origin. Thus it can be implied that the whiting discriminant function is biased in a conservative direction, while maintaining the ability to discriminant between stock origins with a confidence of 75% or better. It is prudent to refrain from revising these estimates up to the nearly unbiased estimate by adding a correction factor to the misclassification rate (Cook and Lord 1978). This conservative approach is consistent with the adoption of the precautionary principle to assessment, resulting in an underestimation of hatchery whiting recovered in all surveys.

Subsequent to the validation of scale marking techniques, a decision was made to abandon OTC marking as the preferred means of marking. This was partly due to the lack of reliable results and the emergence of scale analysis as a viable alternative, but also to an increasing concern amongst BIARC staff about the potential health risks associated with the use of large volumes and high concentrations of OTC. The quantities of OTC required were trebled when the immersion baths were extended to 12hr duration in an attempt to improve the uptake. This was considered too long a time for large numbers of fish (up to 50 000 fish in 1000 l of water) to be held in static conditions. Consequently, the OTC solution was flushed out and fresh added every four hours. Reports on the residual persistence of OTC in water required that every effort be made to ensure that no OTC escaped into the environment before complete degradation. This was achieved by collecting all of the contents of the OTC baths in a plastic lined pond, treating with concentrated caustic soda and leaving the resultant mixture open to direct sunlight (Mike Rimmer personal communication 1997) before disposal.

It is possible that private operators may eventually take up any expansion of estuarine stocking in Queensland. The possibility of accidental spillage and the hazardous nature of the chemicals involved in marking fish represent an unacceptable public and environmental risk. This risk is made even more unacceptable by the unreliable results. It is therefore recommended that the use of OTC be discouraged as a means of mass marking for open, estuarine water stocking purposes.

It is also acknowledged that scale marks are not easily assessable in all fish and the evolution of cost-effective genetic monitoring techniques could prove to be a superior monitoring tool. Such a method would provide both a method of identification of stocked progeny as well as examining the fundamental relationship between changes in genetic structure and effects on fish performance brought about by stocking for enhancement (Carvalho and Cross 1993).

7 STOCKING THE MAROOCHY RIVER SYSTEM

A. Butcher, P.Palmer, M. Johnston, D. Smallwood, M. Burke, K.Cowden and J. McGuren

7.1 INTRODUCTION

The Queensland Fisheries Management Authority (QFMA) manages fish stocking in Queensland via an approved Fish Stocking Plan that sets out what species may be stocked and where. DPI policy states that any stocking in public waters should follow a protocol that includes application of the precautionary principle and is accompanied by a risk assessment (Taylor-Moore and Retif 1997). These issues were covered at the 1994 scoping workshop and again during a review by DPI Senior Fisheries Management. All stocking in this pilot project was carried out under permit issued by the QFMA.

7.2 METHODS

Fish releases were undertaken with the assistance of the community-based Maroochy River Stocking Group, staff from the Queensland Boating and Fisheries Patrol and local council staff. A stocking protocol was established to provide maximum coordination between the stocking flotilla and DPI staff and to minimise stressing of the fingerlings.

7.2.1 Stocking schedule

Analysis of the preliminary survey data highlighted the preference of juvenile dusky flathead and sand whiting for particular habitats in the Maroochy River. A schedule was developed to ensure that fingerlings would be stocked at a level proportional to the observed catch rate (thus as a reflection of natural density) in the relevant habitats. All fish releases were undertaken on an afternoon rising tide to give the juveniles time to settle into the river conditions in shallow areas when reduced predatory pressures were likely to be minimal.

7.2.2 Harvest and transport

Ponds were partially drained on the evening before the planned stocking event and fully drained early on the day of stocking. Most fingerlings left the ponds via the pond outlet, at which point they were easily captured (Figure 7.1). This method of capture helped to reduce the incidence of scale loss. Fingerlings were counted into containers of aerated seawater, and delivered by truck to selected boat ramps on the river.

A 10 tonne truck was equipped to transport large numbers of fingerlings (up to 100 000/load). This equipment included 3 x 800 l-capacity fish transport tanks with aeration equipment, reticulated oxygen to each tank, plus equipment necessary for handling and transferring fish at the stocking site (e.g. large siphon hoses, buckets, tubs, dipnets).

Figure 7.1: Dusky flathead fingerlings were captured at the pond outlet during harvesting.

7.2.3 Distribution and survival

Fingerlings were siphoned from the transport truck (Figure 7.2) into small (50–100 l) aerated containers and distributed to their release sites by small outboard craft (Figure 7.3). Water exchange was undertaken during the distribution by the fleet, and fingerlings were distributed into shallows within each region (Figure 7.4). Stocking operations were closely monitored to assess fingerling mortality at all stages of distribution. In addition, three replicate samples of 50 fingerlings were kept in 0.5 m^3 cylindrical cages at each region (Figure 7.5) and monitored daily to estimate the extent of short-term survival and harvest/transport related mortality. Most stocking events were completed over a 2 to 3 day period. At the end of each release, further samples of fingerlings were kept in the cylindrical cages in the river at densities ranging from 20 to 25/cage for long-term survival experiments lasting up to 35 days. These fish were monitored monthly to ascertain survival rates.

Figure 7.2: Siphoning fingerlings from the transporter at the Code Hole, Maroochy River.

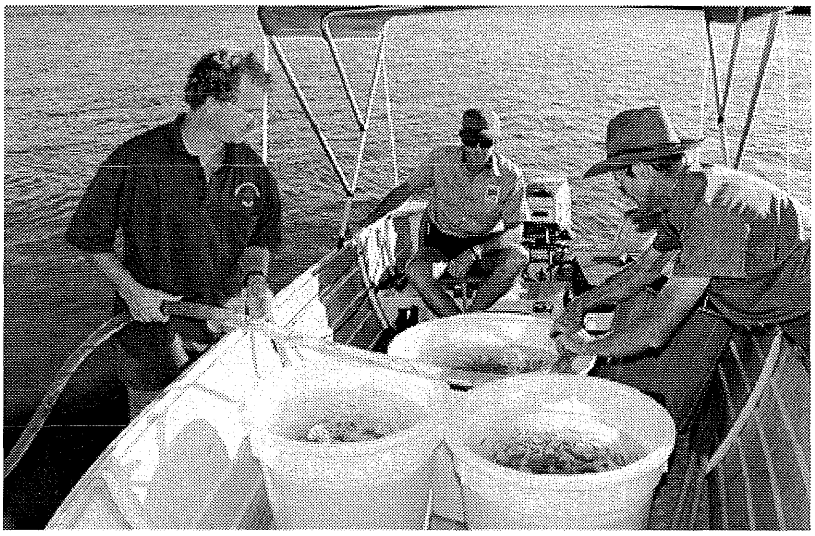


Figure 7.3: Loading dusky flathead fingerlings into aerated containers aboard a small vessel on the Maroochy River.

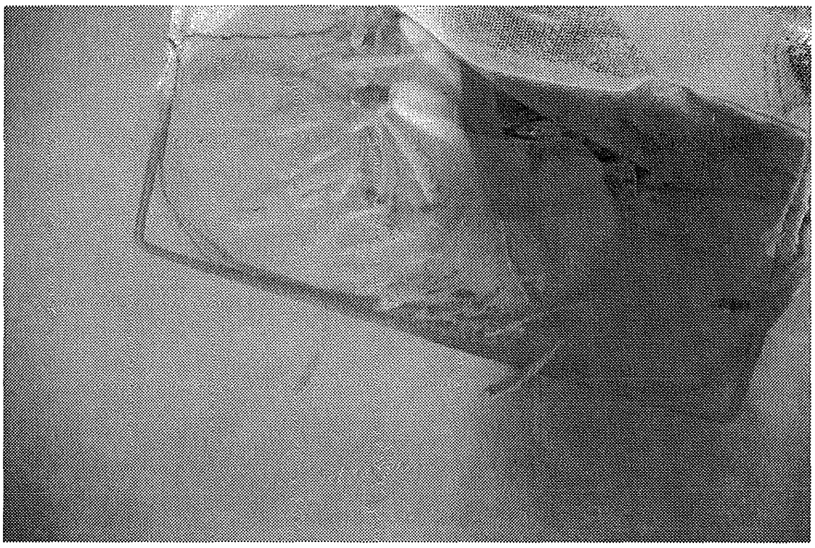


Figure 7.4: Releasing sand whiting into the Maroochy River.

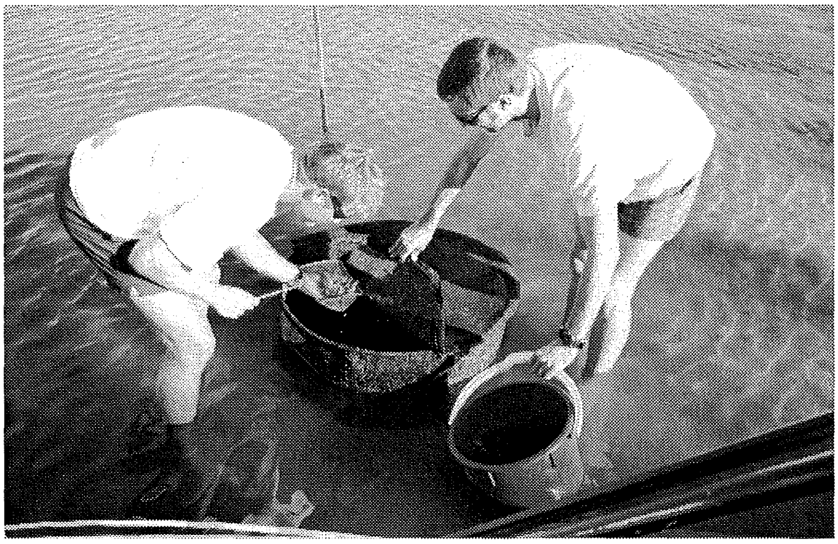


Figure 7.5: Counting dusky flathead fingerlings into cage for *in situ* survival experiment.

7.3 RESULTS

7.3.1 Stocking Schedule

Stocking schedules were developed for each species and for each stocking event. The stocking densities and areas stocked reflected the average natural density of each species in the river from the preceding 12 month period. Stocking schedules were based on a predetermined maximum estimate of fingerlings to be stocked. However, because of the uncertainty of final production survival rates prior to harvest, they were presented as a range of stocking numbers, (see Tables 7.1 – 7.4, below).

Table 7.1: Conditional stocking schedule for dusky flathead in December 1996.

Zone	Geographical Area	Stocking rate (%)	Production numbers			
			50 000	55 000	60 000	65 000
A	Mouth to Channel Is.	17	8000	9000	10 000	11 000
B	Channel Is. to MWB	13	6500	7000	8000	8500
C	MWB to DLB	25	12 500	14 000	15 000	16 000
D	Eudlo Ck	1	500	500	500	500
E	Petrie Ck	3	1500	2000	2000	2000
F	DLB to Coolum Ck	40	20 000	22 000	24 000	26 000
G	Dunethin Rock	1	500	1000	1000	1000

Table 7.2: Conditional stocking schedule for sand whiting in March 1997.

Zone	Geographical Area	Stocking rate (%)	Production numbers			
			200 000	250 000	300 000	350 000
A	Mouth to Channel Is.	10	20 000	25 000	30 000	35 000
B	Channel Is. to MWB	9	18 000	22 500	27 000	31 500
C	MWB to DLB	48	96 000	120 000	144 000	168 000
D	Eudlo Ck	12	24 000	30 000	36 000	42 000
E	Petrie Ck	14	28 000	35 000	42 000	49 000
F	DLB to Coolum Ck	6	12 000	15 000	18 000	21 000
G	Dunethin Rock	1	2000	2500	3000	3500

Table 7.3: Conditional stocking schedule for dusky flathead in December 1997.

Zone	Geographical Area	Stocking rate (%)	Production numbers			
			30 000	40 000	50 000	60 000
A	Mouth to Channel Is.	10	4000	4000	5000	6000
B	Channel Is. to MWB	14	5600	5600	7000	8400
C	MWB to DLB	30	12 000	12 000	15 000	18 000
D	Eudlo Ck	19	7600	7600	9500	11 400
E	Petrie Ck	8	3200	3200	4000	4800
F	DLB to Coolum Ck	15	6000	6000	7500	9000
G	Dunethin Rock	4	1600	1600	2000	2400

Table 7.4: Conditional stocking schedule for sand whiting in April, 1998.

Zone	Geographical Area	Stocking rate (%)	Production numbers			
			50 000	70 000	90 000	100 000
A	Mouth to Channel Is.	20	10 000	15 000	18 500	20 500
B	Channel Is. to MWB	23	11 000	16 000	20 500	22 500
C	MWB to DLB	26	13 000	18 000	23 500	26 000
D	Eudlo Ck	0	0	0	0	0
E	Petrie Ck	0	0	0	0	0
F	DLB to Coolum Ck	28	14 000	20 000	25 500	28 500
G	Dunethin Rock	0.2	100	150	200	200

7.3.2 Harvest and transport

Harvesting sand whiting from ponds was reasonably straightforward, although care was needed to avoid scale loss during handling. As previously mentioned (Section 6.4) harvesting dusky flathead from ponds was occasionally difficult because too much benthic algae developed during the growout period. Dusky flathead tended to hide in the pond detritus as water levels fell and often became entangled in clumps of algae that blocked exit channels on the floor of the pond. Therefore management procedures aimed at limiting benthic algal growth were important for nursery-pond production of dusky flathead fingerlings.

To estimate transport-stocking densities, fish were counted into the transporting tanks using the simplest and most gentle methods possible, so as to minimise stress and handling damage. Initially, counting methods entailed a reference bucket or scoop (containing a known number of fish) that was used to compare and adjust similar buckets or scoops; the number of similar buckets or scoops was then used as a multiplier to derive the total. A second method of estimation was developed using bulk wet-weight. This entailed weighing a known quantity of fish in a known volume of water and using it as a reference against which unknown quantities of fish in known volumes of water were then estimated. The advantage of this technique lay with the time saving it allowed during peak labour times of harvest.

7.3.3 Distribution and survival

This project was responsible for 11 major releases of hatchery-reared fish into the Maroochy River system. The details of each release are listed below (Table 7.5). Distribution was undertaken primarily by the Maroochy River Stocking Group, aided by the QBFP and Maroochy Shire Council funded River Watch group.

Health assessments undertaken on samples of fish from each harvest have indicated that most fingerlings were generally in good health and condition. Losses of fingerlings at harvest were generally low (<1%). However, some batches of fish did display some loss of equilibrium during transport and release. Both short-term (24–48 hr) and long-term (1 month) survival trials were conducted with a stocking level of 25 fish/cage. Survival was variable for the different batches of fish, but whiting consistently showed higher survival rates than flathead (Table 7.6).

Table 7.5: Maroochy River stocking program fish release particulars

Species	Date	Number	Size range	Purpose
whiting	15/3/95	12 000	22-41 mm	Ministerial announcement to signify project commencement.
whiting	24/7/96	250	52-101 mm	Show of appreciation for donation from Boating Industry Association.
flathead	17/12/96	20 000	34-58 mm	First major releases of flathead in the program (65,000 total).
	18/12/96	33 000	29-49 mm	
	19/12/96	12 000	25-40 mm	
whiting	9/4/97	75 000	25-57 mm	First major releases of whiting in the program (250,000 total).
	10/4/97	100 000	26-63 mm	
	11/4/97	75 000	30-57 mm	
flathead	16/12/97	20 000	35-55 mm	Second major release of flathead in the program (33,000 total).
	17/12/97	13 000	30-51 mm	
whiting	21/4/98	22 000	40-55 mm	Second major releases of whiting in the program (72,000 total).
	12/5/98	50 000	41-62 mm	

Table 7.6: Results of survival trials conducted in the river during and after each stocking event (means ± s.e.).

Species/Date	n	24 hr % survival	48 hr % survival	n	1 month % survival
Flathead Dec-96	500	63 ± 21	63 ± 21	225	33 ± 15
Flathead Dec-97	500	54 ± 29	46 ± 26	250	65 ± 10
Whiting Mar-97	500	87 ± 5	77 ± 8	200	73 ± 7
Whiting April 98	500	96 ± 2	88 ± 5	200	75± 10

7.4 DISCUSSION

The policy governing fish stocking practices in Queensland waters (Taylor-Moore and Retif draft) had not been developed at the time of the scoping workshop. Although the initial impetus for this pilot program was from a recommendation from the State Government Inquiry into Recreational Fishing, many of the important issues pertaining to stocking in southern Queensland waters were canvassed during discussions at the workshop (refer to Section 2.2).

The process of stocking was protracted, beginning with the draining of the growout ponds at BIARC and culminating with the completion of the in situ survival trials. Although the production team at BIARC began with only limited experience in handling such large numbers of fingerlings, they were soon able to establish appropriate techniques that would improve survival rates in subsequent stocking events. Health assessments undertaken on samples of fish from each of the major releases indicated good health and condition for all fingerlings at harvest. Losses of fingerlings at harvest and during transport were variable, but improved with the experience of each stocking. Distribution of fingerlings within the river was an important task in which the local stocking group played an integral role.

