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Impoundment stocking strategies for Australian native fishes in eastern and northern Australia:

With an assessment of the value of scales as tags for stocked barramundi

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Impoundment stocking strategies for Australian native fishes in eastern and northern Australia:

With an assessment of the value of scales as tags for stocked barramundi

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Objectives

1. To determine optimal stocking size and release strategies to maximise the survival of four fish species (golden perch, silver perch, Australian bass and barramundi) in stocked impoundments.
2. Identify differences between impoundments that may influence the survival and growth of fish stocks.
3. To verify the reliability of scale pattern analysis as a means of identifying different batches of fish.
4. Ensure adequate replication of stocking strategies for barramundi, golden perch and silver perch.

Outcomes

Achievements

This project has provided scientifically validated information on optimal stocking sizes and optimal release strategies for four popular freshwater angling species. We now also have a better understanding of the impacts of different predators and impoundment conditions on stocking success. This information will enable community groups and fisheries managers to determine cost-effective stocking strategies and maximise survival of stocked fish.
This information has been summarised in a user-friendly fish stocking manual.
By following this advice, stocking groups can increase survival of stocked fish by more than 10 times (depending on past stocking practices by each group), or ensure that they get the most cost-efficient result in terms of numbers of fish reaching legal size per stocking dollar. A copy of the stocking manual has been sent to every fish stocking group in Queensland, and also to peak angler representative bodies and fisheries management agencies in New South Wales and Victoria. The manual has also been made available in PDF format on the internet. The advice in the stocking manual, and outlined in this report, will lead to improved impoundment fisheries and associated economic benefits in those areas where it is implemented.

Our evaluation of the use of scales as tags has shown that scales do have potential as low-cost batch tags, but there are also limitations. Such tags are likely to be more reliable for fish stocked at larger sizes. Our research has proven the need for verification of scale patterns as tags through use of a secondary tagging system. If researchers recognise the limitations of scales and assess reliability of scales for each new species via secondary tagging, then costly research mistakes can be avoided in the future.

The majority of Australian freshwater recreational species do not breed in impoundments. Therefore, stocking programs are essential to maintain recreational fisheries. Stocking of impoundments with native fish for recreational fishing enhancement is a beneficial but expensive socio-economic activity. It is important to optimise stocking strategies to avoid wasting money and effort. Through use of micro-tagging technology we were able to compare the relative stocking success of three size classes (20–30 mm, 35–45 mm and 50–65 mm) of Australian bass, barramundi, golden perch and silver perch over three years. We also compared three release strategies: deep water release, shallow water release and release into floating artificial cover. Micro-tagged fish were released annually into 35–200 ha impoundments located in sub-tropical Queensland.

In each dam we also recorded various environmental parameters, including water level at time of stocking, water temperature, prevalence of different habitat types, and relative abundance of predatory and prey fish species. Predatory species were collected in the vicinity of release sites, following stocking of barramundi, golden perch and silver perch. Stomach contents of predatory fish species were examined to determine if there had been any predation of stocked fingerlings at the time of release.

Micro-tagging also provided us with an opportunity to collect some information on growth of the four test species, and also an opportunity to assess the effectiveness of scale patterns as batch tags. Scales lay down growth rings called circuli. In theory, different growth conditions should lead to different circuli patterns in the scales. We compared scale patterns of barramundi reared in different tanks with different temperature conditions, and also compared scale patterns of barramundi reared in different years. Many previous studies have assumed differences detected in scale patterns in scales taken from fish prior to release of fish from the hatchery should remain the same in fish that have been at large. We compared the pre-release results with results from recaptured micro-tagged fish.

Release strategies

Results indicated that for all species the 50–65 mm size class had the highest relative survival rate, although recapture rates varied between years and dams. Variability can in part be attributed to the presence of predatory species. In general, when the purchase price of fingerlings is taken into consideration the 50–65 mm size class was the most cost effective to stock. However, if there are few predators present then 35–45 mm and even 20–30 mm fish can become the most cost effective to stock, but this will vary according to hatchery price structures. In the majority of cases survival of the 20–30 mm size class of all species was poor and not cost effective.

There was variation in the relative success of the different release strategies between dams and years. Stomach contents analysis suggests this variation was mainly attributed to chance distribution of predators at time of release. Shallow water releases appear suitable for all four species but it is recommended fish be released in at least three large batches into different locations around the dam to spread the risk of predation.

Silver perch and golden perch were found to have higher survival rates in the absence of non-Murray-Darling Basin predatory fish species. These species are therefore best stocked in dams within the Murray-Darling Basin. Mouth almighty and fork-tailed catfish were found to have an adverse impact on the survival of barramundi stocked at less than 45 mm total length. In the presence of these two species we recommend stocking barramundi at 50 mm or larger, as this is by far the most cost-effective option. It is quite likely that these same species would also impact severely on golden perch, silver perch and Australian bass.

Stocking of Murray-Darling strain golden perch, silver perch and Australian bass into dams dominated by barramundi is likely to meet with failure. Very few or no recaptures were made of micro-tagged fish of these three species stocked in these dams.

Water level at the time of stocking was also found to have a major influence on the success of stocking. Survival was positively related to water level. Stocked fingerlings have much better survival when water levels are high. We recommend stocking at high water levels and to avoiding stocking when the water level has been drawn down to less than 10% full supply surface area. Low water levels are likely to increase competition, concentrate predatory fish and increase opportunities for predation of fingerlings.

In sub-tropical Queensland, Australian barramundi were found to reach legal size (58 cm) within 14 months of stocking, silver perch reached the legal size of 30 cm in 12 months, golden perch reached legal size (30 cm) in 14 months and Australian bass reached legal size (30 cm) in three years. We recommend stocking fish as early in the season as possible, to take advantage of the spring and summer rapid growth period. With the exception of bass, that means that most fish will reach legal size in the summer of the following year—a time of year when fish are catchable. Delaying stocking until late summer or even autumn means that fish may not reach legal size until the following autumn, immediately before the winter slow-down in angling success. Delayed stocking will also mean that fish will remain at a small size in the winter season and therefore be susceptible to predation for a longer period.

Scale patterns

A key finding of this study is that reliance on classification rates of reference sets of scales is not always a sufficient predictor for estimating correct classification rates of scales from recaptured fish. Before any studies embark on use of scale pattern analysis for a given species, verification of the method’s suitability or limitations should be carried out. This could be done either by micro-tagging, marking of otoliths with alizarin or oxytetracycline (OTC), or stocking of reference fish into separate ponds to grow out. Without such verification, studies could end up with totally misleading results, particularly in the case of large-scaled, fast-growing species like barramundi.

Scale pattern analysis as a method for barramundi has both potential and limitations as a cheap batch tag. Scale pattern analysis may have some application with barramundi up to 400 mm total length (TL). Correct discrimination can reach levels above 90%. However, scale pattern analysis appears unsuitable for larger barramundi as thickening of the scales reduces readability. For fish less than 400 mm TL, scale pattern analysis may be particularly useful for separating hatchery fish from wild stocks, as early conditions are likely to be dissimilar between these two groups. For scale pattern analysis to be effective, fish should be stocked at larger sizes (i.e. larger than 35 mm) so that more circuli are available for inclusion in any analysis. If more circuli are available, then the reliability of the method increases. The 20–30 mm fish were classified correctly at only just over half the rate of the 35–45 mm and 50–65 mm size classes.

To produce several batches of fish with unique scale patterns, it would appear that for barramundi temperature manipulation alone is not enough. Variation in rearing techniques (e.g. pond versus tank and feeding regimes) may also be required.

One difficulty with scale pattern analysis is that fish from the same batch, of the same age and reared under identical conditions can lay down variable numbers of circuli. For example, 50–65 mm fish from year four had between 16 and 34 circuli. This means some fish were laying down circuli at twice the rate of others. Therefore, if comparing the first 15 circuli between fish held under in the same tank with fluctuating conditions, it does not necessarily mean that each of the 15 circuli were laid down on the same days or under the same conditions in each individual fish. The amount of variability in rates of laying down circuli will influence the ability to discriminate between batches.

Keywords

Fish stocking, release size, release strategies, stocking strategies, batch tagging, visual implant elastomer (VIE) tag, coded wire tag, impoundment, lake, dam, Australian bass, silver perch, barramundi, golden perch, scale pattern analysis, Australia.

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Chapter 1: Introduction

1.1 Background

In the nine years preceding this study, stocked fisheries based on Australian native freshwater species were established in many Queensland waters. Nineteen million fingerlings were stocked in this period (Hollaway and Hamlyn 1998) and a further seven million fish were stocked into Queensland public waters during the period of this project (DPI&F unpublished data). The majority of stocked fish were placed in impounded waters. Stocking was conducted under the auspices of the DPI&F translocation policy, designed to minimise inappropriate transfer of fish species and genetic strains between river basins. Since development of these fisheries, growth in angler participation has been tremendous. It is estimated that 192 100 fishers fished in Queensland freshwaters in the twelve month period up to September–October 1996 (Roy Morgan Research 1996). This had grown to 217 000 anglers by 2001 of which 123 500 fished in impoundments, 85 000 people exclusively (DPI&F Fishweb). The new fisheries have helped to relieve pressure on coastal recreational and commercial fisheries by shifting angler effort.

In Queensland, the main species that have been stocked into impoundments, listed in descending order, are golden perch (both *Macquaria ambigua ambigua* and *M. a. oriens*), silver perch (*Bidyanus bidyanus*), barramundi (*Lates calcarifer*), Australian bass (*Macquaria novemaculeata*) and sooty grunter (*Hephaestus fuliginosus*) (Table 1.1). Species stocked in lesser numbers include Murray cod (*Maccullochella peelii peelii*), Mary River cod (*M. p. mariensis*), sleepy cod (*Oxyeleotris lineolatus*), eel-tailed catfish (*Tandanus tandanus*), southern saratoga (*Scleropages leichardti*) and snub-nosed garfish (*Arrhamphus sclerolepis*) (QFS unpublished stocking data). The latter four species may establish breeding populations in impoundments and normally do not require ongoing stocking once established.