High mortality rates of juveniles just after stocking have been reported for several species (Inoue 1976, Tsukamoto *el al.* 1989, Kristiansen and Svåsand 1990, Furuta 1996). During post-stocking survival experiments in the Maroochy River, the survival rate of whiting was consistently higher than that of flathead. It could be argued that the survival-experiment cages were inappropriate for flathead, but there was considerable variability in the survival rate of this species, ranging from > 90% to < 50% after 48 hours. Trials conducted with sand whiting had better results. One interesting aspect of the survival trials was that fingerlings from different ponds showed different levels of tolerance to peak periods of stress during harvesting, transport and stocking. We believe these results were influenced more by pond trophic levels and the resultant fingerling condition by the end of the growout phase, just prior to harvest, rather than by survival trial cage suitability. Application of the short-term survival trial results to the release data suggests that in some releases nearly half of the fingerlings may not have survived the first 48 hours. This was not completely unexpected, and survival certainly improved in subsequent releases. It was beyond the scope of this pilot program to determine optimum release strategies (such as size at and location of release) experimentally. These are important questions with implications for fingerling survival. Answering these questions by carefully designed field trials should be a priority for any future research into stocking in Queensland estuarine waters.

8 ASSESS THE EFFECTIVENESS OF STOCKING

A. Butcher, D. Mayer, D. Smallwood, M. Johnston, L. Williams and S. Clapham

8.1 INTRODUCTION

Evaluating the effectiveness of stocking is recognised as being fundamental to justifying its expense (Rutledge and Matlock 1986, Blankenship and Leber 1995, Cowx 1998, Welcomme and Bartley 1998, Hilborn 1998). This aspect of stocking has rarely been considered, possibly because of the historical philosophy of "hatch and release" (Richards and Edwards 1986), the cost (Brouha 1995) and the technical limitations. However, with the recent worldwide resurgence of interest in marine stocking, and an increasing sensitivity to ecological issues, assessing the impact and effectiveness of stocking is now considered an important objective in any program. Assessing the effects of stocking involves looking for any net increase in the total population and examining the survival of the released stock (Howell 1998). Such information is necessary for investigating the question of whether the introduced fish augment or displace the natural population (Hilborn 1998, Hepell and Crowder 1989).

There are a number of different criteria by which stocking programs can be evaluated. In this study, 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, which began during the preliminary surveys in January 1996, was continued after stocking to trace growth and movement of hatchery-bred chosen species and to monitor total population size within the river. Recreational and commercial catches were monitored to determine whether catches changed as a result of stocking. In addition, catches from both fishery sectors were sampled to determine whether hatchery-bred fish were surviving and being recruited into the commercial and recreational catch. Finally, the economics of the pilot program were examined assessed using two conservative models.

8.2 METHODS

8.2.1 Fishery-independent sampling

8.2.1.1 Effect on total population of each species

8.2.1.1.1 Sampling gear relative efficiency

The question of relative gear efficiencies had to be examined before the question of measuring population numbers could be investigated. Estimates of relative net efficiency were initially based on observational evidence after nine months of sampling. These were refined by a direct comparison of catches obtained by the different gear types. The data for this exercise came from two sources –

1. A Latin-square experiment; comprising four net types (fence, fyke, ring and trawl) deployed at four sites on four consecutive nights in March 1998. Sites were chosen on their ability to be sampled by all four gear types. This design was replicated in September 1998, giving 32 observational units. An additional

covariate factor (binary, having levels 'suitable' and 'unsuitable') was included in the analysis, to adjust for observations where the net type was not well suited to the location sampled.

2. Pairing of nets at three sites during regular sampling. During the main Maroochy River fishery-independent study six adjacent sites were paired. Two were fence nets with trawl nets, and one was a ring net with a trawl net. Incomplete sampling at these six locations across the 26 months gave 136 observational units.

These two data sets were combined into pooled analyses for dusky flathead and sand whiting separately. Fishery independent sampling conducted during the preliminary survey (refer to Section 3.2), was continued after stocking occurred. Dusky flathead and sand whiting catch data were collected and tabulated for estimation of abundance.

8.2.1.1.2 Effect on population

The effect of stocking on population abundance was investigated by running the total catch time-series data set through three abundance estimate models (general linear models of raw and log-transformed data, and MCMC) to obtain serial estimates of absolute abundance of each species in the Maroochy River. Time series analyses were performed on these estimates to investigate the effects of the stocking events. Fourier curves were fitted, with one cycle/year for each species (a second peak / year was not significant). For dusky flathead a quadratic trend over years was significant ($p<0.05$) and was added to the model. For sand whiting, a significant linear trend over years ($p<0.05$) was added to the model.

8.2.1.2 Hatchery returns - Scale Pattern Analysis

Samples of dusky flathead and sand whiting were obtained after the stocking events for scale pattern analysis (SPA). It was deemed to be pointless to examine adult fish immediately after the stocking event because they would not be stocked fish. Only fish within an appropriate size range were analysed. For example, in the first six months after each stocking event, only fish whose lengths were less than the upper 97.5% confidence limit of length at age 0+ were examined.

Growth parameters for dusky fathead in southeast Queensland have been estimated as follows; $L_\infty = 81$ cm, $k = 0.223$, $t_0 = -0.873$ (Hoyle et al. 2000). While large dusky flathead exhibit some sexual dimorphism in growth, the growth rates of younger males and females (<2 yrs) are equal (Figure 8.1). Given that the dusky flathead produced at BIARC were stocked at 35 mm ± 10 mm (SL), hatchery-reared dusky flathead were not expected to recruit into the commercial or recreational fisheries (legal minimum size limit of 30 cm total length) for at least 12 to 18 months after the first stocking event (Kerby and Brown 1994). It was anticipated that they would be caught by fishery-independent sampling within the first six months of stocking. Thus for six months after the stocking event (up to trip 18), only flathead within the expected size range (upper 97.5% c.i.) were analysed for potential origin. By June, 1997 (trip 18) all dusky flathead were analysed by scale pattern analysis.

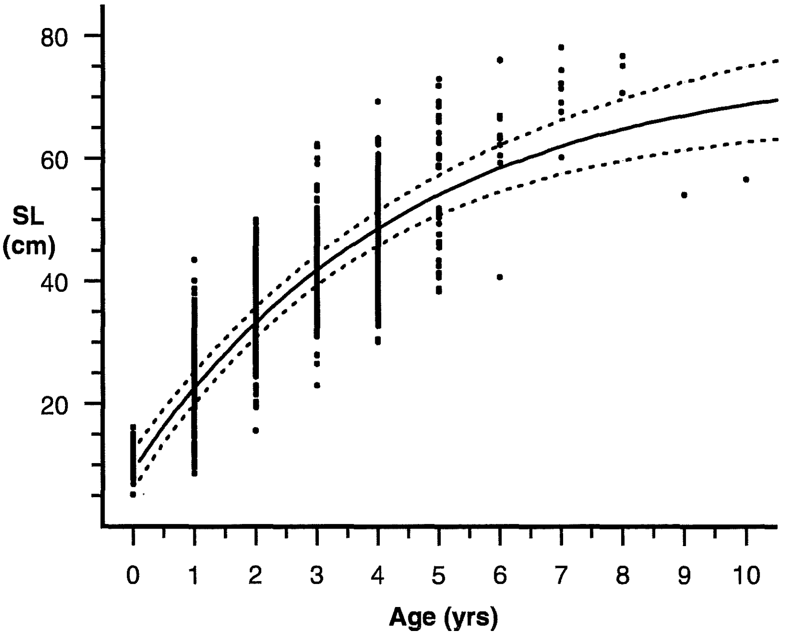


Figure 8.1: Estimated growth rate of dusky flathead from Pumicestone Passage, with the 95% confidence intervals. Produced from data supplied by Hoyle et al. 2000.

Using a similar logic, only sand whiting estimated to be in an appropriate size range were analysed. Previous research had shown that wild sand whiting from the Maroochy River have growth parameters of L_∞ = 38 cm, k = 0.2852, t_0 = -1.071 (Hoyle et al., manuscript). As with dusky flathead, the lengths at age of sand whiting vary to some extent between the sexes, but the growth patterns of male and female fish less than two yrs old are similar (Figure 8.2). The sand whiting produced at BIARC were stocked at a 35 mm ± 10 mm (SL), and hatchery-reared sand whiting were not expected to recruit into the commercial or recreational fisheries (legal minimum size limit of 23 cm total length) for 6 to 12 months after the first stocking event. They were expected in fishery-independent catches within three months of stocking. Thus for three months after the first sand whiting stocking event (trip 16), only whiting within the expected size range (uper 97.5% c.i.) were analysed for potential origin. By June 1997 (trip 18), all captured whiting were analysed for origin.

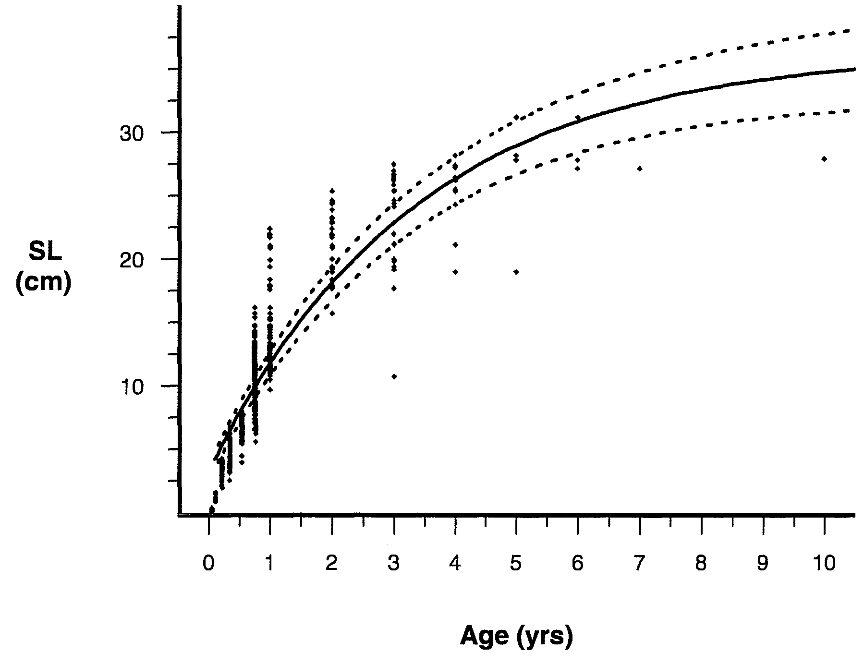
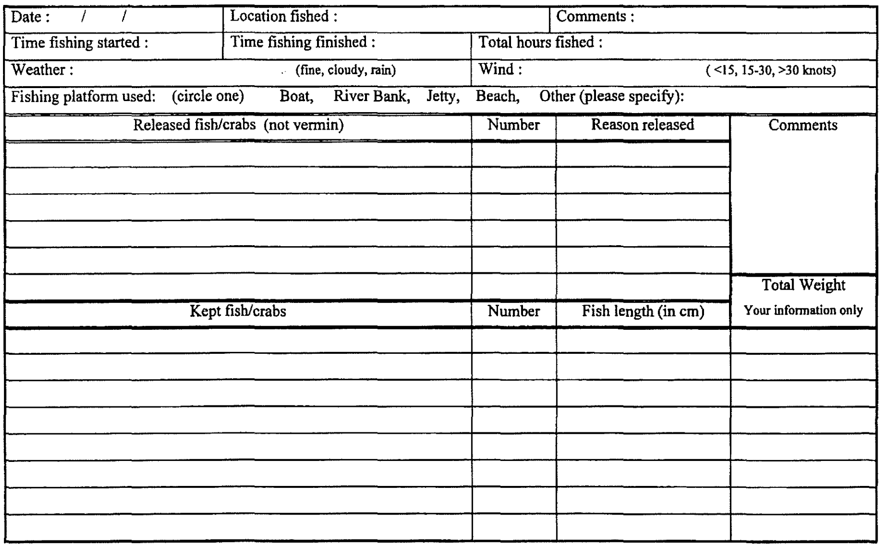


Figure 8.2: Estimated growth rate of sand whiting from the Maroochy River, along with their 95% c.i.. Produced from data supplied by Hoyle et al. 2000.

8.2.2 Recreational Fishery

8.2.2.1 Angler Diary

A "Maroochy River Angler Diary" (Figure 8.3) was developed by DPI staff, based on successful formats used in previous logbook programs. The objective of the diary was to obtain an estimate of fishing activity in the Maroochy River and to highlight the main species taken by the recreational sector. These diaries were given to both boat and shore-based volunteers. Volunteers were recruited on location by personal interview and by recruitment drives through local bait and tackle vendors. Volunteers were shown the format of the logbook and briefed on how to fill out the entries correctly. Each volunteer was personally contacted by follow-up phone interview every two months to encourage ongoing participation.



Date : / /	Location fished :	Comments :	
Time fishing started :	Time fishing finished :	Total hours fished :	
Weather : (fine, cloudy, rain)	Wind : (<15, 15-30, >30 knots)		
Fishing platform used: (circle one) Boat, River Bank, Jetty, Beach, Other (please specify):			
Released fish/crabs (not vermin)	Number	Reason released	Comments
			Total Weight
Kept fish/crabs	Number	Fish length (in cm)	Your information only

Figure 8.3: Maroochy Angler Diary logsheet.

8.2.2.2 Club catch trends

A time series of catch data was made available by one of the local fishing clubs. The data consisted of the catch records from one or two trips/year during either spring, summer or autumn months for the years 1994 to 1999 except 1997. The data also included a fisher skill rating (grade A, B, C, junior or visitor), with grade A fishers the most skilled. The form of CPUE was different for each year because of differences in the fishing effort, skill and time of year for each trip. Trends in catch rate (number of fish/person/trip) were estimated by fitting generalised linear models to the natural logarithm of individual CPUE data for each fish species in the Maroochy River (Genstat© 1998) to estimate yearly catch rate (number of fish/person/trip), standardised against fisher skill (Equation. 8.1).

$$\ln(CPUE)_{ij} = \mu + \tau_i + \beta_j + \varepsilon_{ij} \qquad \begin{cases} i = 1,2,\ldots,5 \\ j = 1,2,\ldots,5 \end{cases} \qquad \textbf{Equation 8.1}$$

where μ was a parameter constant, τ_i was the effect of the ith year, β_j was the effect of the jth fishing grade and ε_{ij} was the normally distributed random error term.

8.2.2.3 Recreational catch - Scale Pattern Analysis

Following the stocking events, allowing adequate time for the stocked fish to grow to a catchable size, dusky flathead and sand whiting scale samples were obtained from the recreational sector during random interviews on the water and two recreational club fishing trips to the Maroochy River in October 1998 and February 1999. Each fish examined was weighed (g) and measured (SL) and representative scales were collected and placed in a vial of 70% alcohol along with an identification label. These scales were analysed (refer to Section 6.2.2 for a description of SPA procedures), against the relevant discriminant functions to estimate their origin.

8.2.3 Commercial Fishery

8.2.3.1 Commercial catch trends

Historical commercial catch statistics, provided through a compulsory logbook program, were available from 1988 to 1998. However, an examination of available catch statistics from the commercial fisheries logbook system (CFISH 22nd March 1999) showed that not all fishers recorded their catch at the 6 x 6 minute sub-grid level of spatial precision which made it impossible to accurately analyse all relevant data. Therefore CPUE information (kilograms caught/day) was extracted from the database for all known commercial fishers who regularly worked in the Maroochy Estuary with catches reported to CFISH logbook grid reference W36 (Maroochydore) areas. Some Maroochy River fishers also hold ocean beach net licences. Their catch for the ocean beach fishery period of June to August was excluded from the analysis. Differences in fishing gear used by fishers and gain in fishing skill over time are some main factors that influence catch trends. To account for differences between fishing operations, generalised linear models were fitted to the natural logarithm of individual daily CPUE data for each fish species. The models included year of capture and fishing operation as additive factors to produce adjusted estimates of annual CPUE. This modelling procedure produced a clearer CPUE trend than those from uncorrected data as the variability due to different operations was significantly reduced in the comparison among yearly CPUE values ($p<0.001$). To protect the confidentiality of fishers, CPUE's derived from catch and effort statistics were presented in relative rather than absolute terms.

8.2.3.2 Commercial catch - Scale Pattern Analysis

Dusky flathead and sand whiting have a legal size limit of 30 cm and 23 (TL) respectively. This is equivalent to an age of about 18+ months for dusky flathead and 22 months for sand whiting (Kerby and Brown 1994). To allow the stocked fish time to recruit into the commercial fishery, dusky flathead and sand whiting scale sample collections began in September 1998 and continued until March 1999. Each fish was measured and scales collected (see Section 8.2.2.3) for analysis against the relevant discriminant function (see Section 6.2.2).

8.2.4 Economic modelling - Methods and Assumptions

Two financial models were developed for assessing the cost-benefit of the stocking pilot-program: 1) an outlay model and 2) a total cost model. The outlay model only considered outlays from the various funding sources. The total cost model included an "overheads" factor to account for labour costs and the operating costs of fisheries research resources. Both models were based on similar assumptions and input criteria (Appendix 13.6).

The costs for the project were separated into development costs and costs associated with fingerling production and monitoring. The development costs were apportioned at 100% of the total project costs in Year 1, 60% in Year 2 and 50% in Year 3. The balance was attributed to costs of production of fingerlings and monitoring for the duration of the project

Development of the technology to produce dusky flathead and sand whiting fingerlings and the development of monitoring protocols had benefits beyond this particular project because the technology could be used by other projects and the private sector with little change. It was agreed that 25% of the development costs could be reasonably attributed directly to this project in any one year.

8.2.4.1 Model Assumptions

The model was based on the following assumptions:

1. That adding juvenile fish to the river system would increase the population and catch of dusky flathead and sand whiting from that system. In other words, the effect would be one of augmentation, not replacement. Monitoring was carried out for a limited period after stocking.

2. That the juveniles surviving the natural processes are all harvested as additional fish from the system within a year of their reaching minimum legal size for capture (30 cm TL for dusky flathead and 23 cm TL for sand whiting). This assumption permits the use of the "marginal value" of these species to the commercial and recreational fishers in this assessment. The work of Reid and Campbell (1997) places an average marginal value to recreational fishers within the Burnett River system at about $1.47/sand whiting and $3.33/dusky flathead. In this assessment, the mean marginal value was assumed to be $3 and $2/fish for recreational caught dusky flathead and sand whiting respectively. The average value of commercially caught sand whiting and dusky flathead approximates the marginal value in this case and was assumed to be $1.17 and $2/fish respectively.

3. Allocation of fish capture was based on the proportion caught by commercial and recreational fishers in the QFMA managed fishery-dependent monitoring scheme. These proportions were assumed to be that recreational fishers caught 70% of the stocked dusky flathead and 60% of the stocked sand whiting.

4. Regional benefits were regarded as minimal, i.e. stocking fish in the Maroochy River would be unlikely to increase the number of fishers along the river. It is possible that with the publicity about the release of the juveniles there would be an immediate and short-term effect that would rapidly diminish and would not be present when the fish reach minimum legal size for capture. Consequently, regional (and state) effects were not considered in this evaluation. Nor was any value assigned to the accrued benefit from newly developed technologies.

8.3 RESULTS

8.3.1 Fishery-independent sampling

8.3.1.1 Effect on total population of each species

8.3.1.1.1 Net efficiency

The net-efficiency experiment data were log-transformed to overcome positive skewness. Zero observations were catered for by adding 0.001 (i.e. equal to 1 fish in 1000 m^2 of area sampled) prior to transformation (Equation 8.2).

$$y = \log(\text{density}+0.001) \qquad \textbf{Equation 8.2}$$

The transformed data were then analysed using general linear models in Genstat©. With the log transformation, the residuals were approximately normally distributed, with no observable trend against the fitted values.

Main-effects models were used, incorporating the effects of 'time', 'site', 'suitability' and 'net type'. While 134 degrees of freedom for the residual was adequate for this analysis, it could not support the pooling of adjacent time constants, e.g. into seasonal averages.

Initial observation-based estimates (Section 5.2.2) of net efficiencies were 95% for ring and fyke nets, 91% for fence nets and 15% for beam trawls for both species. The net efficiency experiment and paired samples showed that ring and fyke nets were catching about the same densities of each species, and the difference between these nets was not significant ($P>0.05$). Data from these nets were therefore pooled as representing the most efficient types, and the other nets compared to them. Average fish densities for all nets were estimated using the bias-corrected back-transformation (Equation 8.3)

$$density = \exp(y + \frac{s^2}{2}) - 0.001 \qquad \textbf{Equation 8.3}$$

Relative efficiency calculations were then estimated from these. Outcomes are listed in Table 8.1.

Table 8.1: Estimates of Net Efficiencies from net standardisation experiment.

Nets	Ring & Fyke	Fence	Trawl
Whiting -			
Fish numbers/1000 m^2	54.0	32.2	3.4
Relative efficiency (%)	100	59.6	6.3
Lower 95% c.i.	-	37.7	5.2
Upper 95% c.i.	-	96.6	12.5
Assumed efficiency (%)	95	60	6
Flathead -			
Fish numbers/1000 m^2	5.12	4.37	2.01
Relative efficiency (%)	100	85.3	39.2
Lower 95% c.i.	-	61.8	35.3
Upper 95% c.i.	-	124.8	68.4
Assumed efficiency (%)	95	80	35

The confidence intervals about these net efficiencies are relatively large, indicating variability in these data. However, the average values were fixed for the more important estimation of comparisons between time points. If the estimated net efficiencies were changed (up or down), then the estimated absolute numbers of fish would also change, but the relativities across time would not.

8.3.1.1.2 Effect on population

A total of 33 sampling trips were conducted in the Maroochy River between January 1996 and December 1998. A complete list of trip dates and sites sampled is given in Appendix 13.4. During these trips, 1078 flathead ranging from 3.6 to 78.3 cm (SL) were sampled, but only those >6 cm SL were used in the analysis (n = 1062). Of these, 790 were sub-adults and adults (>12 cm SL). These were caught mostly by beam trawl or ring nets over muddy substrates in between the Motorway bridge and Coolum Creek. Juveniles (<12 cm SL) were taken primarily by trawling over muddy substrates between the Motorway and David Low Highway Bridge (for site locations refer to Appendix 13.2). Some 9378 whiting ranging from 1.7 to 48.1 cm (SL) were caught during sampling, but only those >4 cm SL were used in the analysis (n = 9374). Of these, 3380 were sub-adults and adults (>10 cm SL). Most were caught in ring nets set over sandy substrates downstream of the Channel/Goat Island complex, within half a kilometer of the river mouth. Most of the juveniles (<10 cm SL) were also caught in ring nets set on sandy or muddy-sand substrates between the mouth and the David Low Highway Bridge. Catches/trip are listed in Table 8.2.

The division of sampling effort in the preliminary surveys meant that initial attempts to statistically fit actual months (each of which only had half the sites present) gave inconsistent results. So the paired 'alternate sites' of trips 4&5, 6&7, 8&9 and 10&11 were pooled into bimonthly samples (nominally allocated to the mid-point date of each pair), to obtain better data coverage.

For each fish species, the densities (numbers/m^2) were analysed by MCMC (see Section 4.2) and general linear models (fitted to both raw and log-transformed data). For the general linear models, a main effects model, pre-corrected for the assumed net efficiencies, was used with 'site' and 'month' terms. In exploratory analyses, the 'adjacent sites' (as used in the analyses of net efficiencies) were pooled to test the 'site' by 'month' interaction, but this showed no sign of being significant, actually having a smaller effect than the estimated random error term. Hence, observed patterns in densities were consistent over sites and times, and the main-effects model was appropriate.

For the general linear models, the "neighbourliness" effect was tested by taking the average weighted densities in the neighbouring areas as a potential covariate. However this had an insignificant effect for either species, and was omitted. The fitted densities from the log-transformed analyses (back-transformed with the bias correction factor) were then scaled up by site areas to give estimated population numbers at each site on each date, and summed to give river totals (Figures 8.4 and 8.5). The 'raw data' (untransformed densities) were similarly processed.

The MCMC model (see Section 4.2) was expanded to cater for the data from all sampling trips, as well as the revised net efficiencies. The model was converted to C^{++} and run on a PC platform under a Windows® interface. The results for dusky flathead >6 cm SL and sand whiting >4 cm SL are given in Figures 8.4 and 8.5 respectively and the estimates are tabulated in Appendix 13.5 along with their 95% confidence intervals. Confidence intervals are indicative 2-way 95-percentiles for the general linear and MCMC raw data series only. The reasons for this are 1) they were calculated from pooled estimates (e.g. across times) of the sector-by-sector estimated densities which are not applicable to individual time intervals when the estimated densities are correctly weighted by sector areas and worked up to the river totals, 2) there are no known statistical method for estimation of confidence intervals of river totals based on the ln-transformed analyses, and 3) MCMC model confidence intervals are derived from individual habitat totals for each time interval. These estimates vary somewhat, as may be expected given the methodology used along with the unbalanced and variable nature of the capture data. By allowing each site and time to have their main-effects constants and density for each species, there was close agreement between estimates based on general linear models of the raw and log-transformed, although the raw data method is sensitive to non-normality and outliers.

Table 8.2: Fishery-independent survey catches of all flathead and whiting from the Maroochy River between January 1996 and December 1998.

Trip	Date	Flathead	Whiting
1	Jan 1996	31	467
2	Feb 1996	24	230
3	Mar 1996	48	286
4	Apr 1996	4	220
5	May 1996	27	268
6	Jun 1996	14	219
7	Jul 1996	15	116
8	Aug 1996	5	250
9	Sept 1996	19	146
10	Oct 1996	6	126
11	Nov 1996	29	277
12	Dec 1996	8	131
13	Jan 1997	39	98
14	Feb 1997	48	456
15	Mar 1997	31	212
16	Apr 1997	49	292
17	May 1997	48	334
18	Jun 1997	65	416
19	Jul 1997	54	372
20	Aug 1996	44	276
21	Sep 1997	44	438
22	Oct 1997	45	536
23	Nov 1997	54	433
24	Dec 197	40	269
25	Jan 1998	64	494
26	Feb 1998	60	538
27*	Mar 1998	59*	296*
28	Apr 1998	48	374
29	Jun 1998	25	281
30	Aug 1998	22	239
31*	Sep 1998	32*	144*
32	Oct 1998	36	332
33	Dec 1998	32	253
Totals		1078	9379

*: denotes gear comparison trials. Results from these trips (which only sampled 4 sites) were not used in population analysis.

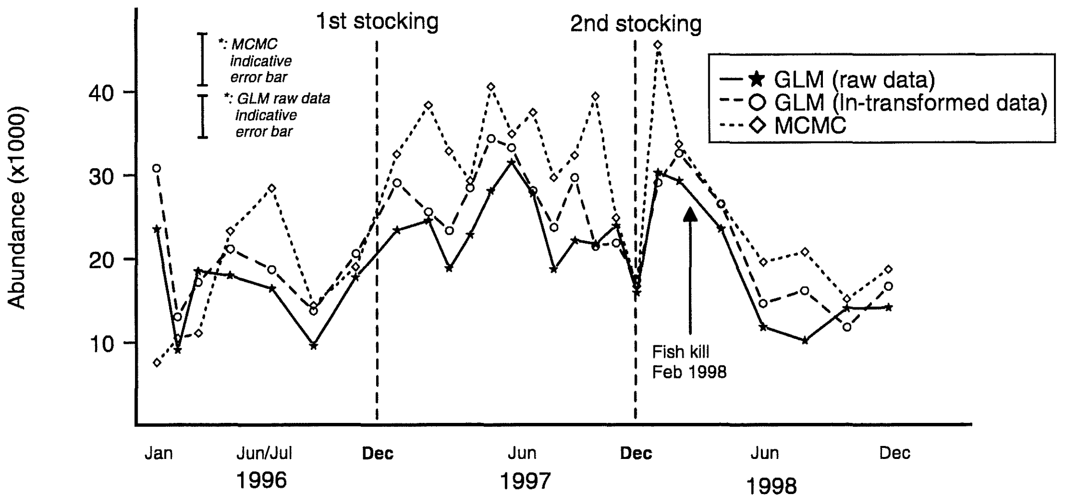


Figure 8.4: Abundance estimates of dusky flathead >6 cm SL in the Maroochy River between January 1996 and December 1998.

*: Confidence intervals are indicative 2-way 95%, for the GLM and MCMC raw data series only. The reasons for this are explained in the paragraph above.

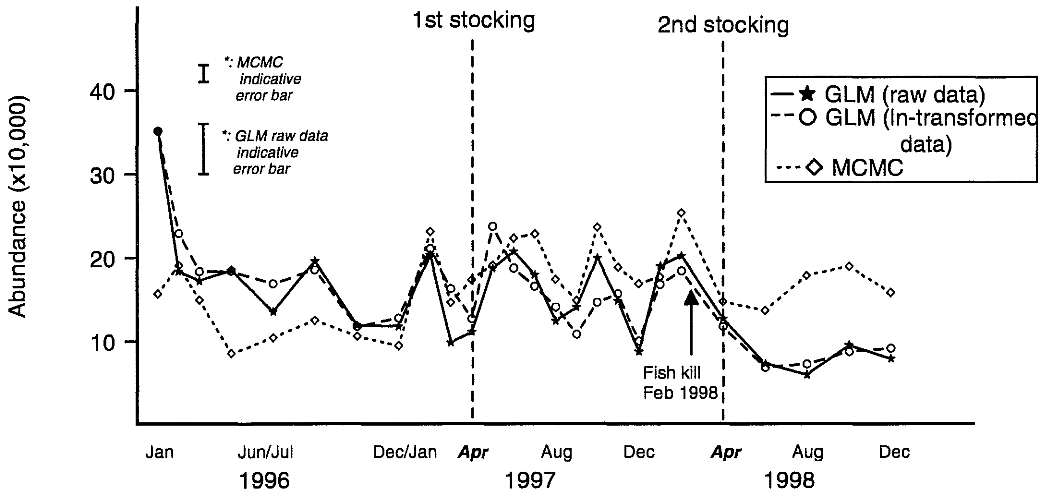


Figure 8.5: Abundance estimates of sand whiting >4 cm SL in the Maroochy River between January 1996 and December 1998.

*: Confidence intervals are indicative 2-way 95%, for the GLM and MCMC raw data series only. The reasons for this are discussed in the paragraph above.

The bias-corrected back-transformed means from the log-transformed general linear model remain the most robust estimates. An analysis of residuals confirmed that the log-transformed data conform to the underlying statistical assumptions of normality (Figure 8.6) which was not the case for the raw-data analysis. The main problem with using the log-transformed results is that there is no known method to estimate standard errors and confidence limits about the fitted estimates of total fish in all strata, but this is of secondary importance compared with obtaining robust estimates of numbers of each species over time.

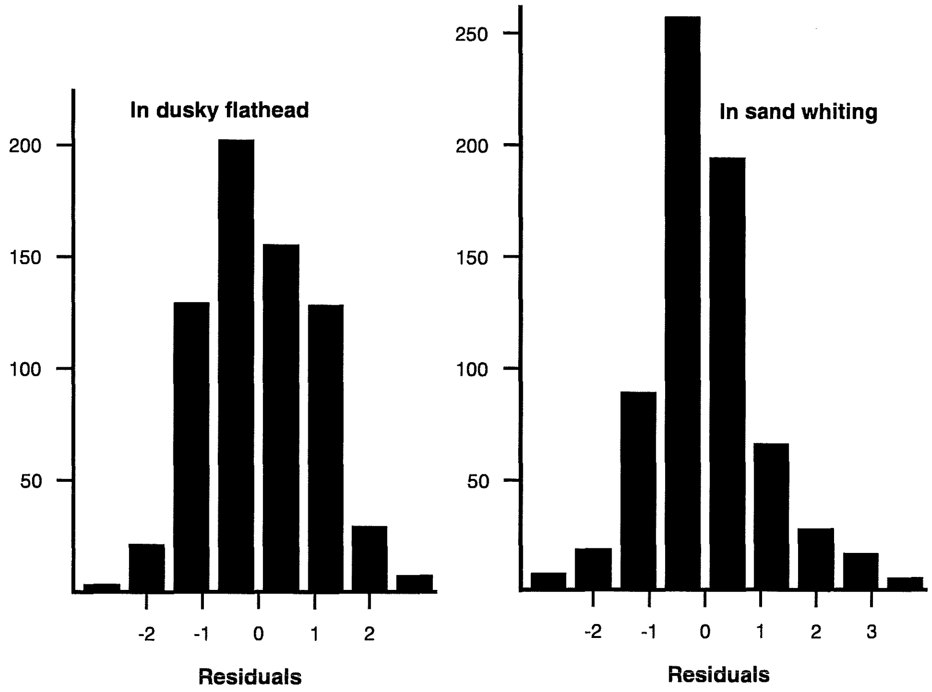


Figure 8.6: Standardised residuals from the main-effects general linear model of log (dusky flathead + 0.001) and log (sand whiting + 0.001).

The MCMC estimates generally followed the same trends as the other methods, but occasionally showed some divergence. This method also displayed sensitivity to the data and parameters used. If we consider the estimates from the log-transformed data as being the most reliable, then there is a trend of slightly increasing relative abundance of dusky flathead between February 1996 (trip 2) and February 1998 (trip 26), after which a marked decline was observed in the abundance of this species.