It is possible that the Murray and Mary River cods may also be able to reproduce to a limited extent in some impoundments, while sooty grunter may breed in feeder streams if suitable habitat is available. None of the top four stocked species breed in impoundments and ongoing stocking is required to maintain their numbers.

Table 1.1 Total stocking of Queensland's five major stocked species from 1977 to January 2001.

Species	Number stocked (1977–January 2001)
Golden perch	13 391 626
Silver perch	5 729 259
Barramundi	4 507 063
Australian bass	3 657 887
Sooty grunter	1 689 837

Development of stocked impoundment fisheries based on Australian native species has also occurred in New South Wales and Victoria, and to a lesser extent in the Northern Territory and South Australia (Table 1.2). Western Australia has permitted stocking of silver perch, golden perch and southern black bream (*Acanthopagrus butcheri*) into private dams. In the southern states (including Western Australia) recreational fisheries based on stocked exotic salmonid species are also in existence.

Table 1.2. Some key Australian native species stocked in public waters in Australia for recreational fishing enhancement in the period 1995/96–2000/01.

Species	**1000s fish stocked by state, 1995/96–2000/01**			
	QLD	**NSW**	**VIC**	**NT**
Golden perch	10 749	6397	1436.2	0
Silver perch	3665	1906	43.5	0
Australian bass	3313	1186	22.7	0
Barramundi	4295	0	0	63
Murray cod	181	981	706.5	0
Sooty grunter	1330	0	0	0
Trout cod	0	458.7	154.2	0
Macquarie perch	0	9	85.6	0
Saratoga	3.6	0	0	0

The bulk of fingerlings used in the Queensland stocking program are produced in private hatcheries. In the past, some barramundi have also been produced for stocking at DPI&F's Northern Fisheries Centre. In other states, most of the stocked fingerlings are produced in state-run hatcheries, although in NSW (in addition to stocking done directly by New South Wales Fisheries) fish community groups purchase fingerlings from private hatcheries. Groups are funded through a dollar for dollar native fish restocking program. Under the program, community groups apply to the New South Wales Recreational Fishing Trust (funded by a recreational fishing licence) for matching funds to purchase fingerlings from licensed commercial hatcheries. The dollar for dollar program has been in operation since 1998. For further information on the Trust, including more recent stocking figures, see the following web address:
https://www.dpi.nsw.gov.au/fishing/recreational/resources/stocking

Similar information on native fish stocking in Victoria can be obtained at the following web address:
https://vfa.vic.gov.au/

Within Queensland, the fish stocking program has been developed by the State Government in partnership with local communities (Hollaway and Hamlyn 1998). Regional fish stocking associations are expected to raise funds to purchase fingerlings for stocking impoundments in their local area. In late 2000, a Stocked Impoundment Permit scheme was introduced in Queensland at the request of stocking groups. Anglers are required to purchase a permit to fish in impoundments that are covered by the scheme. Fish stocking groups that opt to include their impoundment in the scheme receive some funds from the sale of permits to assist with the purchase of fingerlings. At the time of writing (2005), 29 impoundments were covered by this scheme.

For further information see the following web address:
https://www.daf.qld.gov.au/business-priorities/fisheries

Stocked fisheries are still expanding in Queensland, but stocking of fingerlings is expensive. Prices for fingerlings range from 15c for a 50 mm silver perch to $20 or more for a 150 mm saratoga. A 50 mm bass costs approximately 40–50c and a 50 mm barramundi costs from 50–60c. Maintaining a reasonable annual stocking rate of 100 fingerlings per hectare in a large impoundment of 10 000 hectares could cost over $0.5 million per year. Therefore, many large impoundments are never stocked to this level. Even with the impoundment permit scheme in place, such a large impoundment is unlikely to be stocked at desired levels. Nevertheless, many stocked impoundment fisheries have proven very successful in terms of popularity with anglers and productivity. It was estimated by Hamlyn and Beattie (1993) that for every dollar spent on stocking, $18 is spent in the local community by tourist anglers. With continued expansion in the popularity of impoundment fisheries, this ratio is likely to have increased. Boating, tackle and fishing media associated with impoundment fisheries have also expanded greatly in recent years with the development of these new angling opportunities. A more recent study (Rolfe *et al.* 2005) into angling expenditure at three Queensland dams found annual expenditure ranged from $0.95 million to $1.47 million. Most expenditure was in the local economy. The total economic value was estimated to be $1.07 million, $3.2 million and $4.54 million at each of the three dams respectively.

A frequent concern of fish stocking groups and fisheries managers is the probable loss of stocked fry and fingerlings to predators such as spangled perch, eels, mouth almighty, banded grunter, fork tailed catfish and established stocked species.

Fork-tailed catfish are particularly common in coastal impoundments between Maryborough and Rockhampton, and they are also common in gulf drainage impoundments. There is considerable concern about the probable impact of catfish on the establishment of impoundment barramundi fisheries. Every fry lost to predators represents a wasted purchase. Stocking groups need to know the optimal stocking size, best release sites and optimal release strategies to minimise predation risk and enhance survival. Knowledge of factors which may contribute to the survival of stocked fishes in impoundments, including food availability and the physical and chemical characteristics of the water body, will also assist stocking groups to direct their efforts productively.

1.2 Need

Despite the large number of impoundments currently stocked in Queensland for recreational fishing enhancement, and the economic benefits resulting from this activity, prior to this study almost no research had been conducted into developing strategies to maximise survival of stocked fingerlings or to determine the cost-effectiveness of different stocking strategies. Some research had been done on stocking strategies and survival of barramundi stocked in river systems (Russell and Rimmer 1997), but growth rates of impoundment stocked barramundi are approximately three times the rate of river stocked fish (Russell and Rimmer 1997; Rimmer and Russell, 1998). Therefore, the results of river stocking work are not directly transferable to impoundment situations, which represent a completely different ecological system. Some preliminary unpublished work on survival of barramundi stocked at different sizes in an impoundment (Copperlode Dam) was also conducted in 1991 by Hogan. This study suggested that 25 mm barramundi may do as well or better than fish stocked at larger sizes, but the results were complicated by different release years and months for the different size classes.

However, Hogan's data does suggest the importance of early release times for best survival. Department of Primary Industries post-stocking surveys and creel surveys have given an indication of whether a fishery is successful or not, but these surveys have not been designed to test any hypothesis on the effectiveness of release strategies. To achieve maximum productivity at minimum cost, freshwater fish stocking groups require reliable information that will assist them to improve stocking procedures. This information will increase the number of stocked fish reaching catchable size for a given unit of expense. To date, stocking groups have been releasing fry without knowledge of whether different size classes of stocked fry have different probabilities of survival. Similarly, there is no knowledge of whether point-of-release has any influence on survival rates. Properly conducted experiments which examine the relative survival of different size classes of fry and the influence of different release strategies on relative survival, would be of immense benefit to recreational fishing groups and fisheries agencies involved in enhancing impoundment fisheries with native fish species in eastern and northern Australia.

If, for example, a smaller size class was found to survive equally well as a larger size class, then it would make sense for stocking groups to stock the smaller and cheaper size class. If the largest size class survived much better than the cheaper smaller size classes, then it would make more sense for stocking groups to stock the larger size classes. It is a matter of balancing relative cost of fingerlings against relative survival and coming up with the most cost-effective solution. Similarly, knowledge of whether point-of-release has any influence on survival will assist stocking groups maximise the benefits of their stocking activities.

It is clear from post-stocking and creel surveys that stocked fish survive and grow better in some impoundments than others. Knowledge of the environmental characteristics that influence the productivity and carrying capacity of impoundments will benefit stocking groups by directing their efforts to productive locations, or providing advice on actions that may enhance productivity or carrying capacity of impoundments. The current project is a necessary first step towards developing efficient stocking protocols. In the future it is proposed to examine in detail the success of stocked fisheries in a broad range of impoundments. Such work would aim to predict the suitability of different impoundments for different species and strategies to improve the fisheries value of impoundments.

1.3 Objectives

The objectives of the research presented in this report are:

1. to determine optimal stocking size and release strategies to maximise the survival of four species (golden perch, silver perch, Australian bass and barramundi) in stocked impoundments in northern and eastern Australia;
2. to identify differences between impoundments that may influence the survival and growth of stocked fish stocks;

   The third objective is an opportunistic use of the microtagging technology used in this study to identify the different batches of stocked fish. Microtagging provided an excellent opportunity to assess the effectiveness of scale patterns as batch tags.
3. to verify the use of scale pattern analysis as a reliable means of identifying up to three batches of fish;
4. to ensure adequate replication of stocking strategies for barramundi, golden perch and silver perch.

Chapter 2: Effects of release size and release strategy on the relative survival of stocked Australian bass, barramundi, golden perch and silver perch

Objectives

To determine optimal stocking size and release strategies to maximise the survival of four fish species (golden perch, silver perch, Australian bass and barramundi) in stocked impoundments.

2.1 Methods

2.1.1 Receipt and holding of fish

All fish used in this study were purchased from commercial hatcheries. Fish were received at the Southern Fisheries Centre (SFC) between September and January in each year from 1998–99 through to 2001–02, and held in 5000 litre flow-through tanks before and after tagging.

Eighteen thousand each of Australian bass, silver perch and golden perch were ordered annually. For each of these species, three size classes (20–30 mm, 35–45 mm and 50–65 mm), consisting of 6000 fish per size class were supplied. The sizes selected were based on the size ranges commonly being used to stock impoundments in New South Wales or Queensland. Larger fish (e.g. 150 mm or 300 mm) were not selected for research as it was not feasible for most hatcheries supplying the stocked impoundment fisheries to feed and hold fish long enough to reach these sizes. In the case of Australian bass it would take at least 18 months to two years to reach these sizes. The only species for which it would have been feasible to try larger fish was barramundi, and separate river stocking experiments with larger fish were in progress at the time of this study. These are referred to later in the report.