The initial density estimates of sand whiting were as high as 350 000 in the Maroochy River during January 1996. This one-off estimate appears inflated due to the very high catch taken during the first trip when only the more productive downstream sites were sampled (refer to Appendix 13.4). For the rest of the sampling period catches were lower and density estimates ranged between 100 000 and 200 000 over the next two years up to trip 26 (February 1998). After this point, there was a marked decline in estimated abundance of sand whiting, which coincides with the decline observed in dusky flathead abundance estimates.

The time-series analysis for dusky flathead showed significant ($p<0.05$) Fourier (cyclical) and quadratic terms with year 2 numbers being highest (Figure 8.7). The two dusky flathead stocking events were in December 1996 (trip 12) and December 1997 (trip 24), with the expectation of an effect in survey catch rates some six to 12 months after stocking. Modelling the predicted and observed catch data gave a best fit assuming the longest time gap, 12 months after the first stocking. This meant that there was no estimable effect from the second stocking. The effect of the first stocking was not significant because of the high degree of variability in the catch data, but the best estimate was an increase in dusky flathead abundance some 12 months after the first stocking by about 2500.

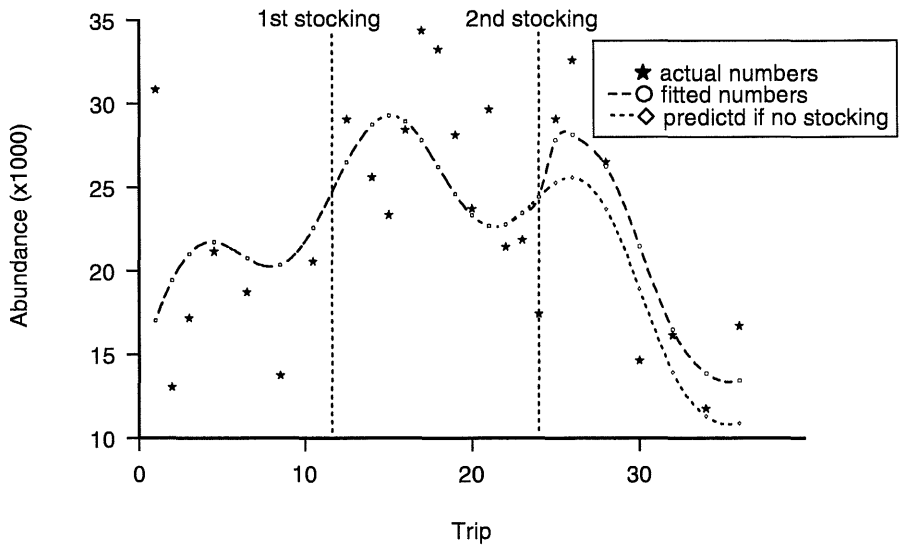


Figure 8.7: Dusky flathead actual, fitted and predicted numbers in the Maroochy River.

The stocking events for sand whiting were at April 1997, (trip 16) and April/May 1998 (trips 27 and 28), with the expectation of increased survey catches about three to six months after these dates. The best fit for the time-series data (Figure 8.8) was an increase in survey catches from September 1997 (trip 21) onwards (the maximum expected from the first stocking during trip 16). This meant that the effect of the second sand whiting stocking could not be estimated because there was no sampling done at the time when an effect would be expected. Again, the effect of the first stocking of sand whiting was not significant due to large variation in the catch data and thus total abundance estimates, but the fitted estimate showed that sand whiting abundance increased by about 6000 after the first stocking.

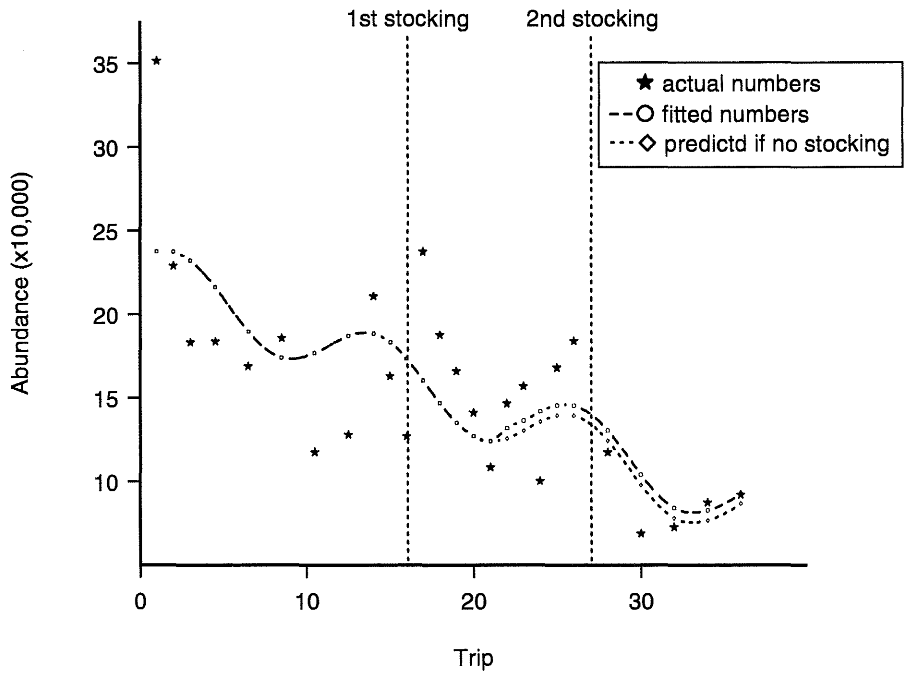


Figure 8.8: Sand whiting actual, fitted and predicted numbers in the Maroochy River.

8.3.1.2 Hatchery returns – Scale Pattern Analysis

Dusky flathead were first stocked in December 1996 (trip 12). The second stocking occurred 12 months later in December 1997 (trip 24). The first fish identified as being of hatchery origin were caught in May 1997 (trip 17), some five months after the first release. In total, 664 dusky flathead of unknown origin were collected by fishery-independent sampling between March 1997 (trip 15) and December 1998 (trip 33). This represents about 39 dusky flathead/trip. It is difficult to draw firm conclusions from this low catch rate. Nevertheless, classification of all the scale pattern data into their most probable origin (Table 8.3) revealed that hatchery bred dusky flathead made up 14 % of all flathead caught since May 1997 (trip 15). This proportion increased to 22% if only fish within the 95% c.i. size range were considered.

The ratio of hatchery-origin dusky flathead increased up to trip 20. However, there were no dusky flathead of hatchery origin identified in September or October 1997 (trips 21 or 22) (Figure 8.9). It was not until November 1997 (trip 23), some 6 months after the first recaptures and 11 months after the first stocking, that significant numbers of hatchery-bred flathead were consistently identified in the fishery-independent sampling, indicating a substantial time lag before the effect of the first stocking was observed. The catch results of the two gear efficiency trials (trips 27 and 31) are not relevant to the overall trends because only 4 sites were sampled in each trial. Allowing for intermittent variability in catches and thus ratios, the overall trend is one of a gradually increasing ratio of hatchery-origin dusky flathead until December 1998 (trip 33). The total catches/sampling event declined after the fish kill in February 1998 (trip 26), but the proportion of hatchery-origin dusky flathead increased.

A total of 2217 sand whiting of unknown origin were collected during fishery-independent sampling between June 1997 (trip 18) and December 1998 (trip 33). When all the sand whiting scale data were classified (Table 8.4), hatchery-bred whiting made up an average of 39% of all whiting caught after trip 17. This increased to 45% if sand whiting within the size range of the 95% c.i. anticipated at the time of sampling were examined. Hatchery-origin ratios increased from June to November 1997 then declined slightly until April 1998 (trip 28). Excluding the gear trials of March and September 1998 (trips 27 and 31), catches declined after the fish kill in February 1998 (trip 26), but hatchery-origin ratios increased from 9 to 48 % (Figure 8.10).

Table 8.3: Scale pattern analysis of dusky flathead captured from the Maroochy River.

Trip	Date	n	Estimated # of Hatchery origin	Estimated # of Wild origin	% Hatchery origin	% Wild origin
Trip 15	Mar 1997	31	0	31	0	100
Trip 16	Apr 1997	49	0	49	0	100
Trip 17	May 1997	48	3	45	6	94
Trip 18	Jun 1997	65	2	63	4	96
Trip 19	Jul 1997	54	10	44	18	82
Trip 20	Aug 1997	44	7	37	16	84
Trip 21	Sep 1997	44	0	44	0	100
Trip 23	Nov 1997	54	6	48	11	89
Trip 24	Dec 1997	40	3	37	8	92
Trip 25	Jan 1998	64	8	56	13	87
Trip 26	Feb 1998	60	7	53	12	88
Trip 27*	Mar 1998	59	11	48	19	81
Trip 28	Apr 1998	48	4	44	8	92
Trip 29	Jun 1998	25	5	20	20	80
Trip 30	Aug 1998	22	7	15	31	69
Trip 31*	Sep 1998	32	6	26	19	81
Trip 32	Oct 1998	36	11	25	31	69
Trip 33	Dec 1998	32	8	24	25	75

*: denotes a gear efficiency trial with samples collected from only 4 sites over 4 consecutive nights.

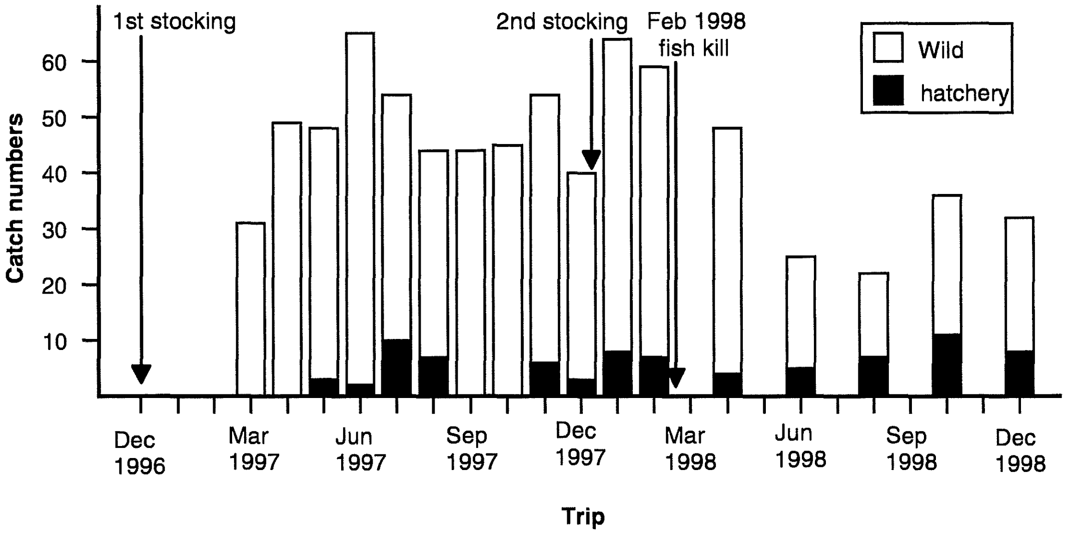


Figure 8.9: Numbers of hatchery-origin and wild dusky flathead in each fishery-independent sample from April 1997 (trip 16) to December 1998 (trip 33). The first stocking of dusky flathead occurred in December 1996 and the second stocking took place in December 1997. A fish kill occurred in late February 1998. Surveys in April and September 1998 were devoted to gear trials and their results were not used in the SPA survey of dusky flathead.

Table 8.4: Scale pattern analysis of sand whiting captured from the Maroochy River.

Trip	Date	n	Estimated # of Hatchery origin	Estimated # of Wild origin	% Hatchery origin	% Wild origin
Trip 17	May 1997	334	0	334	0	100
Trip 18	Jun 1997	416	4	415	1	99
Trip 19	Jul 1997	382	33	349	9	91
Trip 20	Aug 1997	276	11	265	4	96
Trip 21	Sep 1997	438	34	404	8	92
Trip 22	Oct 1997	536	53	483	10	90
Trip 23	Nov 1997	433	66	367	15	85
Trip 24	Dec 1997	269	33	236	12	88
Trip 25	Jan 1998	494	37	457	7	93
Trip 26	Feb 1998	538	47	491	9	91
Trip 27*	Mar 1998	296	16	280	5	95
Trip 28	Apr 1998	374	26	348	7	93
Trip 29	Jun 1998	281	54	227	19	81
Trip 30	Aug 1998	239	90	149	38	62
Trip 31*	Sep 1998	144	64	80	44	56
Trip 32	Oct 1998	332	156	176	47	53
Trip 33	Dec 1998	253	120	133	48	52

*: denotes a gear efficiency trial with samples collected from only 4 sites over 4 consecutive nights.

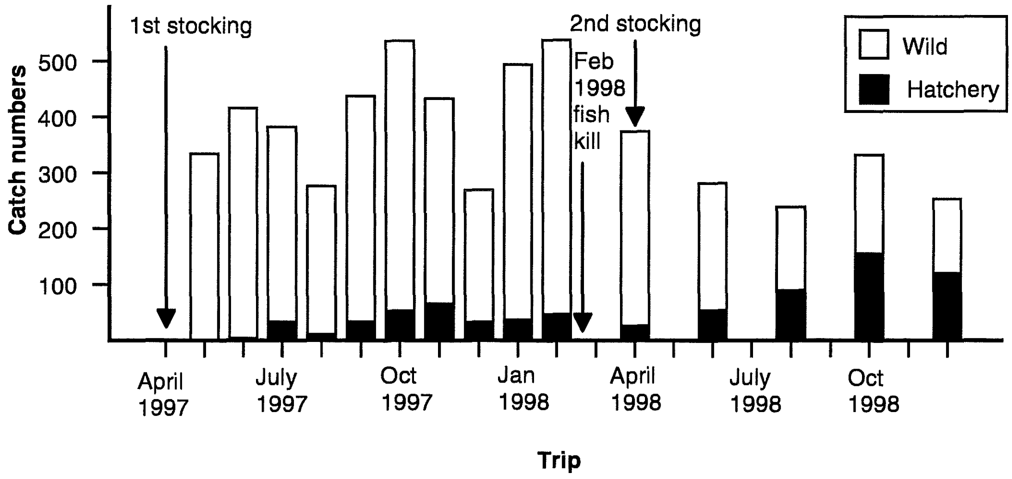


Figure 8.10: Numbers of hatchery-origin and wild sand whiting caught in each fishery-independent sample from March 1997 (trip 15) to December 1998 (trip 33). The first stocking of sand whiting occurred in April 1997 and the second stocking took place in April/May 1998, after the fish kill in late February 1998. Surveys in April and September 1998 were devoted to gear trials and their results were not used in the SPA survey of sand whiting.

8.3.2 Recreational Fishery

8.3.2.1 Angler Diary

Some 50 recreational angler diaries were distributed to interested anglers between December 1995 and August 1996. At least 30 of these were distributed during interviews on the river and local tackle shops distributed the remainder. At the first follow-up phone interview, three weeks later, fewer than 50% of the respondents indicated that they been fishing in the Maroochy River since receiving their diary. Another 32% were no longer interested in participating. The rest were keen to continue providing information, with three fishers requesting more copies of the diary. The dropout rate increased while the recruitment rate fell away. By August 1996, only three fishers were actively filling out diaries. At a progress meeting held at SFC in September 1996 it was decided that the diary program was not having the necessary success with the recreational sector. The amount of data from the diaries completed to date would not be sufficient to provide a robust assessment of recreational angler activity before and after any stocking event. A decision was made to discontinue this part of the recreational fishery assessment and concentrate on assessing recreational catch for hatchery-origin fish.

8.3.2.2 Club catch trends

It is important to note that all club trips were targeting sand whiting and any flathead catches were incidental. Data relate to a single fishing trip in each of the years 1994, 1996 and 1999. There were four trips in 1995, none in 1997 and two in 1998. Fisher skill was an important factor in determining club catch rate. In the general linear model, the variation between fishing skill levels was significant for the sand whiting catch rate ($p<0.01$), but not for dusky flathead ($p=0.153$). There was no significant difference in dusky flathead catch rate between years ($p=0.443$) with 98% of fishers not catching a legal sized fish. Sand whiting catch rates ranged from 12 to 23 fish/person/trip and there were significant differences ($p<0.001$) in catch rates between years. These differences varied from year to year, increasing in both 1996 and 1999, and decreasing in 1995 and 1998 (Figure 8.11).