Hatcheries were encouraged to supply fish of each size class from different spawning events or to manipulate growth rates by holding fish at different densities in different ponds. This was to minimise the risk of the smaller size class being composed mainly of runts and the larger size class mainly of ‘shooters’. Although preferring to obtain all three sizes from a single hatchery, occasionally it was necessary to obtain different sizes from different hatcheries, as it was not always possible for a single hatchery to provide all three size classes within the time constraints of the project. Experiments were based on the assumption that between hatchery differences in post stocking survival would be minimal. A requirement was for all three sizes of a species to be delivered on the same day (if possible) or within a week. This was to enable stocking of the three size classes simultaneously after tagging.

Barramundi were supplied as pellet-weaned 18 mm fish and then grown out at SFC to the three size classes listed above (6000 per size class). Differential growth of the three size classes was achieved by manipulating the water temperature in holding tanks (see chapter 4 for further details).

Upon arrival at SFC, fish were held for at least 24 hours to check for signs of poor condition or health before tagging commenced. Fish apparently in poor health at the time of receipt were rejected. Barramundi were tested for the presence of nodavirus at 26 and 42 days after hatching. Following some health problems with golden and silver perch and a nodavirus outbreak in barramundi whilst fish were held at SFC in the 1998–99 season (see results below), stringent hygiene measures were introduced. These included chlorination of all tanks prior to receipt of fish, sterilisation of nets between use, treatment of fingerlings on receipt with potassium permanganate (even if fish appeared healthy) and receipt of barramundi fry as early in the season as possible to minimise risk of a nodavirus outbreak. While fish were held at SFC, minor infections (e.g. skin parasites, etc) were treated by salt bath (15 parts per thousand [ppt] for 1 hour) or dilute formalin bath (200 parts per million [ppm] for 30 minutes) as required. Tagging did not commence unless fish were in good health. Poor quality fish were not tagged or stocked. Poor quality fish showed signs of fungal or other infection, abnormal or lethargic swimming behaviour and muscular wasting or concave bellies.

Silver perch and golden perch were held in dechlorinated, ultra-violet light [UV] sterilised freshwater until tagged and ready to stock. Australian bass were held in a 50/50 mixture of filtered seawater and dechlorinated UV-treated freshwater. This was converted to 100% freshwater after tagging was completed. Barramundi were held in filtered seawater throughout the grow-out and tagging phase, and converted to freshwater several days prior to stocking. All fish were held at a maximum density of 6 gl^{-1} before tagging and 2 gl^{-1} after tagging. Water temperature was ambient, except in the case of barramundi which were held in heated or chilled water prior to tagging to manipulate growth rates (see chapter 4).

Australian bass and silver perch were fed commercial pellet feed to satiation twice daily. Barramundi were fed a pelleted starter preparation six times daily for up to 35 days during their grow-out phase. Golden perch were fed a combination of frozen black worms and frozen zooplankton to satiation twice daily. Feeding was to ensure that fish maintained condition while being held prior to and post-tagging. Prior to arrival at SFC, golden perch, silver perch and bass were pond-reared on plankton blooms.

2.1.2 Tagging

Two types of tags were used in this project: visual implant elastomer (VIE) tags (Australian bass, silver perch, golden perch, 20–30 mm barramundi) and coded wire (CW) tags (35–45 mm and 50–65 mm barramundi).

VIE tags

VIE tags were supplied by Northwest Marine Technology of the United States. The tags are formed by mixing a coloured fluorescent liquid with a curing agent. The two components remain in liquid form indefinitely if kept separately, sealed and refrigerated. When combined, the mixture remains in liquid form for at least 24 hours if kept on ice. The liquid elastomer is injected under the skin of fish with a fine gauge syringe needle, and sets to a rubbery consistency after one to two hours at room temperature. The tag fluoresces under UV or blue light. VIE tags are inert and non-toxic.

Prior to tagging, several hundred fish were transferred into two 60 L aerated holding containers. Fish were dip-netted with fine soft mesh nets in lots of 10 to 12 and suspended in the nets in 5 L containers containing clove oil anaesthetic ($0.025\ \mathrm{mL/L^{-1}}$)[1].

Each person tagging had two such containers, which were used in rotation to ensure a continuous supply of fish. Fish were ready for tagging when they were anaesthetised.

Figure 2.1 Tagging a silver perch behind the anal fin with a yellow VIE tag (Photo G. Aland).

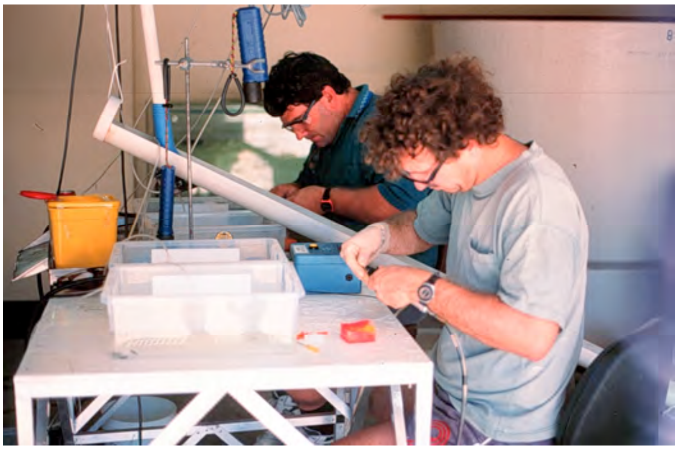

Figure 2.2 VIE tagging set up. Note two taggers in operation, containers for anaesthetising fish and chute down which tagged fish travel to a recovery tank (Photo M. Hutchison).

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[1] Clove oil is not registered for aquaculture use. A suitable registered replacement is Aqui-S which is derived from components of clove oil.

Figure 2.3 Tagging a barramundi with a coded wire tag (Photo Mark Dawson).

Tagging was carried out using two VIE tagging machines (Northwest Marine Technology), fitted with either 27 gauge 1 mL insulin syringe needles (fish >35 mm) or 29 gauge 1 mL insulin syringe needles (20–30 mm fish). The tagging machines were connected to an air compressor which delivered a blast of air to the handpiece (Figure 2.1) when a button was depressed, forcing a small amount of elastomer out through the needle and under the skin of the fish. The amount of material expelled depended on how long the button was depressed—our tags were 3–5 mm long. A counter on the control box of each machine recorded the number of fish tagged. After tagging, fish were transferred to a 1000 litre aerated tank via a water chute (Figure 2.2). Tagged fish recovered from the anaesthetic within a few minutes. Once the required number of fish were tagged in a batch, they were relocated to labelled holding tanks for observation and feeding until release.

Fish were tagged with three different colours of VIE. For bass, golden perch and silver perch, red tags denoted 50–65 mm fish, orange tags 35–45 mm fish and yellow tags 20–30 mm fish. Tags were inserted just beneath the skin in one of three locations: adjacent to the front dorsal fin for fish to be released into artificial floating cover, adjacent to the anal fin for fish to be released in deep water and adjacent to the rear dorsal fin for fish to be released in shallow water. There is little difference in the visibility of tags in these tagging locations for at least eight months after tagging (Gallagher and Hutchison 2004).

Tagging was alternated between left and right sides of the fish depending on the year of release. In the case of barramundi, only 20–30 mm fish were tagged with VIE. These fish were all tagged adjacent to the rear dorsal fin. Red tags were used on fish to be released into deep water, yellow tags on fish to be released into artificial cover and orange tags for fish to be released into shallow water.

CW tags

Like VIE tags, CW tags are used to mark batches of fish. The 1.1 mm long by 0.25 mm diameter magnetised stainless steel tags can be marked with rows of laser-etched numbers denoting a specific batch or individual code. We used plain wire tags (i.e. not coded). Single tags were cut from a continuous roll of wire and implanted into the fish using a Mk IV CW tagging machine (Northwest Marine Technology) (Figure 2.3).

CW tags were used for the two larger size classes of barramundi, as VIE tags were very difficult to see when implanted under the highly reflective skin of these fish. The same problem was encountered with the smallest size class of barramundi, however, CW tags caused an even greater problem as they often exited the skin or penetrated the abdominal cavity, causing injury to the fish. Therefore, VIE tags were retained for the smallest size class of barramundi.

Prior to tagging with CW tags, barramundi were handled and anaesthetised as described above for VIE tagging. The tagging needle was inserted so that it just penetrated the skin of the barramundi. The tagging machine was then activated by a foot pedal, firing the tag into the fish just beneath the skin. Barramundi were tagged at one of three locations to denote the release strategy: just below the anterior part of the front dorsal fin (cover release), between the front and rear dorsal fins (shallow water release) and just below the posterior part of the rear dorsal fin (deep-water release). 35–45 mm barramundi were tagged on the right side and 50–65 mm barramundi were tagged on the left side.

2.1.3 Selection of study sites

Study sites were selected to comply with the DPI&F translocation policy. Sites were also required to be large enough to compare shallow water with deep water releases, yet small enough that an adequate number of the stocked fish could be recaptured to provide a meaningful result. Species stocked into each dam represented common combinations used for stocking in Queensland, in accordance with the existing translocation policy. Most dams in Queensland have multi-species stockings. Most of the dams selected for this project had a previous history of stocking. The four dams selected initially were Lenthall’s Dam (history of bass, silver perch, golden perch and barramundi stockings), Gordonbrook Dam (history of bass, golden perch and silver perch stockings), Cassava Lagoon (history of bass, golden perch and silver perch stocking) and Gooburrum balancing storage (no previous stocking).