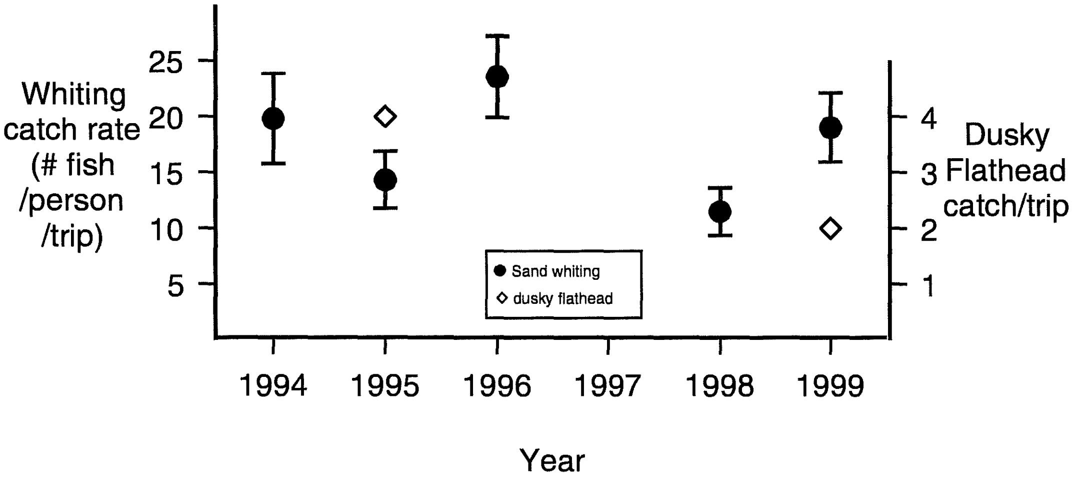


Figure 8.11: Catch rates from recreational fishing club competitions in Maroochy River. Data source: Redcliffe Fishing Club.

8.3.2.3 Recreational catch - Scale Pattern Analysis

A total of 13 dusky flathead ranging in size from 16.2 to 56.3 cm (SL) and 192 sand whiting ranging in size from 13.8 to 34.0 cm (SL) were sampled from the recreational sector in 1998 and 1999. The majority of sand whiting came from two angling club outings to the Maroochy River. Scales from these fish were analysed using the two discriminant functions developed from the reference scale collections. The results are presented below in Table 8.5. The small recreational dusky flathead sample (n = 13) was nearly evenly split between hatchery and wild origin. The sand whiting showed a similar ratio of hatchery to wild origin (44% and 56% respectively). The two club trips concentrated in two different areas, one between the Motorway Bridge and Goat Island (region 2), and the other downstream of Chambers Island (region 1). Samples from the region 2 trip had a higher proportion of sand whiting of hatchery origin (61% compared to 37%).

Table 8.5: Scale pattern analysis of the recreational catch from the Maroochy River.

Species	n	Hatchery	Wild	% Hatchery	% Wild	Av. SL (cm) hatchery	Av. SL (cm) Wild
Flathead	13	6	7	47	53	32.5±1.0	32.3±6.4
Whiting	192	84	108	44	56	21.8±1.0	22.9±1.0

8.3.3 Commercial Fishery

8.3.3.1 Commercial catch trends

The Maroochy River commercial net fishery consists of about six regular operators spending about two-thirds of their yearly fishing effort on the river. Up to six additional operators occasionally net fish or pot for crabs in the Maroochy River, when not spanner crabbing offshore or fishing other estuarine areas. All of the regular fishers live in the Maroochy Shire and hold a combination of commercial fishing endorsements (line, net, ocean beach net and crab). Gill or mesh nets are used in areas where mullet and whiting are likely to swim into the net. Nets were worked either during the day or night, depending on the tides and individual fisher's preferences. Mullet is the main species taken by commercial fishers, with whiting contributing about 9% and flathead less than 1% of the total yearly catch by weight (CFISH 22nd March 1999).

Only nine fishers reported catching flathead and ten reported catching whiting in the Maroochy River. A generalised linear model was applied to the CFISH CPUE data for both species to investigate yearly catch trends. The average yearly catches for the two species were 50 and 1700 kg respectively. Trends in catch rate over the last decade are expressed as a percentage difference from 1988, rather than the actual CPUE (Figure 8.12) to maintain fisher confidentiality. The CPUE for dusky flathead and sand whiting were highly variable. Dusky flathead catches appear to cycle around peaks every three to four years (1988, 1991 and 1995), with an overall decline in CPUE between 1989 and 1998 (> 50% fall in CPUE). This decline had abated since 1997. Sand whiting relative CPUE declined between 1989 and 1990, then rose appreciably by 1992. However, as with dusky flathead, it has declined significantly, especially in 1996, and by 1998 was some 40% lower than in 1992.

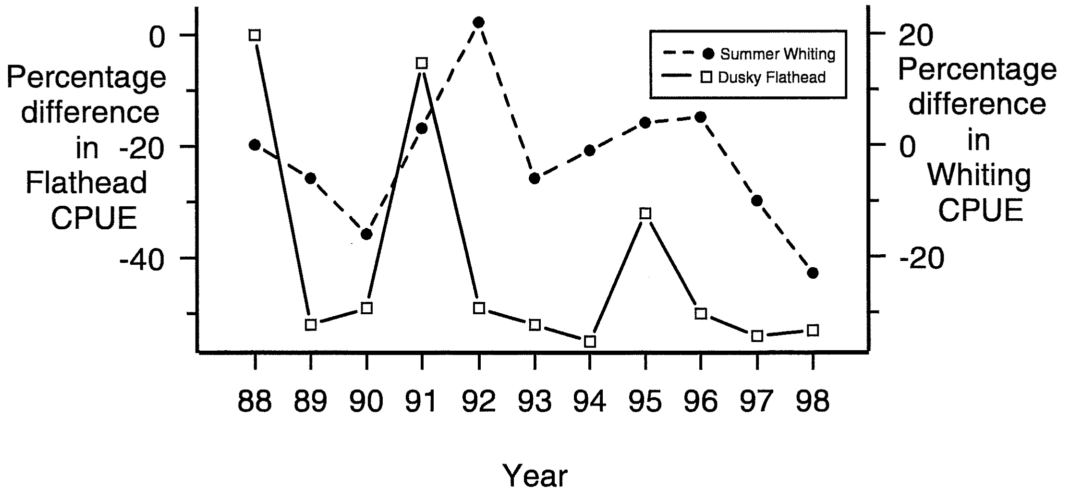


Figure 8.12: Percent difference in yearly CPUE in Maroochy River for dusky flathead and summer whiting. Data source: CFISH 22nd March 1999.

8.3.3.2 Commercial catch - Scale Pattern Analysis

A total of 73 flathead ranging in size from 24.1 to 51.6 cm (SL), and 44 whiting ranging in size from 24.1 to 33.2 cm (SL) were collected from commercial fishers for scale pattern analysis. To boost the sample size, undersized flathead were kept by commercial fishers between February and April 1998 under a QFMA permit. The majority of whiting came from between Eudlo Creek and David Low Bridge. These were analysed for origin using the two discriminant functions developed from the reference scale collections. The results are presented in Table 8.5. Nearly three-quarters of the dusky flathead were classified as being of wild origin. The commercial sand whiting samples had a large average size (and thus age) because of the selectivity of the commercial gear. To overcome this bias against hatchery-origin fish, only the smaller sand whiting within the predicted size range at the time sampling occurred (Av. = 26.8 cm SL) were analysed by scale pattern analysis. The smaller commercially caught sand whiting were more evenly distributed between hatchery and wild origin.

Table 8.5: Scale pattern analysis of commercial sand whiting catches in the Maroochy River.

Species	n	Hatchery	Wild	% Hatchery	% Wild	Av SL (cm) Hatchery	Av. SL (cm) Wild
Flathead	73	19	54	28	72	33.3±2.2	33.2±2.2
Whiting	44	23	21	52	48	24.3±0.8	24.3±0.7

8.3.4 Economic analysis

The total cost of this pilot project, before any benefits were attributed, was around $645 000 in the Outlay model (Appendix 13.7) and about $915 000 in the Total Cost model (Appendix 13.8). In the best-case scenario, where all fish are captured immediately they reach 'legal' size, and they are additional to the fish already in the system, then the cost to the community is about $580 000 or about $17 per additional fish for the Outlay model and $840 000 or about $24 per additional fish for the Total

Cost Model. The cost per fish is more sensitive to the number of fish stocked than to the survival rate.

8.4 DISCUSSION

8.4.1 Fishery-independent sampling

8.4.1.1 Effect on total population estimates

There was an unexpectedly large variation in the survey catches of both species over the course of the 33 sampling trips. It was anticipated that there would be some increase in catch rates over the first six months as staff improved their gear deployment techniques. However, the total catch varied markedly (from 24 to 64 dusky flathead and from 212 to 538 sand whiting) with only a weak seasonal pattern emerging from the time-series analyses. On several occasions when sampling followed periods of heavy rainfall, low catches were recorded, but this failed to explain much of the overall variation.

All three density estimate models provided similar assessments of the abundance of dusky flathead and sand whiting populations in the Maroochy River. While stratified untransformed densities are often appropriate to build into population density estimates (M. Haddon personal communication 1999), our results showed heterogeneous variances and skewness in the distribution of residuals. Log-transformation of the raw resulted in normalisation of the residuals. The MCMC model tended to 'overestimate' densities when net sampling efficiency fell below 20% (especially beam trawling for sand whiting). It may be possible to overcome this by omitting the beam trawl based data from the MCMC analysis, but that would lead to further bias of densities in upstream regions where beam trawling was the principal method of sampling. The MCMC model needs further research and development to overcome this problem. The MCMC derived population estimates based on the first nine trips only (Table 4.4) are quite different from those for the same time points but based on all the data (Appendix 13.5). Initially, we attributed this problem to over-parameterisation as only one net type was used at each site, thus α, β and c parameters could not all be estimated by posterior distributions. However, this over parameterisation does not preclude Baysian inference as long as a suitable informative prior distribution is specified (Gelfand and Sahu 1999). Gilks et al. (1996) outline a number of possible reasons for non-convergence and errors in MCMC and contend that successful modelling is more an art than science. This complex multi-tiered model certainly tests the new (MCMC) methodology, but in this case we believe its estimates were not adequately stable. The model will require further development if we are to be confident of its application in future population assessments.

As expected, dusky flathead abundance estimates were well below those of sand whiting. Dusky flathead did show slightly increasing abundance over the first 26 months of this survey (up to 12 months after the first stocking). Highest densities were observed in May 1997 (trip 17) and again in January 1998 (trip 25), some 12 months after the first restocking (December 1996), as expected from the time series analysis. The effect was lost after February 1998 (trip 26) with the advent of a major perturbation in the river, described below. The estimated size of the sand whiting population appeared to be highly variable during the first 12 months, probably reflecting the sampling intensity. The overall trend was of a slowly declining population prior to February 1998 (trip 26). In February 1998 there was a major overflow of Wappa Dam on the northern arm of the Maroochy River. Down-river movement of large rafts of aquatic weed (*Salvinia molesta* and *Eichhornia crassipes*) were associated with this overflow. These became submerged after prolonged contact with the estuarine waters of the lower Maroochy estuary and proceeded to rot. We suspect this caused massive oxygen depletion in the river and resulted in a major fish kill, as reported to the Department of Environment (18.12.98). We have no estimate of the number of resident dusky flathead and sand whiting that were either killed by this event or migrated out of the river to more suitable habitats. Regardless of the mechanism, the effect was observed in depleted catches later in 1998. It is quite possible that this fish kill, at a crucial time after the stocking events, masked any positive effect of stocking on the resident population of dusky flathead and sand whiting in the river. The effect of the overflow was augmented by a second major overflow of Wappa Dam in September 1998. Large rafts of weed were again observed to within 0.5 km upstream of the river mouth. Again, a large fish kill was reported to the Department of Environment (now EPA) which attributed the cause of mortality to oxygen depletion. The overall effect of these events was a reduction of fish abundance in the Maroochy River after February 1998.

A cyclical abundance trend was modelled for both species. The best fit was poor ($R^2 < 0.5$ for both species) because of the high level of variation in catches leading to highly variable population estimates. The models indicated that the population of sand whiting increased naturally during the summer months and decreased naturally over winter. This would tend to support anecdotal evidence of poor catches during winter. The dusky flathead population appeared to increase during autumn each year and decrease in spring. Although both models have one cycle per year, there is no apparent reason for them to be linked, unless juvenile sand whiting are a significant source of food for dusky flathead in the Maroochy River. The models indicated a slight positive effect on the population of dusky flathead and sand whiting attributable to the stocking, but the increases were not statistically significant for either species. We suggest that this was the result of the lack of statistical power due largely to the inherent variability in the distribution, behaviour and catchability of the fish in the estuary. If there are to be similar stocking programs in future that require monitoring as an index of performance, then alternative sampling and survey strategies should be examined. It was disappointing that the full effect of the second stocking of each species could not be observed because of the short time-series of data. Various authors (Blankenship and Leber 1995, Cowx 1998) have recommended against short stocking trials because of this aspect of detection. It would have been very useful to continue monitoring for at least another 12 months to allow time for fish from the second stocking event to grow to a size where they were vulnerable to capture by the monitoring program.

8.4.1.2 Hatchery returns–Scale Pattern analysis

Scale pattern analysis has proven to be a reasonably reliable technique for differentiating between wild and hatchery-origin fish of both species. It is not very labour intensive, and provides a relatively quick answer to the question of origin. One of its best features is that it is non-destructive on the fish being sampled. On the other hand, there is some degree of error associated with using this technique. In the case of dusky flathead the nearly equal classification error implies little bias in the discriminant function. However, for sand whiting, the discriminant function was conservative in its estimate of hatchery-origin fish. This conservatism provides scientific robustness to the interpretation of the results in that any estimate of the proportion of the population that is of hatchery-origin is more likely a minimum estimate and the reality should be even more favourable. It is pertinent to note that, as with the cyclical modelling, there appeared to be around 12 months delay between the time of stocking and the time that a significant numbers of hatchery-origin dusky flathead were observed in the survey catches, but only four to six months delay in sand whiting being observed in the fishery-independent catches. This adds support to our basic assumptions associated with the stocking program.

Dusky flathead have a peak spawning period between September and December, and wild growth rates indicate that they should reach a size commensurate with recapture in 6 months (Hoyle et al 2000). Our results support this with the first hatchery-origin fish being recaptured 5 months after the first stocking event. However recaptures were highly variable in the first 10 months after stocking. There is no obvious reason for the absence of hatchery-origin dusky flathead in the September and October 1997 survey catches. The overall catches of dusky flathead declined markedly after the fish kill in February 1996, but the hatchery-origin ratios increased. The overall trend has been for a relatively low ratio of hatchery-origin dusky flathead (<20%) from 6 months after the first stocking until the fish kill in February 1998. We suspect that this is a result of high stocking and post-stocking mortality amongst hatchery-origin dusky flathead, combined with continual recruitment of wild dusky flathead juveniles. Our catch results indicate that even though dusky flathead are reported to be relatively tolerant of high turbidity and low salinities, preferring muddy-silty intertidal habitats (Kailola et al. 1993) many either died or moved out of the Maroochy River as a result of the fish kill. However, scale pattern analysis indicates that this effect was more pronounced on the wild stock with markedly higher ratios of hatchery-origin dusky flathead after the fish kill. We believe this is evidence of successful recruitment of hatchery-origin dusky flathead from the second stocking, as a direct consequence of reduction in wild recruitment brought about by the fish kill. These results provide evidence that stocked dusky flathead have survived and grown in the Maroochy, contributing to the total population especially after the February fish kill.

Sand whiting have a spawning period between September and March and may spawn more than once/breeding season (Morton 1985). The first hatchery-origin fish were observed in June 1997 (trip 18), some 2 months after the first stocking event. Ratios of hatchery-origin fish increased after this point as stocked fish grew and became increasingly vulnerable to capture by the fishery-independent gear. However, this ratio declined after November 1997 (trip 23), most probably due to the increasing presence of wild-origin recruits. The fish kill in February 1998 caused a marked decline in overall catches of sand whiting, but the second stocking appeared to produced a classical stocking response. Ratios of hatchery-origin sand whiting increased noticeably, most probably in the absence of natural recruitment. The survey was curtailed prior to establishing the temporal strength of this effect, but the results indicate that hatchery-reared sand whiting made up a significant proportion to the total catch.

If we accept that there was a decline in populations of both dusky flathead and sand whiting after February 1998, then the obvious conclusion is that the river suffered a temporary decline in population levels as a consequence of the fish kill. While we have no information about whether or not the large proportion of hatchery-origin fish represent a displacement of the natural population, we think it is unlikely, given the stock reduction resulting from the fish kill and the suggested decline in commercial CPUE data. Examining the issue of augmentation versus displacement was beyond the scope of this study, but is an important issue (Blankenship and Leber 1995, McEacheron et al. 1998, Leber et al. 1998, Cowx 1998) that should be investigated in future estuarine stocking research. However, it can be said that the scale pattern analysis ratio of sand whiting supports the concept that stocked fish can successfully exploit under-utilised habitats immediately following perturbations such as fish kills.