In year one of the project, four dams located in south-eastern Queensland coastal drainages were selected. The dams used and species stocked in each dam are shown in Table 2.1. Locations of the dams are shown in Figure 2.4. After year one, one of the dams (Lenthall’s Dam) was dropped as a study site because very few fish of any species had been recaptured. We believe this was due to both the prolific growth of aquatic weed to a depth of 4 m around the dam margins which hindered electrofishing operations, and because the dam frequently overflowed with consequent loss of fish downstream. A smaller private dam (Simpson’s Dam) was used as a replacement site from year two onwards (Figure 2.4). This dam had a history of barramundi and bass stockings.

In year four, following several years of very low recaptures of silver and golden perch, two new dams were selected for stocking with these species. The new dams, Storm King Dam located in the northern Murray-Darling Basin near Stanthorpe and Tarong Power Station Dam near Nanango in the upper Burnett system, replaced Gooburrum Balancing Storage, Simpson’s Dam and Gordonbrook Dam as release sites for golden and silver perch. Storm King Dam had a history of stocking with golden perch, silver perch and Murray cod, whilst Tarong Power Station dam had received some limited stockings of golden perch at least five years prior to our stocking experiments. We suspected that interactions with bass, barramundi and other predators not native to the Murray-Darling Basin might have contributed to the poor returns of golden and silver perch, so the two new dams were selected to provide an environment free of these species to test this hypothesis.

Simpson’s Dam and Gooburrum Balancing Storage continued to be used for barramundi stocking in year four.

2.1.4 Sorting and stocking procedures

Post-tagging and prior to stocking, fish were held in separate 5000 L tanks that were labelled according to the size of fish and tag location. Up to 2000 fish were in each tank. To be certain there was no major post-tagging mortality, fish were held for at least 48 hours prior to stocking. Post-tagging mortality was generally less than 1% across all size classes. No further tests were done to compare post-tagging mortality of the different size classes as we were satisfied that post-tagging mortality was low.

On the day of stocking, water levels in the tanks were dropped to 20% capacity, and the fish captured and transferred to aerated 100 L containers. From there, barramundi were counted into 20 L buckets that were filled to about 25% capacity and aerated.

Up to 334 × 20–30 mm fish, 223 × 35–45 mm fish and 167 × 50–65 mm fish were transferred to a single bucket ready for bagging. The contents of each bucket were then tipped into a double-layered plastic bag which was filled with medical oxygen, sealed with a double rubber band and labelled. Plastic bags containing fish were loaded into an insulated container with a 10 cm layer of water in the bottom. The layer of water was used as a safety measure to enable fish to survive should any bag split. For each of the nine treatments, up to 667 fish were stocked. The number varied according to number of fish supplied, pre- and post-tagging mortalities and the size of the dam to be stocked. Numbers of fish released within a batch were recorded on the day of release.

Transport of the bagged fish from SFC to the release locations took from 2.5 to 4 hours. On arrival, bags of fish to be released in shallow water were floated in the shallows to allow the water temperature to equilibrate, and then infused with water from the dam for up to 10 minutes to allow the fish to acclimatise before release.

Care was taken to release the three size classes *at least* two to three metres apart from each other to minimise potential cannibalism. This was particularly important with barramundi and these were released up to 10 metres apart.

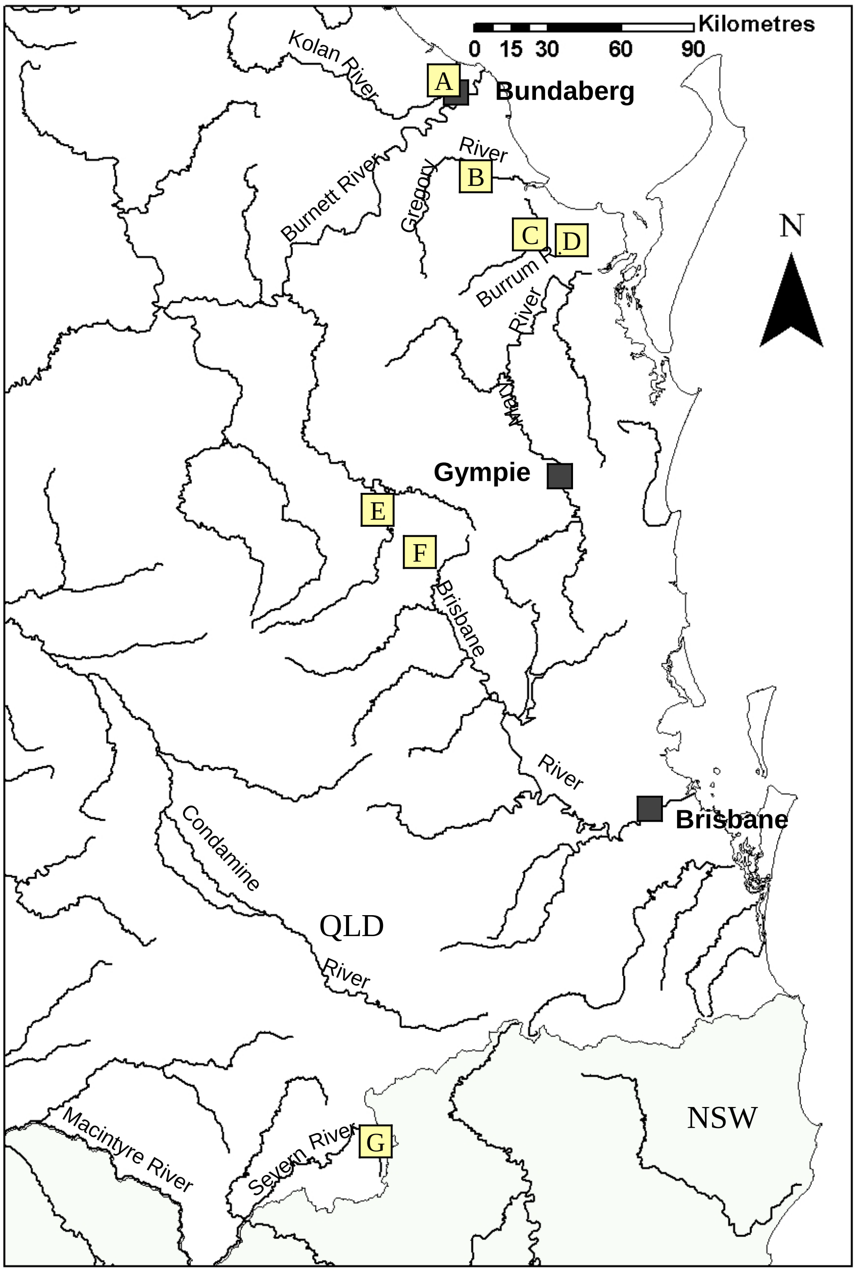

Figure 2.4 Location of impoundments used for stocking experiments in this study.

A: Gooburrum Balancing Storage

B: Simpson’s Dam

C: Lenthall’s Dam

D: Cassava Lagoon

E: Gordonbrook Dam

F: Tarong Power Station Dam

G: Storm King Dam

Table 2.1 Dams stocked with tagged fish during the course of the project.

Dam	**Full supply surface area hectares**	**Project years stocked**	**Tagged species stocked**			
			Bass	**Barramundi**	**Golden perch**	**Silver perch**
Lenthall’s Dam	400	1 (1998/99)	✓		✓	✓
Gordonbrook Dam	200	1 (1998/99)	✓		✓	✓
		2 (1999/2000)	✓		✓	
		3 (2000/01)	✓		✓	
Cassava Lagoon	90	1 (1998/99)	✓		✓	
		2 (1999/2000)	✓	✓	✓	✓
		3 (2000/01)	✓	✓	✓	✓
		4 (2001/02)		✓	✓	✓
Gooburrum Storage	70	1 (1998/99)				✓
		2 (1999/2000)		✓		✓
		3 (2000/01)		✓		✓
		4 (2001/02)		✓		
Simpson’s Dam	28	2 (1999/2000)	✓	✓	✓	✓
		3 (2000/01)	✓	✓	✓	✓
		4 (2001/02)		✓		
Storm King Dam	70	4 (2001/02)			✓	✓
Tarong Dam	40	4 (2001/02)			✓	✓

Fish for deep-water release were taken out into water at least 6 m deep and at least 50 m from the shore. After a 5 to 10 minute acclimatisation period, the bags were turned on their side and the fish allowed to swim out. Again, the three size classes of fish were released apart from each other. Just prior to release of the artificial cover batch of fish, three floating cover devices were deployed in the dam. Cover devices consisted of 2 m long × 1 m wide, 90 mm diameter poly pipe frames with brush wood suspended from 500 pound monofilament line (Figure 2.5).

The floating devices were anchored 2–3 m apart in 2–2.5 m deep water, just off the edge of weed beds or other natural cover (Figure 2.6). The devices were designed to provide a temporary predator-free refuge for newly released fish. Between 500 and 700 fish were released into each device. If the devices were already in the water from a previous release of fingerlings, they were removed from the water and reset in a different position to ensure they were predator-free.

When cover devices had been set, the remaining bags of fish were removed from the insulated containers and released into the floating cover devices following the same procedures as for the shallow and deep-water releases. A different size class of fish was released into each cover device.

Figure 2.5 Artificial cover device prior to deployment in dam (Photo M. Hutchison).

Figure 2.6 Releasing silver perch into artificial cover devices deployed in dam (Photo M. Hutchison).

Four to five people were involved in each release. This enabled simultaneous release of deep-water and shallow-water batches and minimised the delay until cover batches were released. The total time to release all fish at each site was approximately 30 minutes.

2.1.5 Recapture and identification

Post-stocking surveys of the tagged fish were done quarterly, starting a few months after the initial stocking date. Methods of capture included electrofishing with a purpose-built boat in the shallow littoral areas, and setting various sized gill nets throughout each dam. All sampling was carried out at night to standardise effort.