8.4.2 Recreational fishery

The results of the angler diary survey are disappointing, but not unexpected. Previous work by various authors (Matlock 1991, Grambsch and Fisher 1991, Cameron and Begg in draft) have shown that running a recreational diary program is expensive, time consuming and a poor substitute for on-site surveys such as fishery-independent sampling. It is probably the only method available to some recreational fisheries, but otherwise should be used only as a secondary adjunct to traditional techniques such as sampling. Given that the diary was never fully budgeted in this program, nor was there sufficient lead-in time before the first stocking event, it was very unlikely that it would show any real trend prior to the stocking events. Logbook programs are often based on unrealistic expectations and if not thoroughly designed and reviewed, will rarely give statistically robust results. The analysis of club catch trends, although a biased snapshot of superior recreational fishers, supports the low expectations of the diary program in that catches appear to be highly variable. There is an increase in catch rate of sand whiting between 1998 and 1999 which appears supportive of the positive effect of restocking. However, a larger increase was also observed between 1995 and 1996, prior to the expected effect of the first token stocking (15.3.95). There is thus some doubt as to whether the 1998–99 increase can be attributed to the stocking operation.

The recreational catch of dusky flathead and sand whiting included a significant number of hatchery-origin fish. It was interesting that a higher proportion of hatchery-origin whiting were obtained from samples collected further up-river. Anecdotal evidence indicates that some sand whiting do migrate in and out of the river with each tidal cycle. Certain fishers target these fish during the tidal flow. The mouth of the Maroochy River was always perceived as an area for loss of stocked fish that might diminish the effect of stocking. However, the very positive result from 1999 recreational catches taken further upstream (up to 61% from hatchery-origin) indicate that stocking can augment catches.

8.4.3 Commercial fishery

Although commercial activity is restricted to upstream of the Cod Hole Boat Ramp, it is far more consistently recorded than recreational club fishing in the Maroochy River. However, there are resolution problems with interpreting the CFISH data. In particular, the grids W36-6 and W36-1 incorporate the Maroochy River as well as the adjacent ocean beaches. Several of the commercial netters fish in both areas. Fortunately, these fishers were identified and their catch records for the ocean beach tailor and mullet seasons were removed from the data set prior to analysis. Since 1988, the commercial catch data display a decreasing trend, particularly since 1991 for dusky flathead and 1996 for sand whiting, although dusky flathead catches have stabilised since 1996. The dusky flathead stabilisation probably occurred too early to be attributed to the stocking, but further analysis of 1999 data, when available, may show an effect due to stocking. The scale pattern analysis indicates that hatchery-origin fish did contribute significantly to the commercial catch with sand whiting contributing a larger proportion than dusky flathead.

8.4.4 Economic analysis

It is extremely difficult to evaluate the economics of a restocking program when the cost of producing the effect is itself not able to be quantified (Welcomme 1998). This is because there are essentially five components that need to be considered before the whole process can be evaluated. They are:

1. Separating development costs from production and monitoring costs.
2. Deciding the proportion of development (or research) costs attributable to the project where the development will be immediately useable in other projects or to commercial enterprise.
3. Placing a monetary value on the harvested product from all sectors involved in the fishery.
4. Monitoring for a sufficient period so the net effect of the stocking can be assessed.
5. Estimating regional/state economic effects as a result of the stocking.

Apart from Kitada et al. (1992), Ungeson et al. (1993) and Masuda and Tsukamoto (1998), who demonstrated the cost-effectiveness of restocking several commercially important marine species in Japan, there have been few economic analyses of stocking in the marine environment.

For the above reasons, a different level of economic scrutiny has been applied to this program than to comparable studies (Rutledge et al. 1990; Bannister and Addison, 1998; Moskness et al. 1998). Such scrutiny may be more realistic (Hilborn 1998), but it makes it difficult to compare the economic indicators with those from other studies. The main differences with this analysis are that it makes no allowance for indirect benefits such as the regional benefit of a successful stocking program, the benefits of the information gained associated with a demonstration of the feasibility concept, nor the effects of the 1998 fish kill. It has been demonstrated during this pilot program that data were not collected over a sufficiently long period to enable full assessment of the effect of the stocking events. This problem was amplified by the fish kill in 1998 that would have affected survival rates of both stocked and wild fish. Consequently, to carry out a cost-benefit analysis of the program, models were developed to estimate the potential number of fish available for recapture. The most optimistic outcome of the modelling (that each stocked fish captured was valued at between $17 and $24) was higher than that found in other studies (Rutledge et al. 1990, Russell and Rimmer 1995). It is reasonable to expect that developmental studies such as this will be expensive, and the absence of data on the effectiveness of the second stocking may have inflated the cost of each fish caught. Additional monitoring would have been required to carry out this evaluation, but would itself also have increased the total cost of the program. Lessons learned from this program, and the introduction of economies of scale, should contribute to significant cost reductions per fish in future stocking operations.

9 GENERAL DISCUSSION

A. Butcher and J. Burke

9.1 INTRODUCTION

There is growing recognition across the fishing community that stocking can be an effective counteraction to the inevitable pressures on our river systems brought about by the expansion of recreational and commercial fishing pressure. This interest is buoyed by several reports in the scientific literature on successful enhancement of native populations by hatchery releases (Kitada et al. 1992, Honma 1994, Leber et al. 1995, McEacheron et al. 1998, Leber et al. 1998). Other reports cite evidence of successful recruitment of hatchery releases into the commercial and recreational sector (Olson et al. 1995, Hendricks 1995, Lee 1995, Moskness et al. 1998, Rimmer and Russel 1998, Masuda and Tsukamoto 1998).

From the outset of this study, it was acknowledged that there have been some flaws in the conduct of previous stocking exercises. These include i) a failure to consider economic issues, ii) a belief that stocking is a general panacea for the relief of declining catches and iii) a failure to adequately monitor the effect of stocked fish on the standing population. Consequently, considerable effort was directed towards trying to avoid the pitfalls of too simplistic an approach to what was and is in fact an exceedingly complex process.

Historically, stocking programs have rarely been accompanied by an appropriate assessment of the associated cost-benefit. Some exceptions include the Japanese flounder (*Paralichthys olivaceus*) stocking program in Fukushima prefecture which has recorded a 30% recapture rate and a cost-benefit ratio of more than 300% (Masuda and Tsukamoto 1998), and the Japanese chum salmon (*Oncorhynchus keta*) stocking program which has reported a 3 % recapture rate (Hilborn 1998). Several other stocking programs reported to be "border-line" may have been economically successful had the recapture rate been slightly higher (Moskness et al. 1998, Bannister and Addison 1998), but most stocking programs fail to investigate the economic issues with any rigour. Although a cost/benefit was outside the original charter of the pilot program, it was subsequently applied to deal with the above concerns.

A second major area of contention is the perception by many that stocking is a general panacea that will alleviate declining catches brought about by over-fishing, declining water quality or habitat disturbances (Leary et al. 1995, Radonski and Loftus 1995, Travis et al. 1998). Fisheries management objectives are largely determined by public demand, and stocking is recognised as a very effective management tool when used with the right species for the right reasons (Harris 1995). Some would argue that if fishery resources are declining, fisheries management should address the underlying causes such as habitat degradation and/or overfishing (Stone 1995, Flagg et al. 1995, Leary et al. 1995). Realistically, this is often harder to achieve than stocking because fisheries resource managers rarely have ultimate control over habitat management (Radonski and Loftus 1995) and habitat restoration can be both prohibitively expensive and socially disruptive (McGinnis 1994). As Grimes (1995) points out, much of the stocking debate is really to do with resource allocation amongst a wide diversity of stake-holders.

Whatever the reason behind a stocking program, it needs clearly defined quantifiable objectives and to be well managed and reviewed (White et al. 1995, Blankenship and Leber 1995, Cowx 1998, Hilborn 1998). Stocking programs should be designed to contribute to better management of aquatic resources by providing feedback protocols (Welcomme 1998) that allow an assessment of their impact on a complex and often unpredictable environment.

All of the above issues were considered in the design and implementation of this program, but being one of the first attempts in Australia to investigate the effects of estuarine stocking in an objective way, it has not been able to comprehensively investigate all of the areas of contention. However, honest effort was directed towards the bulk of the recognised problem areas. The study has served to illustrate the difficulties in trying to estimate dynamic processes in a complex ecosystem vulnerable to many uncontrolled inputs. This problem is not unique to the discipline of stocking, and it serves to highlight the fact that natural influences can confound the best-designed experiments. Being a pilot program, it had several broad objectives. The success with which the program investigated these objectives are discussed below.

9.2 OBJECTIVES

9.2.1 Objective 1: Develop technology to undertake large- scale breeding of finfish (whiting, flathead) for stocking a south Queensland Estuary.

The inability to culture marine fishes beyond early larval stages has always been recognised as a major hurdle to widespread marine stocking (Blankenship and Leber 1995). The preferred species for stocking at the genesis of this program were the premier angling species dusky flathead, *Platycephalus fuscus*, and sand whiting, *Sillago ciliata.* Of these species, small-scale production had only been achieved once previously with sand whiting (Battaglene et al. 1994). Research at BIARC had previously led to the successful mass culture of several marine and estuarine fish species including Australian bass (Burke 1994), barramundi (Palmer et al. 1992). Adoption of green-water culture production techniques led BIARC researchers to early success in the Maroochy River Pilot Stocking Program with mass-production of fingerlings. During the term of the program several production problems were experienced, but the supply of fingerlings was never a constraint to the study.

Problems encountered in production included variability in natural food productivity, growout survival, and harvesting success. The variability of pond productivity was thought to be exacerbated by the artificial liners used in the growout ponds. This problem can be overcome with adaptive pond management, but the inherent variability of pond dynamics makes it difficult. Variability in growout survival may have been due to overstocking resulting from poorly defined production targets. Density estimates of chosen species in the Maroochy River, and thus stocking requirements, were unavailable until well into the production cycle. This meant that the growout ponds were stocked at higher than optimum densities to provide some flexibility in production targets. Prior knowledge of optimum stocking densities would alleviate this problem. Harvesting strategies at BIARC are based on successful pond draining, but on several occasions dusky flathead growout ponds developed dense algal matting that hindered successful drainage and harvesting. This problem relates to the variability of pond productivity mentioned above.

Regardless of the production problems, the early success of attempts at mass production of both species represents an aquaculture milestone. The success reflected the appropriate choice of methodology (green-water culture), the availability of appropriate facilities (hatchery and ponds) and the presence of skilled staff based at BIARC. The incorporation of the Health Assessment Index as a means of validating fingerling quality introduced a level of quality assurance into the supply of fingerlings. The general application of the Health Assessment Index to all future stocking programs should be considered, as has been recommended by several authors (Blankenship and Leber 1995, Coates 1998).

9.2.2 Objective 2: Undertake a large, extended stocking of a south Queensland estuary (the Maroochy River).

There has been one other recent marine stocking program in Queensland, although there is an extensive and closely managed program involving freshwater impoundments throughout the State (Hamlyn 1998). Russell and Rimmer (1995) have reported on the stocking of 69,000 barramundi in the Johnston River, north Queensland. All fish stocking in Queensland is carried out in accordance with an approved Fish Stocking Plan which sets out what species may be stocked and where. The Maroochy River stocking program represented a change from this policy in that it was approved by State Cabinet and previewed at a scoping workshop and again at a post workshop review by DPI Senior Fisheries Management. Most of the important issues pertaining to stocking in southern Queensland waters were considered during the workshop. Although there was little input from local interest groups, they readily agreed to participate in the actual stocking events.

The process of stocking was a protracted event, involving hatchery production, harvesting, transport and distribution. The production team at BIARC successfully reared nearly 100 000 dusky flathead and 335 000 sand whiting fingerlings for stocking between 1995 and 1998. Harvesting and transport techniques were refined to improve the survival rate of stocked fish. Distribution of fingerlings within the river attracted a good deal of media interest and the assistance of the Maroochy River Stocking Group was vital to the successful distribution of fingerlings into the river.

As with stocking programs overseas (Masuda and Tsukamoto 1998, McEacheron et al. 1998) short-term post-stocking survival of both species was variable. Stocking rates were elevated to take account of some degree of stocking mortality. Conducting trials to define an optimum release strategy for each of the species was outside the scope of this pilot program, but has important implications for fingerling survival and should be investigated in any future research into stocking.

9.2.3 Objective 3: Develop protocols to monitor the effectiveness of stocking in the Maroochy River estuary.

To monitor the effectiveness of stocking in the Maroochy River, we required a method to easily identify hatchery-bred fish after their release and subsequent capture, and a method to estimate the natural and stocked densities of dusky flathead and sand whiting. The method had to be easy to apply to large numbers of fish at a time, must not affect their survival or growth, must be retained on the fish for the duration of their life and be relatively inexpensive. Several techniques were considered at the scoping workshop (August 1994), but only Scale Pattern Analysis (SPA) and chemical otolith marking (OTC) were considered to be economically practicable. Despite reports of successful use of OTC in overseas studies (Secor et al. 1991, McEacheron et al. 1995, Ukenholz et al. 1997, McEacheron et al. 1998, Reinert et al. 1998), we were unable to establish reliable OTC marks in either sand whiting or dusky flathead. This may have reflected a problem with the immersion methodology used, even though a wide range of exposure protocols was tested. The use of this chemical led to associated problems of disposal of large quantities of contaminated seawater, which Choo (1994) claims to have a half-life in excess of 250 hours in covered tanks. Expansion of estuarine stocking in Queensland could lead to the widespread use of OTC for mass fish marking. The likelihood of accidental spillage, the toxic (at high concentrations) and residual nature of the chemicals involved and the well-publicised concerns about the unrestricted use of antibiotics represent an unacceptable public and environmental liability. The unreliable results make this risk even more unacceptable. We recommend that the use of OTC as a means of mass marking for stocking purposes be discouraged.

Discriminant functions developed from reference dusky flathead and sand whiting SPA were 78% and 77% accurate respectively in differentiating hatchery-origin stock from an unknown source. This compares well with other scale pattern recognition experiments (Cook and Lord 1978, Major et al. 1978, Willett 1996) and is comparable or better than OTC retention rates recorded by some authors (Drawbridge et al. 1993; Blom et al. 1994, Reinert et al. 1998). The dusky flathead discriminant function had similar hatchery and wild misclassification rates which gave it a balanced error structure in terms of mis-identification. This meant that although some hatchery fish could not be identified in the post stocking samples, an equal number of wild fish could be erroneously identified as hatchery fish and thus the total estimated recruitment rate would not be affected. The sand whiting discriminant function was conservative in its estimate of hatchery-origin sand whiting numbers, being twice as likely to misclassify hatchery-origin sand whiting as wild than wild-origin as hatchery-reared fish. This meant that some 5% more hatchery fish would be incorrectly identified as wild fish than the number of wild fish incorrectly identified as hatchery fish. Thus, in reality, the recruitment of hatchery fish into the exploitable population would be higher than our estimates. However, it was decided to adopt the lower, conservative recruitment estimates.

To improve the accuracy of identifying hatchery reared fish, there is scope to use the improved technology of genetic monitoring techniques. If successful, these techniques would be superior because they would allow the level of recruitment to be estimated with higher accuracy, at the same time facilitating the monitoring of the genetic contribution of the stocked fish to subsequent generations, that is a primary concern for the long-term “fitness” of native fish stocks. Several authors have argued that stocking to increase population and harvest levels is often done at the expense of genetic diversity (Leary et al. 1995, Thorpe 1998, Conover 1998). Masuda and Tsukamoto (1998) go further and propose the maintenance of genetic diversity as a government responsibility. We support these arguments and propose that cost-effective genetic monitoring techniques be applied to future stocking programs.

9.2.4 Objective 4: Undertake a full-scale monitoring program in association with the experimental stocking program.

This exercise was designed to demonstrate the effectiveness or otherwise of stocking in a habitat known to have been temporarily damaged. Given the underlying complexity of what superficially appears to be such a simple hypothesis, the stocking team was required to make a number of crucial assumptions about the chosen species populations with respect to growth and survival of wild and stocked fish, and the effectiveness of marking and capture techniques. The major assumptions upon which the interpretive analysis was based are as follows:

1. density estimates of the wild population were truly representative
2. in each species, introduced and wild fish both had similar rates of natural mortality and growth, and were equally catchable in the survey, recreational and commercial gear types
3. natural recruitment did not influence the ratio of stocked to wild fish within the size-range examined
4. there was no time-related change in the accuracy or bias of the scale pattern analysis.

During the study we made 33 fishery-independent sampling trips between January 1996 and December 1998. The catch data from these trips exhibited an unexpectedly large amount of variation with no seasonal pattern. However, as with the studies of McEacheron et al. (1998) and Leber et al. (1998), we were able to assess the densities of the chosen species both before and after the stocking events. Three models were used and all gave similar estimates of abundance of dusky flathead and sand whiting populations in the Maroochy River. The models all indicated that dusky flathead densities increased slightly during the first 26 months of the survey (up to 12 months after the first stocking). Sand whiting densities, on the other hand, changed little in the ten months after stocking prior to February. Both populations suffered a significant decline in densities after February 1998, which was probably due to a major perturbation in the river resulting in a large fish kill. The extent of dusky flathead and summer whiting mortality or migration following the fish kill is unknown. Effectively the net result was a short-term decline in the river's carrying capacity and depressed fishery-independent catches in the late 1998.