The power-on time during electrofishing was recorded, as were the number and duration of net sets. Approximately equal sampling effort was applied at each dam. Electrofishing captures were placed in a 200 litre flow-through holding tank on the electrofishing boat. The night session was broken up into at least three periods of electrofishing operation, depending on the number/density of fish in the holding tank requiring processing. Gill nets were checked every hour and the fish removed and placed into the holding tank.

All recaptured fish were anaesthetised in a diluted solution of clove oil (0.25 mL/L).[2] Fish were held in the anaesthetic until they lost equilibrium and did not react strongly to touch. Anaesthetised individuals were then measured (total length) and scanned for tags. Fish were measured to provide additional information on growth rates, which will be of interest and value to stocking groups.

VIE tags were detected with the aid of a bluelight flashlight and amber glasses. The same observer was used on all occasions and tag colours were compared to reference tags. CW tags were detected with an electronic wand, which was sensitive enough to separate the six tagging locations (i.e. three on each side of the fish).

If a wire tag was not detected in a barramundi, it was assumed that the fish had a VIE tag. If the VIE tag could not be detected by blue flashlight, the fish was sacrificed by immersion in an ice slurry for later processing. This involved skinning the fish and searching meticulously using blue flashlight and amber glasses. VIE tags were found using this method in over 95% of cases. However, it was impossible to know if fish in which no tags were found were those that had lost VIE tags or CW tags.

A maximum of 50 barramundi per year class per dam were sacrificed. This cap was implemented for ethical reasons and to minimise confounding effects of removal of fish. If the cap was reached, further samples of wire-tagged barramundi were ignored for the statistical comparison of batch recapture rates. However, subsequent recaptures of wire-tagged and wire-free barramundi were used for growth information. Wire-free recaptured barramundi were assumed to be fish stocked at 20–30 mm.

2.1.6 Analyses

Statistics

Data on the relative recapture rates of the different batches of fish were analaysed in Genstat™ using a generalised linear model (GLM) of binomial proportions with a logit link function. This model used actual recaptures as a proportion of the number of fish stocked in each category. The maximal model was run with the following factors: size at stocking, release location, dam, year and number of sampling trips, and included interaction terms for these factors.

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[2] Clove oil is not registered for aquaculture use. A suitable registered replacement is Aqui-S which is derived from components of clove oil.

All factors fitted in the GLM were fixed effects and of specific interest.
The significance of each factor or term in the model was assessed by a forward stepwise procedure. Significant terms and factors were kept in the model. Other factors were rejected. Adjusted mean recapture rates were calculated for each size class and release strategy using the predict function. Means and standard errors calculated using this function were adjusted for the effects of other terms in the model. The dispersion parameter was fixed at 1 (McCullagh and Nelder, 1989; Genstat, 2005).

Cost benefit analysis

Survival ratios were based on adjusted mean recapture rates. The relative survival ratios of the different size classes of fish were compared with the relative cost ratio of the different size classes based on current hatchery price structures. If the survival ratio is greater than the cost ratio, then the first of the two size classes being compared is the most cost-effective to stock. For example, in the comparison between 50–65 mm Australian bass and 35–45 mm bass:

Survival ratio (S) = 1.16
Cost ratio (C) = 1.44
S<C, therefore it is more cost-effective to stock 35–45 mm bass.

If the survival ratio was greater than 1.44, then it would have been more cost effective to stock the 50–65 mm size class of bass.

The inverse relative survival ratio gives an indication of how cheap the less cost-effective size class would have to be before it became more cost-effective to stock that size class. So for the above example:

Inverse survival ratio = 0.862,

Therefore, in the above example, 35–45 mm bass would have to cost more than 86.2% of the price of 50 mm bass, before 50 mm bass could be considered more cost effective. As long as 35–45 mm bass cost below 86.25% of the price of 50 mm bass, they will remain more cost effective to stock. In chapter 3, impoundment specific factors which can vary the cost benefit and recapture ratios are examined. Knowledge of these factors will enable stocking groups to estimate likely cost benefit scenarios for their specific situation.

Growth

The total lengths of all recaptured fish were recorded. Mean total length and standard deviation of total length were calculated for each size class of each species at each dam. For those groups with sufficient recapture data, growth information was plotted as simple line graphs to give some indication of seasonal changes in growth rates and time taken to reach legal size in each dam.

This information was used to estimate potential effects of earlier or later stockings on size attained by the first winter season and time to legal size.

2.2 Results

Of the 210 000 fish tagged and stocked, a total of 3938 (1.9%) were recaptured. Recapture rates of individual batches ranged from 0% to 27%. Recapture rates of all the batches are detailed below.

2.2.1 Australian bass release size and release strategy

Figure 2.7 shows the mean recapture rates for Australian bass adjusted for the factors ‘year’, ‘release strategy’ and ‘dam’. Figure 2.8 shows the mean recapture rates by ‘release strategy’ adjusted for ‘size at stocking’, ‘dam’ and ‘year’. Figures 2.9A to 2.9H show recaptures of Australian bass in each dam and year.

In the GLM, the term ‘trip’ was aliased with the term ‘year’. Running the model with the term ‘year’ rather than ‘trip’ resulted in a lower mean residual deviance value, 3.417 compared to 17.31 (Table 2.2). The GLM identified ‘size at release’, ‘release strategy’, ‘year’ and ‘dam’ as significant effects (Table 2.3).

There was considerable variation in recaptures between dams and years, but the overall trends were for the largest two size classes to have relatively higher recapture rates than the 20–30 mm size class, and for deep water releases to have relatively lower recapture rates than shallow water or artificial cover releases. Table 2.4 shows the relative recapture rates of bass by size class (based on adjusted means) and also shows the relative cost ratios of these fish. Based on this data, overall 35–45 mm bass are the most cost-effective to stock.

Table 2.2 GLM of Australian bass stocking experiment. Constant + size at release + release strategy + dam name + year.

	d.f.	deviance	Mean deviance	Deviance ratio	Approx chi probability
Regression	8	3709.2	463.649	463.65	<.001
Residual	54	184.5	3.417		
Total	62	3893.7	62.802		

Table 2.3 GLM of Australian bass stocking experiment showing significance levels for factors compared to the reference levels size at release 20–30 mm, release strategy cover, Dam name Cassava and Year 1.

Factor	Estimate	t probability
Size at release 35–45 mm	0.8442	<.001
Size at release 50–65 mm	1.0265	<.001
Release strategy deep	–0.4911	<.001
Release strategy shallow	–.0292	0.614
Dam name Gordonbrook	–2.5335	<.001
Dam name Simpsons	–4.877	<.001
Year 2	0.6163	<.001
Year 3	–2.140	<.001

Table 2.4 Adjusted mean relative recapture ratios of different size classes of Australian bass compared with relative cost ratios based on current hatchery prices. The most cost effective size is in bold type for each paired comparison. An inverse relative survival ratio is shown in parentheses. Overall 35–45 mm is the most cost effective size to stock and 20–30 mm the least.

Size class comparison	Relative survival ratio	> or <	Cost ratio
50–65 mm: **35:45 mm**	1.16 (0.862)	<	1.44
50–65 mm: 20–30 mm	2.43 (0.411)	>	2.3
35–45 mm: 20–30 mm	2.10 (0.476)	>	1.6

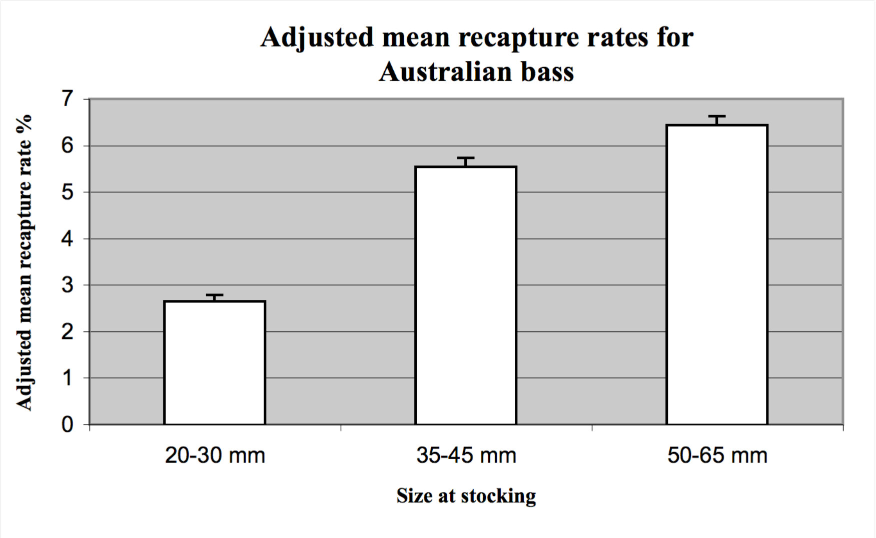


Figure 2.7 Adjusted mean recapture rates (per cent) for Australian bass stocked at three different sizes. Values have been adjusted for the factors 'dam', 'year' and 'release strategy'.

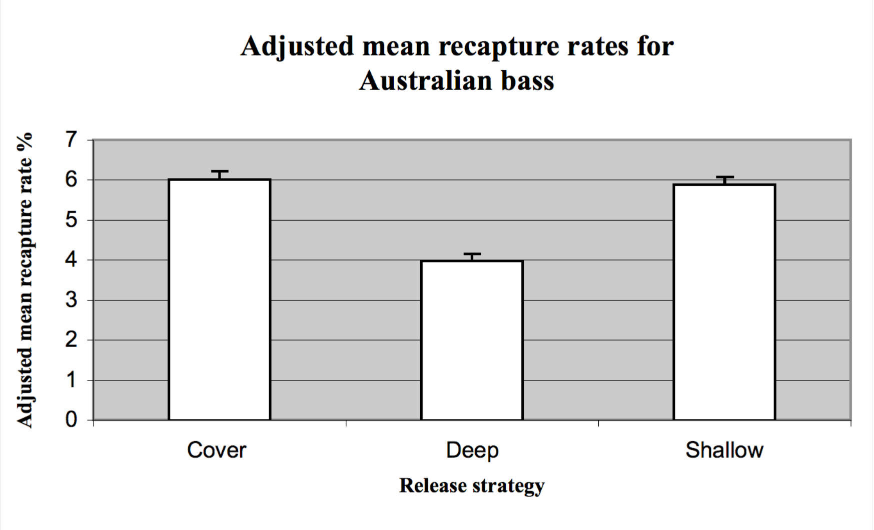
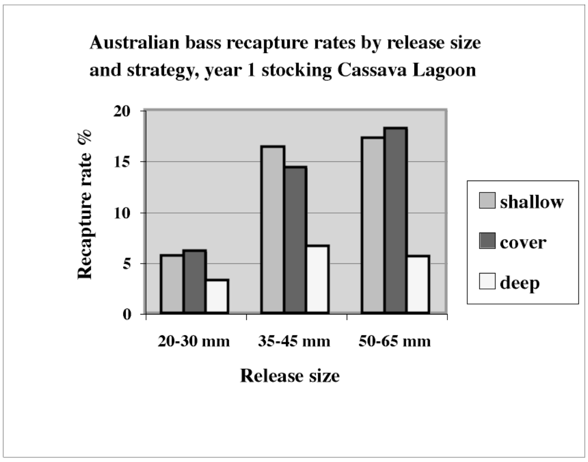
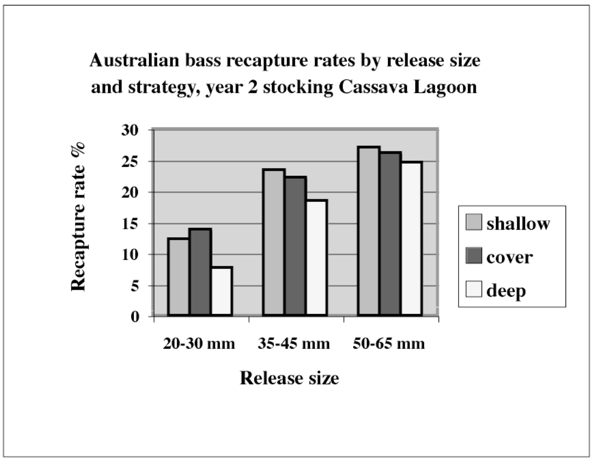


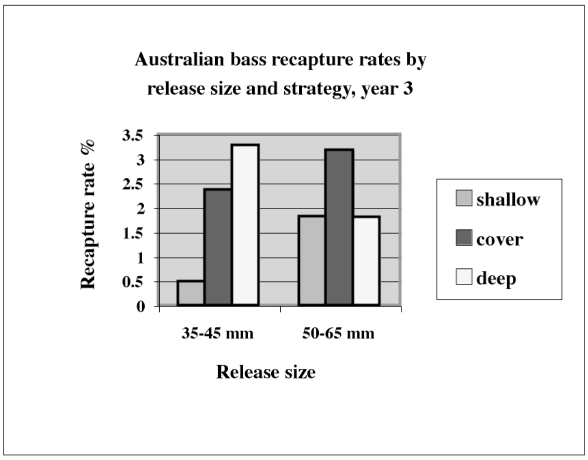
Figure 2.8 Adjusted mean recapture rates (per cent) for Australian bass stocked by three different release strategies. Values have been adjusted for the factors 'dam', 'year' and 'size at release'.


Australian bass recapture rates by release size and strategy, year 1 stocking Cassava Lagoon
Recapture rate %
20
15
10
5
0
20-30 mm
35-45 mm
50-65 mm
Release size
shallow
cover
deep

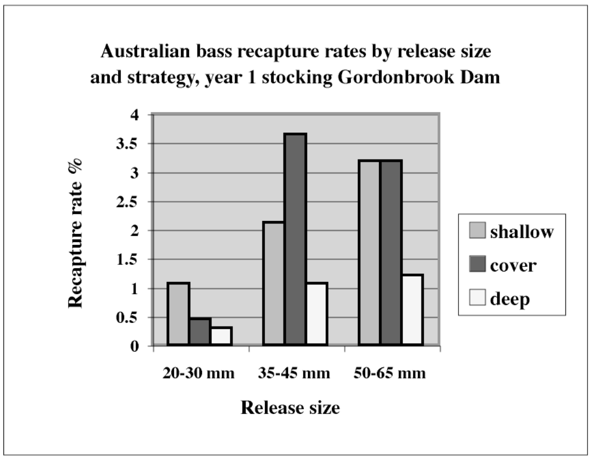
A


Australian bass recapture rates by release size and strategy, year 2 stocking Cassava Lagoon
Recapture rate %
30
25
20
15
10
5
0
20-30 mm
35-45 mm
50-65 mm
Release size
shallow
cover
deep

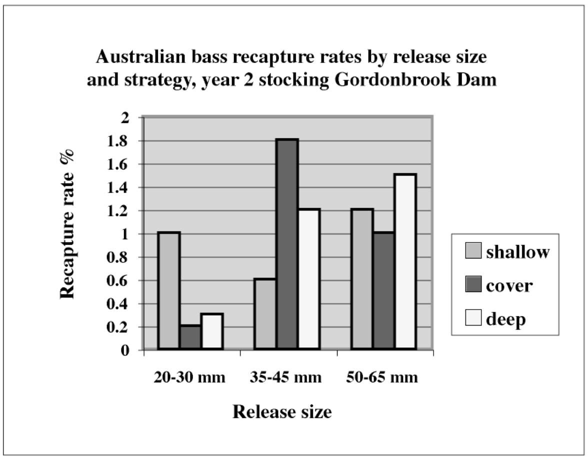
B


Australian bass recapture rates by release size and strategy, year 3
Recapture rate %
3.5
3
2.5
2
1.5
1
0.5
0
35-45 mm
50-65 mm
Release size
shallow
cover
deep

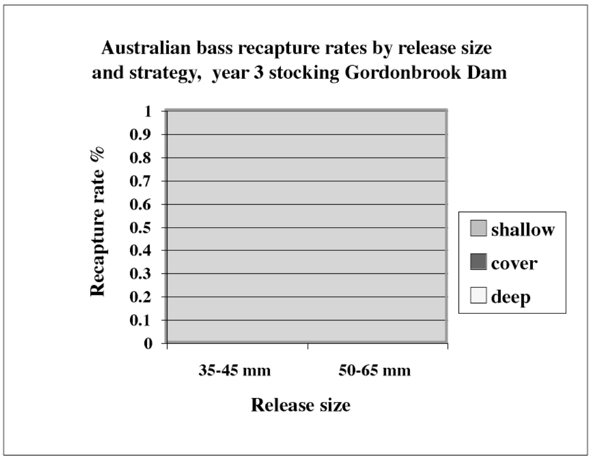
C


Australian bass recapture rates by release size and strategy, year 1 stocking Gordonbrook Dam
Recapture rate %
4
3.5
3
2.5
2
1.5
1
0.5
0
20-30 mm
35-45 mm
50-65 mm
Release size
shallow
cover
deep

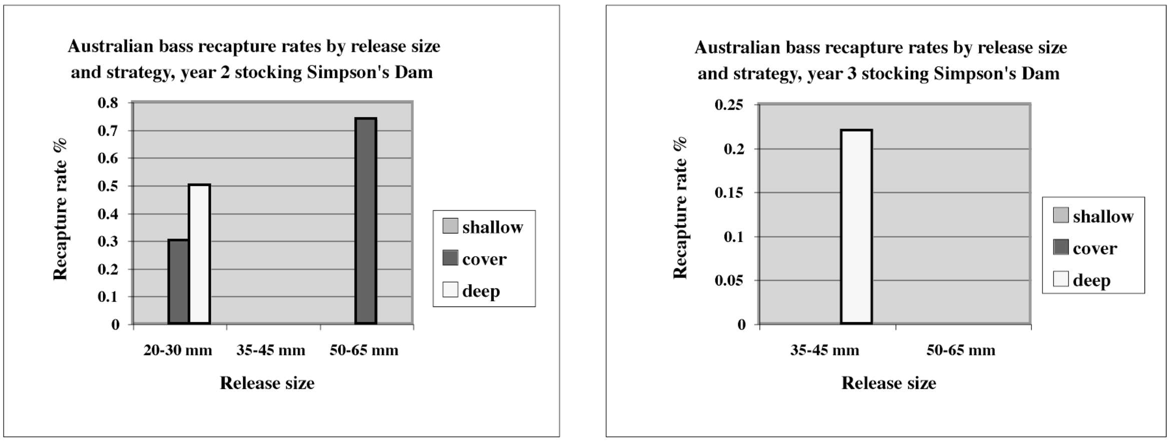
D


Australian bass recapture rates by release size and strategy, year 2 stocking Gordonbrook Dam
Recapture rate %
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
20-30 mm
35-45 mm
50-65 mm
Release size
shallow
cover
deep

E


Australian bass recapture rates by release size and strategy, year 3 stocking Gordonbrook Dam
Recapture rate %
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
35-45 mm
50-65 mm
Release size
shallow
cover
deep

F



G H

Figure 2.9 Recapture rates (as per cent of number stocked) of Australian bass by release size and release strategy. Recaptures are shown in each dam by release year. A-C: Cassava Lagoon release Years 1 to 3. D-F: Gordonbrook Dam, release Years 1 to 3. G-H: Simpson's Dam, release Years 2 and 3. Note variation in catch rates between dams and years.