All models used to estimate the abundance of the chosen species had drawbacks. Density estimates from the raw data displayed heterogeneous variances and a skewed distribution of residuals. The MCMC model gave over-optimistic estimates of abundance when net efficiencies were low. Hence, only the robust log-transformed data were analysed for stocking effects on the populations of each species over time, but this method was unable to estimate confidence intervals.

To investigate changes in the chosen species densities through time required modelling the total catch time-series and fitting Fourier curves to estimate both the predicted trends and the observed post-stocking effects on the populations. This enabled comparison of the effects of the stocking against what might have happened if stocking had not occurred. There was no statistically significant increase in overall density of either species subsequent to stocking, although a stocking signal was detected for each species about 12 months after the first stocking of dusky flathead and six months after the first stocking of sand whiting. The variability in the sample catches, length of signal-delay, catastrophic changes in the ecology of the system at a critical time after stocking and the termination of the project prior to any chance of detecting an effect of the second stocking have 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.

Scale pattern analysis has 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. We attributed this result 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. We believe this is evidence of successful recruitment of hatchery-origin dusky flathead from the second stocking. Ratios of hatchery-origin sand whiting increased from 2 months after the first stocking in April 1997 as stocked fish grew to within the sample gear size range. 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 successful recruitment in an under-exploited habitat i.e. a recruitment bottleneck occasioned by a recent fish kill.

The monitoring program detected an appreciable proportion of hatchery-origin fish of both species being recruited into the recreational and commercial sectors. Similar results have been achieved with mullet in Hawaii (Leber et al. 1995), barramundi in north Queensland (Rimmer and Russell, 1998) and red drum in Texas (McEacheron et al. 1998). Scale pattern analysis also highlighted the delay (of up to 12 months) between stocking and recruitment. Hatchery-origin dusky flathead comprised up to 47% of the recreational and 28% of the commercial catch, while sand whiting contributed up to 44% of the recreational and 52% of the commercial catches. Hepell and Crowder (1998) note that stocking may cause an increase in juvenile cohorts, but does not necessarily lead to long-term population increases. The above snapshot (12 months of the survey catch trend) is encouraging, but gives no indication of how long this effect can be maintained without further stocking. This may have been answered by a longer survey period.

Displacement is an important consideration in any major stocking exercise (Blankenship and Leber 1995, Hilborn 1998, Hepell and Crowder 1998, Cowx 1998) but is difficult to demonstrate. Displacement is most likely to occur in an aquatic ecosystem that is at full carrying capacity. We suspect that in 1995, the Maroochy River was not at full carrying capacity following the fish kills in 1993 and 1994. Proving displacement requires rigorous research using control and release experiments. Recent studies by Leber et al. (1998) proved that stocking did not cause displacement of native populations of Pacific threadfin in Hawaii. Likewise, McEacheron et al. (1998) reported a similar result for red drum in Texas. However, such research was outside the scope of this study.

To determine whether stocking has increased the number of animals available for capture requires pre- and post-stocking evaluation of the standing stock (Cowx 1998).

Ideally, such surveys would contain information about commercial and recreational capture rates as well as independent surveys of fish stocks. The cost to undertake such additional monitoring over time is often significant compared to actual production and stocking costs (Brouha 1995), but needs to be incorporated in budgetary planning for future estuarine stocking programs. This study has highlighted the strengths and weaknesses of several of these approaches to measuring the success of stocking programs. It provides a base line for review and development in future marine stocking exercises.

Clearly the uncertainties in our data about the effects of marine fish stocking in the Maroochy River, combined with the assumptions used in the economic analysis have led to a modelled cost that was much higher than the value placed on the fish by the recreational angler (e.g. for whiting the estimated cost is about $17 compared to a value of $2.50). However, when undertaking such a project, socio-economic and other benefits are often viewed as more important by the decision makers than the actual outlays to undertake the project and the estimated outcomes (Welcomme, 1998). The results from this pilot-program will have an important role in policy decisions about the appropriate economic indicators in future publicly funded stocking endeavours.

9.3 MANAGEMENT IMPACTS

The findings of this stocking program have several implications for management. In future, all stocking programs will be expected to follow the principles outlined in the QFM Policy Paper No. 4 (Taylor-Moore and Retif 1997). The evolution of this policy has been largely influenced by discussions prior to and during the implementation of the Maroochy River pilot stocking program. The policy paper provides a series of guidelines designed to ensure a best practice approach to all fish stocking. The guidelines include the need to:

1. identify ecological, economic and social objectives;
2. prioritise and select species;
3. develop an integrated species management plan that contains clear objectives;
4. define quantitative measures of performance;
5. use genetic resource management to avoid deleterious genetic effects;
6. use disease and health management;
7. develop stocking tactics based on ecological, biological and life-history information;
8. identify released hatchery fish and assess stocking effects;
9. determine optimum release strategies; and
10. use adaptive management.

Fisheries management is a fine balance between public demand for access to healthy fisheries resources and public demand for the fisheries resources to be kept healthy (Grimes 1995) and there is an obligation on management to consider the reasons for stocking. Stocking an estuarine environment has an effect on recreational and commercial catches, either real or perceived and has the potential to inadvertently increase fishing effort. Successful stocking can cause an increase in juvenile cohorts, but it doesn't necessarily lead to a long-term increase in population sizes (Hepell and Crowder 1998). Marine stocking is different from the many successful put-and-take freshwater fisheries (Horak 1995, Lee 1995, Stone 1995). However, there are several essential ecological criteria that will enhance the chance of successful marine stocking. These include stocking where recruitment bottlenecks have been identified, in under-utilised niches caused by habitat modification, when overfishing or major perturbations such as fish kills have occurred (Hale et al. 1995, Travis et al. 1998, Thorpe 1998, Heppel and Crowder 1998, Hilborn 1998, Masuda and Tsukamoto 1998). There are several factors that reduce the ability to detect a benefit. These include changes in time and size of first sexual maturity, that can mask short-term changes in population levels, low or variable suvivorship of stocked fish, migration and anthropogenic factors such as poorly planned stocking programs with ill-defined objectives, and monitoring programs that are too short (Coates 1998, Hepell and Crowder 1998, Hilborn 1998).

Stocking isn't a substitute for failing to restore degraded habitats or preventing overfishing (Stone 1995). There may be alternative management measures such as constraining fishing effort or improving habitats that will allow the stocks to rebuild to the environment's carrying capacity, or taking no action at all (Welcomme 1998, Masuda and Tsukamoto 1998). However, there will always be cases where biological or socio-political influences dictate that stocking is the only viable alternative. There may never be complete consensus on the benefits or otherwise of estuarine stocking programs because of the interplay between socio-economic and ecological issues. However, there are now some comprehensive guidelines in place that should ensure that stocking decisions are appropriate and likely to lead to measurable outcomes. This program has demonstrated that most of the necessary knowledge and skills to undertake a large-scale stocking program are available.

10 CONCLUSIONS AND RECOMMENDATIONS

This pilot program has significantly advanced our understanding of the complexities involved in stocking fish on a large scale into an estuary and assessing the effect of the operation. The program was the largest marine stocking exercise yet undertaken in Australia, and its findings will provide valuable guidelines for future marine stocking programs in this country.

We have demonstrated that large scale production of fingerlings of two of south Queensland's most important recreational fish species—summer whiting (*Sillago ciliata*) and dusky flathead (*Platycephalus fuscus*)—is technically feasible in a hatchery environment. We also developed appropriate transportation and release techniques, which resulted in the introduction of about 100 000 dusky flathead and 330 000 sand whiting fingerlings into the estuary.

A critical requirement in determining the success of any stocking operation is the ability to identify whether sampled fish were derived from the wild population or from the hatchery. Scale pattern analysis techniques developed and tested during the course of the program were able to demonstrate that hatchery-reared fish survived and grew to the point where they appeared as an appreciable proportion in the catches of both commercial and recreational fishers.

Demonstrating that a stocking operation results in increased catches is technically feasible but very demanding in terms of human and financial resources. Our inability to show a convincing, statistically significant increase in population size should not be taken to suggest that such an increase did not occur. Factors contributing to this equivocal result include the February 1998 fish kill (which left insufficient time to fully assess the effect of the later fingerling releases), and the difficulty of attaining sufficient statistical power to detect differences in population size in an inherently variable system.

In the event that a decision is made to progress estuarine or marine stocking programs in the future, we offer the following recommendations:

1. That marine or estuarine stocking programs should be recognised as one of several management options available for restoring degraded fishery resources. Stocking programs should be targeted at situations where there is a reasonable expectation of having a beneficial effect. This is more likely to be the case where there is some evidence of niche under-utilisation, overfishing or a recruitment bottleneck that cannot be overcome effectively by other management methods.

2. That such programs follow the "best practice" principles outlined in the QFM Policy Paper No. 4 (Taylor-Moore and Retif 1997).

3. That such programs incorporate an adequately-resourced monitoring component designed to test the effectiveness of the operation, and that the monitoring component be of appropriate duration in the context of the species' growth rate and longevity.

4. That optimum size at release and optimum release strategy be determined through field trials, integrated with the monitoring component.

5. That the use of oxytetracycline baths as a means of mass marking fingerlings be discouraged, and that alternative methods involving the use of unambiguous genetic markers be investigated and compared to the scale pattern technique.
6. That the Health Assessment Index be used routinely to assure the physiological quality of fingerlings prior to their release.

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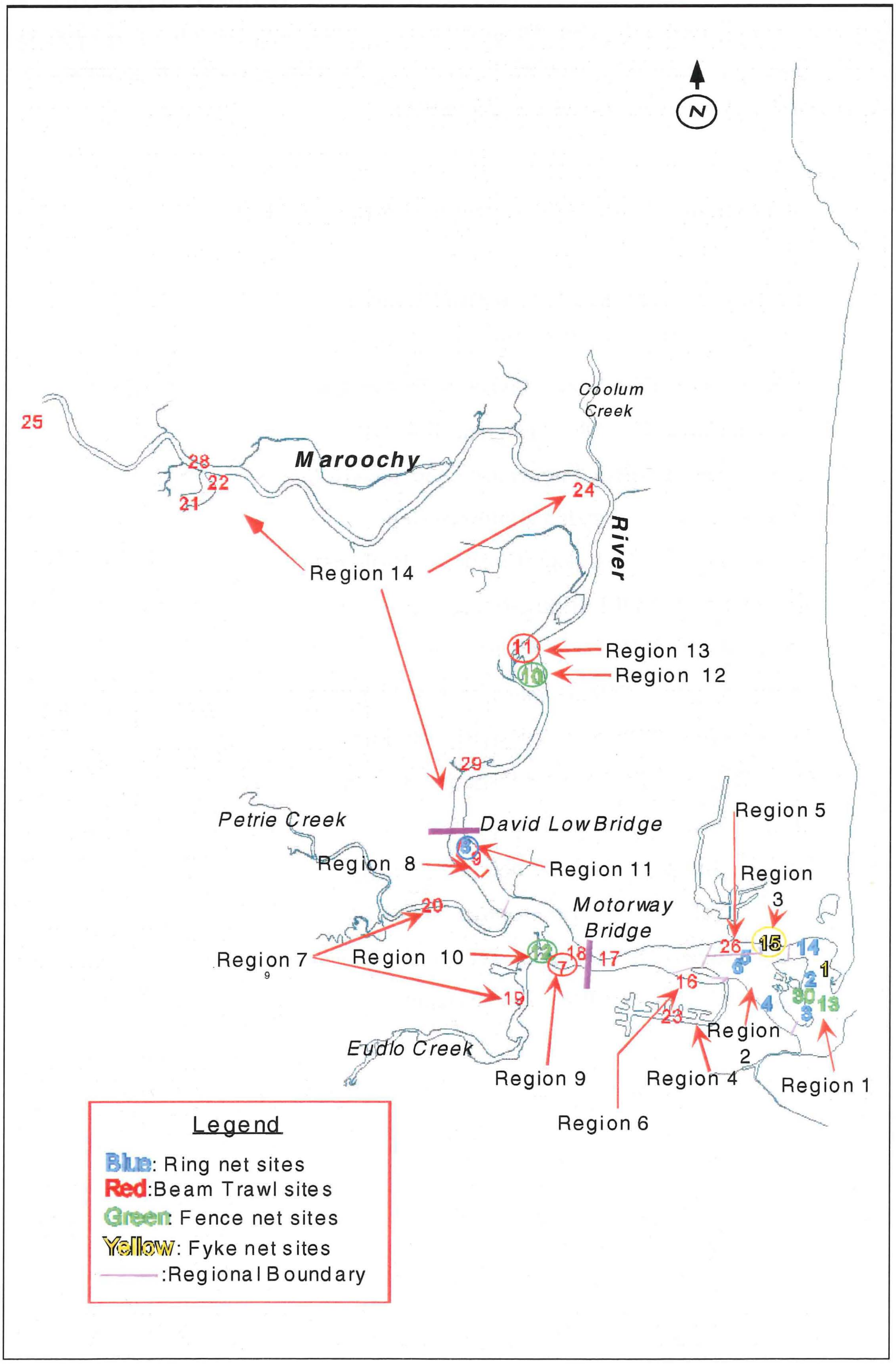
13 APPENDICES

APPENDIX 13.1: LIST OF DELEGATES ATTENDING THE SCOPING WORKSHOP TO REVIEW A PROPOSAL TO ENHANCE PUMICESTONE PASSAGE WITH FISH SPECIES OF RECREATIONAL ANGLING IMPORTANCE – JOONDOBURRI CONFERENCE CENTRE, BRIBIE ISLAND, AUGUST 25-25, 1994.

Chair: Mike Dredge – DPI, Fisheries Services Manager, SEQ

Delegates:
Ian Brown – DPI, Senior Fisheries Biologist
Charis Burridge – CSIRO, Research Officer
John Burke – DPI, Senior Fisheries Technician
Darren Cameron – DPI, Fisheries Biologist
David Die – CSIRO, Population Dynamicist
John Doohan – Sunfish, Committee Rep.
Clive Keenan – DPI, Senior Fisheries Biologist
David Mayer – DPI, Biometrician
Paul Palmer - DPI, Fisheries Biologist
Barry Pollock – DPI, Manager Marine Fisheries
Ross Quinn – DPI, Senior Fisheries Biologist
John Russell – DPI, Senior Fisheries Biologist
Terry Ryan – GrowFish Rep.
Wayne Sumpton - DPI, Fisheries Biologist
David Walter – DoE, Environmental Officer
Dan Willett – DPI, Fisheries Technician
Yougan Wang – CSIRO, Biometrician

Appendix 13.2. Geographical location of all sites and regions in the Maroochy River.



APPENDIX 13.3: MCMC STANDARD INPUT DATA FOR NEIGHBOURLINESS, NEST SIZE, GEAR TYPE AND HABITAT NUMBER.

13.3.1: Site neighbourliness; length of shared boundaries.

Site #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	26	28	29	30	31
1	0	150	225	0	0	300	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	150	0	375	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
3	225	375	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	325
4	0	0	0	0	800	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	50
5	0	0	0	800	0	0	0	150	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	275
6	300	0	0	0	0	0	475	0	0	0	450	0	225	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	475	0	400	0	0	0	175	275	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	150	0	400	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	300	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	450	0	0	300	0	0	0	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	175	0	0	50	0	0	475	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	225	275	0	0	0	25	475	0	200	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0	200	0	100	100	325	375	125	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0	0	100	0	0	0	0	125	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0	0	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0	0	325	0	0	0	0	0	0	900	0	0	0	0	0	0	175	0
18	0	0	0	0	0	0	0	0	0	0	0	0	0	375	0	0	0	0	200	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0	0	125	125	0	0	200	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	506	0	0	350	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	350	0	125	0	0	0	75	0
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	125	0	75	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	75	0	0	125	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	50	0	0
26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	125	50	0	0	0
28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	175	0	0	0	0	0	75	0	0	0	0	0	0
29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	506	0	0	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	900	0	0	0	0	0	0	0	0	0	0	0	0
31	0	100	325	50	275	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

13.3.2 : Site nest area (m^2), Region area (m^2),gear type* and habitat number.