2.2.2 Barramundi release size and release strategy

Figures 2.10 and 2.11 show adjusted mean recapture rates for barramundi by 'size at release' and by 'release strategy' respectively. Figures 2.12A to 2.12I show recapture rates for barramundi by 'dam' and 'year'. In the majority of cases 50–65 mm fish had the highest recapture rates. There was one anomalous result from Cassava Lagoon where 20–30 mm barramundi had the highest recapture rate. No barramundi were captured from the Year 4 release into Cassava Lagoon.

Analysis of the data by a GLM of binomial proportions showed that 'release strategy' did not significantly affect recapture rate.'Size at release' was, however, significant with recapture of 50–65 mm fish significantly higher than that of 20–30 mm fish (p<.001). Recapture of 35–45 mm fish was not significantly different to that of 20–30 mm fish (p=.125). 'Dam', 'year' and 'number of sampling trips' also had significant effects on recapture rates (see Tables 2.5 and 2.6).

Overall, fish stocked at 50–65 mm were recaptured at higher relative rates than the other size classes. Table 2.7 shows relative recapture ratios of the different size classes based on the adjusted means and also shows cost ratios based on current hatchery price structures. On this basis, 50–65 mm is currently the most cost effective size to stock.

Table 2.5 GLM of barramundi stocking experiment. Constant + size at release + release strategy + dam name + year + sampling trips.

	d.f.	deviance	Mean deviance	Deviance ratio	Approx chi probability
Regression	9	369.6	41.065	41.06	<.001
Residual	56	256.7	4.583		
Total	65	626.3	9.635		

Table 2.6 GLM of barramundi stocking experiment showing significance levels for the variate sampling trips and for factors compared to the reference levels size at release 20–30 mm, release strategy cover, Dam name Cassava, Year 2.

Factor or variate	Estimate	t probability
Size at release 35–45 mm	0.204	0.125
Size at release 50–65 mm	0.887	<.001
Release strategy deep	–0.016	0.879
Release strategy shallow	–.183	0.100
Dam name Gooburrum	1.217	<.001
Dam name Simpsons	1.517	<.001
Year 3	0.630	<.001
Year 4	–2.373	<.001
Sampling trips	–0.295	.030

Table 2.7 Adjusted mean relative survival ratios of different size classes of barramundi compared with relative cost ratios based on current hatchery prices.
The most cost effective size is in bold type for each paired comparison. An inverse survival ratio is shown in parentheses. Overall 50–65 mm is the most cost effective size to stock and 35–45 mm the least.

Size class comparison	Relative survival ratio	> or <	Cost ratio
50–65 mm: 35–45 mm	1.947 (0.514)	>	1.44
50–65 mm: 20–30 mm	2.38 (0.420)	>	2.3
35–45 mm: **20–30 mm**	1.22 (0.820)	<	1.6

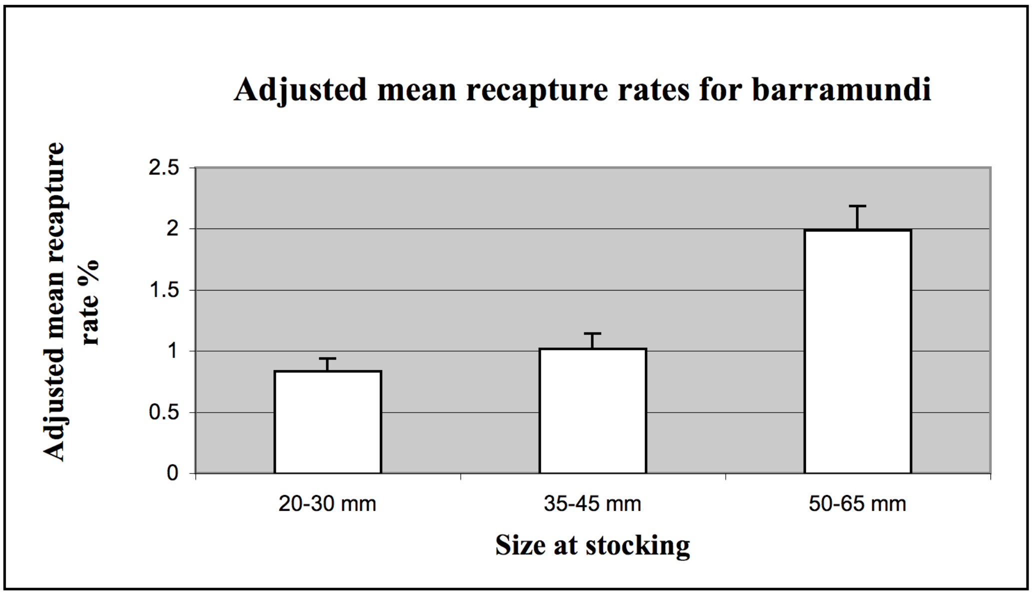


Figure 2.10 Adjusted mean recapture rates of barramundi stocked at different sizes. Values have been standardised by averaging over the levels for the factors ‘dam’, ‘year’, and ‘release strategy’. The value for the variate ‘number of sampling trips’ has been fixed.

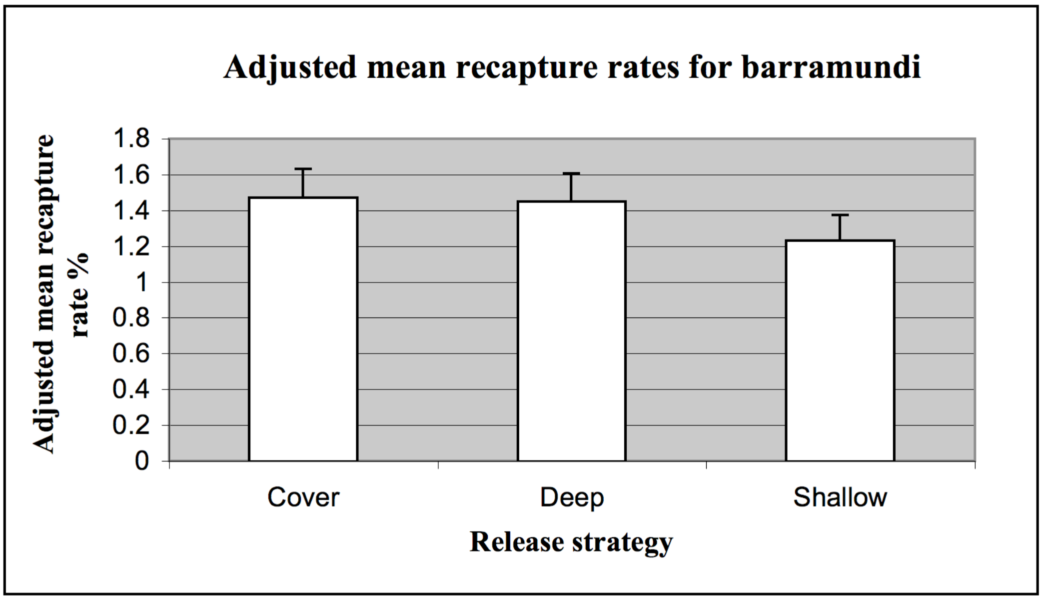
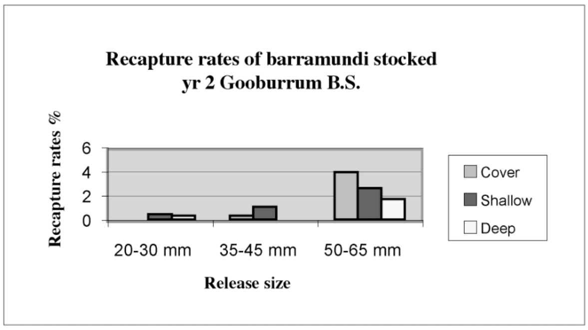
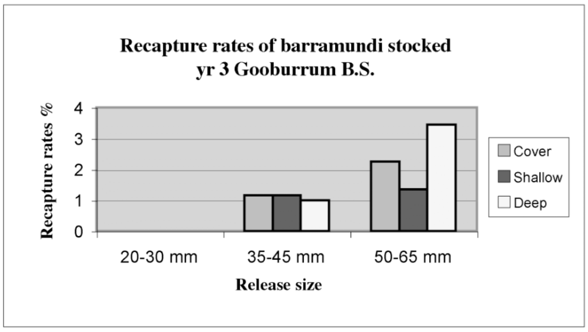


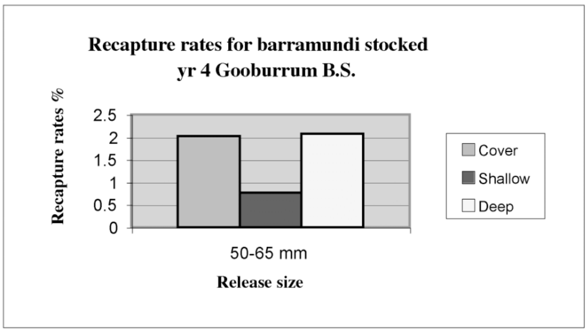
Figure 2.11 Adjusted mean recapture rates of barramundi released by different strategies. Values have been standardised by averaging over the levels for the factors ‘dam’, ‘year’, and ‘size at release’. The value for the variate ‘number of sampling trips’ has been fixed.