Site	Net area	Region area	Gear type	Habitat code #
1	625	131 250	1	1
2	500	50 000	2	1
3	625	75 000	1	1
4	1000	231 250	3	1
5	625	318 750	1	1
6	625	187 500	1	2
7	625	281 250	1	2
8	625	243 750	1	2
9	500	12 500	2	3
10	725	212 500	4	4
11	725	31 250	4	5
12	1450	100 000	4	6
13	725	431 250	4	7
14	725	456 250	4	7
15	1450	556 250	4	7
16	1450	350 000	4	7
17	1450	462 500	4	8
18	1450	56 250	4	9
19	1200	18 750	3	10
20	625	18 750	1	11
21	1200	12 500	3	12
22	1450	568 750	4	13
23	725	225 000	4	14
24	725	625 000	4	14
26	725	93 750	4	14
28	725	625 000	4	14
29	725	231 250	4	14
30	725	9375	4	10
31	1200	68 750	3	1

*: gear types are; 1 = Ring net, 2 = Fyke net, 3 = Fence net and 4 = Beam trawl

APPENDIX 13.4: SAMPLING DATES AND SITES IN THE MAROOCHY RIVER BETWEEN JANUARY 1996 AND DECEMBER 1998.

Trip	Date	No. Days	Sites Sampled																														
1	Jan-96	4	1	2	3	4	5	6	7	8	9	10	11	na	13	14	na	na	na	na	na	na	na	na	na	na	na	na	27	na	na	na	na
2	Feb-96	6	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	na	na	na	26	*	na	na	na	na
3	Mar-96	10	1	2	3	4	5	6	7	8	*	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	*	na	na	na	na
4	Apr-96	4	*	2	3	4	5	6	*	*	*	*	*	*	13	*	15	16	*	*	*	*	*	22	23	*	*	26	*	na	na	na	na
5	May-96	4	1	*	*	*	*	*	7	8	9	10	11	12	*	14	*	*	17	18	19	20	21	*	*	24	**D**	*	27	na	na	na	na
6	Jun-96	4	*	2	3	4	5	6	*	*	*	*	*	*	13	*	15	16	*	*	*	*	21	22	23	*	**D**	*	*	28	na	na	na
7	Jul-96	4	1	*	*	*	*	*	7	8	9	10	11	12	*	14	*	*	17	18	19	20	*	*	*	24	**D**	26	**D**	*	na	na	na
8	Aug-96	4	*	2	3	4	5	6	*	*	*	*	*	*	13	*	15	16	*	*	*	*	21	22	23	*	**D**	*	**D**	28	na	na	na
9	Sep-96	4	1	*	*	*	*	*	7	8	9	10	11	12	*	14	15	*	17	18	19	20	*	*	*	24	**D**	*	**D**	*	na	na	na
10	Oct-96	4	*	2	*	4	5	6	*	*	*	*	*	*	*	*	*	16	*	*	*	*	21	22	23	*	**D**	*	**D**	28	29	na	na
11	Nov-96	4	1	2	3	*	5	*	7	8	9	10	11	12	13	14	*	*	17	18	19	20	*	*	*	24	**D**	26	**D**	*	*	30	na
12	Dec-96	4	*	2	3	4	5	6	*	*	*	*	*	*	13	*	15	16	*	*	*	*	21	22	23	*	**D**	*	**D**	28	29	30	na
13	Jan-97	6	1	*	*	*	*	*	7	8	9	10	11	12	*	14	*	*	17	18	19	20	*	*	*	24	**D**	26	**D**	*	*	*	na
14	Feb-97	6	1	2	3	4	5	6	7	8	9	10	11	12	13	14	*	16	17	18	19	20	21	22	23	24	**D**	26	**D**	28	29	30	na
15	Mar-97	6	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	**D**	26	**D**	28	29	30	na
16	Apr-97	5	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	**D**	26	**D**	28	29	30	na
17	May-97	5	1	*	3	4	5	6	7	8	9	10	11	*	13	14	15	16	17	18	19	20	21	22	23	24	**D**	26	**D**	28	29	30	31
18	Jun-97	5	1	2	3	4	5	6	7	8	9	10	11	12	**D**	14	15	16	17	18	19	20	21	22	23	24	**D**	26	**D**	28	29	30	31
19	Jul-97	5	1	2	3	4	5	6	7	8	9	10	11	12	**D**	14	15	16	17	18	19	20	21	22	23	24	**D**	26	**D**	28	29	30	*
20	Aug-97	5	1	2	3	4	5	6	7	8	9	10	11	12	**D**	14	15	16	17	18	19	20	21	22	23	24	**D**	26	**D**	28	29	30	31
21	Sep-97	5	1	2	3	4	5	6	7	8	9	10	11	12	**D**	14	D	16	17	18	19	20	21	22	23	24	**D**	26	**D**	28	29	30	31
22	Oct-97	5	1	2	3	4	5	6	7	8	9	10	11	12	**D**	14	**D**	16	17	18	19	20	21	22	23	24	**D**	26	**D**	28	29	30	*
23	Nov-97	5	1	2	3	4	5	6	7	8	9	10	11	12	**D**	14	**D**	16	17	18	19	20	21	22	23	24	**D**	26	**D**	28	29	30	31
24	Dec-97	5	*	2	3	4	5	6	7	8	9	10	11	12	**D**	14	**D**	16	17	18	19	20	21	22	23	24	**D**	26	**D**	28	29	30	31
25	Jan-98	5	1	2	3	4	5	*	7	8	9	10	11	12	**D**	14	**D**	16	17	18	19	20	21	22	23	24	**D**	26	**D**	28	29	30	31
26	Feb-98	5	1	2	3	4	5	6	7	8	9	10	11	12	**D**	14	**D**	16	17	18	19	20	21	22	23	24	**D**	26	**D**	28	29	30	31
27	Mar-98	5	special gear trial and second whiting restocking event carried out during March 1998																												
28	Apr-98	5	1	2	3	4	5	6	7	8	9	10	11	*	**D**	14	**D**	16	*	18	19	20	21	22	23	24	**D**	26	**D**	28	29	30	31
29	Jun-98	5	1	2	3	4	5	6	7	8	9	10	11	*	**D**	14	**D**	16	17	18	19	20	21	22	23	24	**D**	26	**D**	28	29	30	31
30	Aug-98	5	1	2	3	4	5	6	7	8	9	10	11	*	**D**	14	**D**	16	17	18	19	20	21	22	23	24	**D**	26	**D**	28	29	30	31
31	Sep-98	5	repeat of special gear trial carried out during September 1998																												
32	Oct-98	5	1	2	3	4	5	6	7	8	9	10	11	*	**D**	14	**D**	16	17	18	19	20	21	22	23	24	**D**	26	**D**	28	29	30	31
33	Dec-98	5	1	2	3	4	5	6	7	8	9	10	11	12	**D**	14	**D**	16	17	18	19	20	21	22	23	24	**D**	26	**D**	28	29	30	31

*: denotes times where no sampling occurred at specified site.

na: denotes sites which were not yet included in survey sampling regime.

APPENDIX 13.5: DENSITY ESTIMATES OF DUSKY FLATHEAD (>6 CM SL) AND SAND WHITING (>4 CM SL) IN THE MAROOCHY RIVER AFTER EACH TRIP.

The three methods of calculation used were; 1) GLM using the raw data, 2) GLM using the log-transformed raw data, and 3) an MCMC model using the raw data. All three methods use net efficiency estimates obtained from the gear trials. Thus the initial 6 MCMC estimates differ from those given in Chapter 3. Note that Confidence Intervals are 2-way 95% c.i.'s and are indicative only. They were calculated from pooled estimates (across times) of the sector-by-sector estimated densities which are not applicable to individual time intervals when the estimated densities are correctly weighted by sector areas and worked up to the river totals. There are no known statistical method for estimation of confidence intervals of river totals based on the ln-transformed analyses. MCMC model confidence intervals are derived from individual habitat totals for each time interval.

	WHITING			FLATHEAD		
Month	raw data	ln-transf.	MCMC	raw data	ln-transf.	MCMC
1	351 254	351 516	156 850	23 547	30 853	7598
2	183 695	229 045	190 430	9109	13 063	10 482
3	172 373	183 352	149 427	18 500	17 183	11 089
4.5	185 341	183 885	85 429	17 990	21 168	23 323
6.5	135 680	169 071	104 635	16 461	18 726	28 440
8.5	196 118	185 756	125 245	9627	13 751	14 399
10.5	118 965	117 643	105 922	17 782	20 580	18 978
12.5	118 214	128 102	94 798	23 399	29 083	32 490
14	203 596	210 776	231 252	24 570	25 619	38 352
15	98 804	163 026	146 452	18 852	23 366	32 851
16	111 351	127 028	173 393	22 870	28 454	29 286
17	187 687	237 686	191 670	28 098	34 380	40 597
18	207 682	187 716	223 364	31 529	33 290	34 954
19	179 504	166 087	228 684	27 791	28 149	37 509
20	124 653	141 238	173 913	18 754	23 743	29 689
21	140 905	108 518	149 138	22 176	29 680	32 333
22	199 717	146 675	236 285	21 742	21 459	39 399
23	148 823	157 003	188 346	23 968	21 880	24 915
24	87 905	100 336	168 864	15 954	17 444	16 709
25	190 176	168 173	176 995	30 325	29 099	45 609
26	202 170	184 076	253 445	29 284	32 622	33 680
28	127 269	117 593	147 457	23 561	26 531	26 547
29	73 481	69 106	136 922	11 838	14 652	19 600
30	60 425	72 922	178 729	10 189	16 168	20 778
32	95 635	87 618	189 395	14 055	11 781	15 154
33	79 487	92 004	158 514	14 189	16 717	18 758
AVG :	**153 112**	**157 152**	**167 906**	**20 237**	**23 055**	**26 289**
C.I.(±)	30 966	*	17 112	3475	*	3978
Av. Yr 1	191 918		131 134	16 145		16 330
Av. Yr 2	150 737		183 847	23 309		32 424
Av. Yr 3	118 377		177 351	19 063		25 732

*:no known method of calculation.

APPENDIX 13.6: INPUT DATA AND ASSUMPTIONS USED FOR THE ECONOMIC MODELLING.

Biological Assumptions:

13.6.1 Capture weights and values

Category	Fish/kg	Price/kg	Price/fish	Proportion caught by sector
Flathead commercial	2.5	$5.00	$2.00	0.3
Flathead recreational	3		$3.00	0.7
Whiting commercial	6	$7.00	$1.17	0.4
Whiting recreational	9		$2.00	0.6

13.6.2 Survival estimates

Yearly survival	Whiting	Flathead
Part of Year 0	0.4	0.3
Year 1	0.5	0.5
Year 2	0.5	0.5
Year 3	0.6	0.6
Year 4	0.7	0.7

13.6.3 Fish numbers available for recapture

Year		1995–96	1996–97	1997–98	1998–99	1999–00	2000–01	2001–02
Fish releases	Whiting	12 000	262 000	72 000				
Fish release classes	Whiting 95–96		4800	2400	1200			
	Whiting 96–97			104 800	52 400	26 200		
	Whiting 97–98				28 800	14 400	7200	
	Total # whiting	available	for	capture	1200	26 200	7200	
Fish releases	Flathead 96–97		53 000					
	Flathead 97–98			37 000				
Fish release classes	Flathead 96–97			15 900	7950	3975	2385	
	Flathead 97–98				11 100	5550	2775	1665
	Total # flathead	available	for	capture			2385	1665

13.6.4 Outlay model expenditure

Centre	Fund source	Cost Centre	1995–96	1996–97	1997–98	1998–99	1999–00	2000–01	2001–02
SFC	PPV	Operating	$15 000	$20 000	$25 000	$25 000			
BIARC	PPV	Operating	$25 000	$25 000	$25 000				
SFC	Con. Rev.	Salaries	$35 000	$40 000	$42 000				
SFC	PPV	Salaries	$45 000	$45 000	$48 000	$125 000			
SFC	QCL	Salaries	$65 000	$65 000	$65 000				
BIARC	Con. Rev.	Salaries	$80 000	$80 000	$80 000				
BIARC	PPV	Salaries	$45 000	$40 000	$42 000				
	Salaries - total		$270 000	$270 000	$277 000	$125 000			
	Operating - total		$40 000	$45 000	$50 000	$25 000			
TOTAL			$310 000	$315 000	$327 000	$150 000	$0.00	$0.00	$0.00
	Research proportion		1	0.6	0.5				
	Production proportion			0.4	0.5	1	1	1	1

13.6.5 Total Cost model expenditure

Centre	Fund source	Cost Centre	1995–96	1996–97	1997–98	1998–99	1999–00	2000–01	2001–02
SFC	PPV	Operating	$15 000	$20 000	$25 000	$25 000			
BIARC	PPV	Operating	$25 000	$25 000	$25 000				
SFC	Con. Rev.	Salaries	$35 000	$40 000	$42 000				
SFC	PPV	Salaries	$45 000	$45 000	$48 000	$125 000			
SFC	QCL	Salaries	$65 000	$65 000	$65 000				
BIARC	Con. Rev.	Salaries	$80 000	$80 000	$80 000				
BIARC	PPV	Salaries	$45 000	$40 000	$42 000				
	Salaries - total		$270 000	$270 000	$277 000	$125 000			
Add on factor for overheads		2.7							
	Salaries with overheads		$729 000	$729 000	$747 900	$337 500			
	Operating - total		$40 000	$45 000	$50 000	$25 000			
TOTAL			$769 000	$774 000	$797 900	$362 500	$0.00	$0.00	$0.00
	Research proportion		1	0.6	0.5				
	Production proportion			0.4	0.5	1	1	1	1

APPENDIX 13.7: OUTLAY MODEL RESULTS

Costs of project. Base Year

Year	1995–96	1996–67	1997–98	1998–99	1999–00	2000–01	2001–02
Total research outlay ($)	$310 000	$189 000	$163 500	$0	$0	$0	$0
Research ppn	**0.25**	**0.25**	**0.25**				
Research allocation ($)	$77 500	$47 250	$40 875				
	-$89 716	-$52 093	-$42 919	$0	$0	$0	$0
Production outlay ($)	$0	$126 000	$163 500	$150 000	$0	$0	$0
	$0	-$138 915	-$171 675	-$150 000	$0	$0	$0
Discounted CF	*-$89 716*	*-$191 008*	*-$214 594*	*-$150 000*	*$0*	*$0*	*$0*
Cumulated DCF	***-$89 716***	***-$280 724***	***-$495 318***	***-$645 318***			

Maximum benefit, assuming the year class is immediately available and is totally harvested.

Year	1998–99	1999–00	2000–01	2001–02
Total # whiting available for capture	1200	26 200	7200	
Total # flathead available for capture	1200		2385	
Total		26 200	9585	1665

Total fish “caught”	38 650
Project cost	-$645 318
Mean cost per fish	$16.70

The most optimistic view is for 38 650 fish to be available for capture at a mean cost of $16.70 each.

If there is <u>no</u> increase in the number of fish caught, then the cost to the community, given the assumptions, is about $640 000.

If fish are caught as shown above, then the cost to the community is as follows;

Year	1998–99	1999–00	2000–01	2001–02
Whiting caught by recreational sector	$440	$31 440	$8640	
Flathead caught by recreational sector			$1431	$999
Whiting caught by commercial sector	$560	$12 227	$33 360	
Flathead caught by commercial sector			$5009	$3497
Total value	$2000	$43 667	$18 440	$4496
Discounted totals	$2000	$41 587	$16 725	$943

NPV -$584 062

APPENDIX 13.8: TOTAL COST MODEL RESULTS

Costs of project. Base Year

Year	1995–96	1996–67	1997–98	1998–99	1999–00	2000–01	2001–02
Total research outlay ($)	$769 000	$464 400	$398 950	$0	$0	$0	$0
Research ppn	**0.25**	**0.25**	**0.25**				
Research allocation ($)	$192 250	$116 100	$99 738				
	-$222 553	-$128 000	-$104 724	$0	$0	$0	$0
Production outlay ($)	$0	$126 000	$163 500	$150 000	$0	$0	$0
	$0	-$138 915	-$171 675	-$150 000	$0	$0	$0
Discounted CF	*-$222 553*	*-$226 915*	*-$276 399*	*-$150 000*	*$0*	*$0*	*$0*
Cumulated DCF	***-$222 553***	***-$489 469***	***-$765 868***	***-$915 868***			

Maximum benefit, assuming the year class is immediately available and is totally harvested.

Year	1998–99	1999–00	2000–01	2001–02
Total # whiting available for capture	1200	26 200	7200	
Total # flathead available for capture	1200		2385	
Total		26 200	9585	1665

Total fish “caught”	38 650
Project cost	-$915 868
Mean cost per fish	$23.70

The most optimistic view is for 38 650 fish to be available for capture at a mean cost of $23.70 each.

If there is <u>no</u> increase in the number of fish caught, then the cost to the community, given the assumptions, is about $640,000.

If fish are caught as shown above, then the cost to the community is as follows;

Year	1998–99	1999–00	2000–01	2001–02
Whiting caught by recreational sector	$1440	$31 440	$8640	
Flathead caught by recreational sector			$1431	$999
Whiting caught by commercial sector	$560	$12 227	$33 360	
Flathead caught by commercial sector			$5009	$3497
Total value	$2000	$43 667	$18 440	$4496
Discounted totals	$2000	$41 587	$16 725	$943

NPV -$854 612