Recapture rates of barramundi stocked
yr 2 Gooburrum B.S.
Recapture rates %
6
4
2
0
20-30 mm
35-45 mm
50-65 mm
Release size
Cover
Shallow
Deep

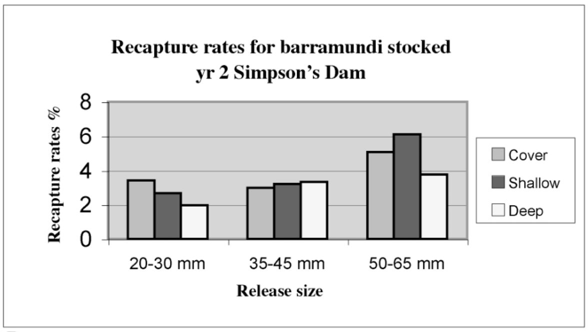
A


Recapture rates of barramundi stocked
yr 3 Gooburrum B.S.
Recapture rates %
4
3
2
1
0
20-30 mm
35-45 mm
50-65 mm
Release size
Cover
Shallow
Deep

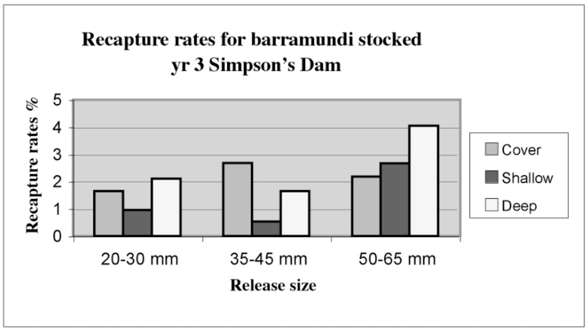
B


Recapture rates for barramundi stocked
yr 4 Gooburrum B.S.
Recapture rates %
2.5
2
1.5
1
0.5
0
50-65 mm
Release size
Cover
Shallow
Deep

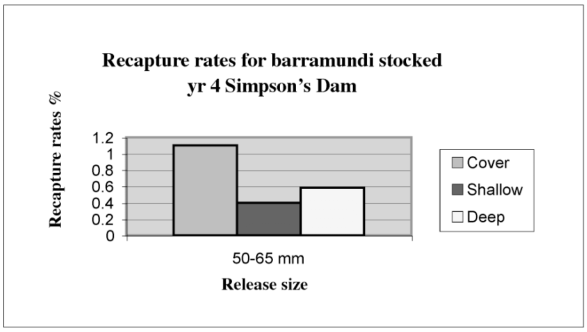
C


Recapture rates for barramundi stocked
yr 2 Simpson's Dam
Recapture rates %
8
6
4
2
0
20-30 mm
35-45 mm
50-65 mm
Release size
Cover
Shallow
Deep

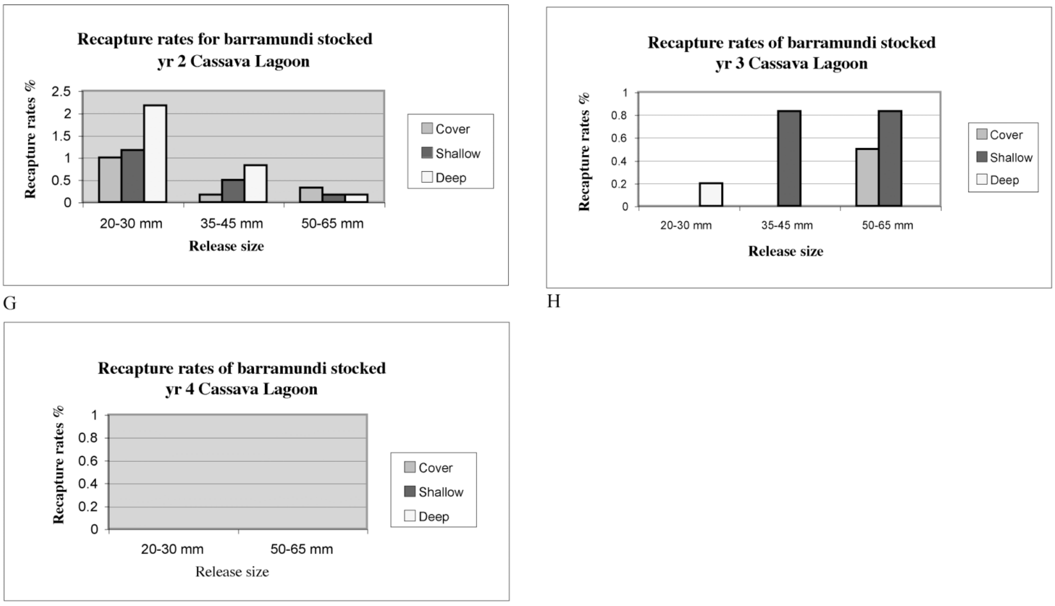
D


Recapture rates for barramundi stocked
yr 3 Simpson's Dam
Recapture rates %
5
4
3
2
1
0
20-30 mm
35-45 mm
50-65 mm
Release size
Cover
Shallow
Deep

E


Recapture rates for barramundi stocked
yr 4 Simpson's Dam
Recapture rates %
1.2
1
0.8
0.6
0.4
0.2
0
50-65 mm
Release size
Cover
Shallow
Deep

F



G

H

I

Figure 2.12 Recapture rates (as per cent of number stocked) of barramundi by release size and release strategy. Recaptures are shown in each dam by release year. A-C: Gooburrum Balancing Storage release Years 2–4. D-F: Simpson's Dam, release Years 2–4. G-I: Cassava Lagoon, release Years 2–4. Note variation in catch rates between dams and years.

2.2.3 Golden perch release size and release strategy

Figures 2.13 and 2.14 show adjusted mean recapture rates for golden perch by ‘size at release’ and by ‘release strategy’ respectively. Figures 2.15A to 2.15D show recapture rates for golden perch by ‘dam’ and ‘year’. For dams and years that golden perch were recaptured, 50–65 mm fish had the highest recapture rates. However, there were no recaptures for golden perch stocked into Simpson’s Dam, Gordonbrook Dam or Cassava lagoon in Years 3 and 4. The GLM containing the factors and variates ‘size at release’, ‘release strategy’, ‘dam’ and ‘number of sampling trips’ was significant (Table 2.8). The term ‘year’ was not run in the model due to near collinearity or aliasing between Storm King Dam, Tarong Dam and Year 4.

Analysis of the data by a GLM of binomial proportions showed that ‘release strategy’ had a significant effect on recapture rates (see table 2.9). Cover released fish had lower recapture rates than shallow or deep water released fish. ‘Size at release’ was also significant with 50–65 mm and 35–45 mm golden perch recaptured at higher rates than 20–30 mm fish (p<.001). Storm King Dam and Tarong Power Station Dam were significantly different to Cassava Lagoon (p<.001) but other dams were not (see Table 2.9). ‘Number of sampling trips’ was also a significant variate (p<.001) influencing recapture rates.

Overall, fish stocked at 50–65 mm had higher recapture rates than the other size classes. Table 2.10 shows relative survival ratios (recapture rates) of the different size classes based on the adjusted means and also shows cost ratios based on hatchery price structures, that at the time of writing did not vary between the size classes. Therefore on this basis, it is currently most cost effective to stock golden perch at 50–65 mm.

Table 2.8 GLM for golden perch stocking experiment. Constant + size at release + release strategy + dam name + sampling trips.

	d.f.	deviance	Mean deviance	Deviance ratio	Approx chi probability
Regression	9	415.66	46.1843	46.18	<.001
Residual	71	52.20	0.7353		
Total	80	487.86	5.8483		

Table 2.9 GLM of golden perch stocking experiment showing levels for the variate sampling trips and for factors compared to the reference levels size at release 20–30 mm, release strategy cover, Dam name Cassava.

Factor or variate	Estimate	t probability
Size at release 35–45 mm	1.329	<.001
Size at release 50–65 mm	2.328	<.001
Release strategy deep	0.964	<.001
Release strategy shallow	0.577	<.001
Dam name Gordonbrook	–8.8	0.687
Dam name Simpson’s	–11.6	0.606
Dam name Storm King	5.92	<.001
Dam name Tarong	7.31	<.001
Sampling trips	0.945	<.001

Table 2.10 Adjusted mean relative survival ratios of different size classes of golden perch compared with relative cost ratios based on current hatchery prices. The most cost effective size is in bold type for each paired comparison. An inverse survival ratio is shown in parentheses. Overall 50–65 mm is the most cost effective size to stock and 20–30 mm the least.

Size class comparison	Relative survival ratio	> or <	Cost ratio
50–65 mm: 35–45 mm	2.325 (0.430)	>	1
50–65 mm: 20–30 mm	8.107 (0.123)	>	1
35–45 mm: 20–30 mm	3.487 (0.287)	>	1

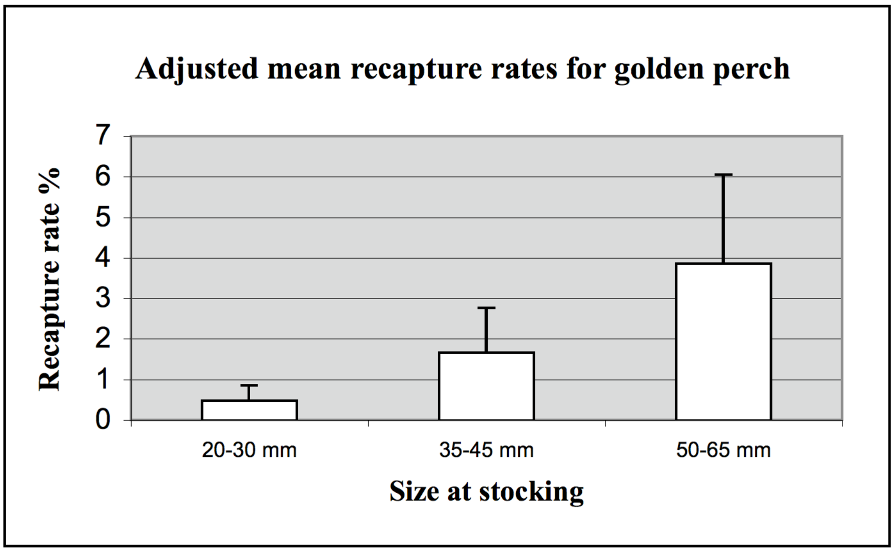


Figure 2.13 Adjusted mean recapture rates of golden perch stocked at different sizes. Values have been standardised by averaging over the levels for the factors 'dam name', and 'release strategy'. The value for the variate 'number of sampling trips' has been fixed.

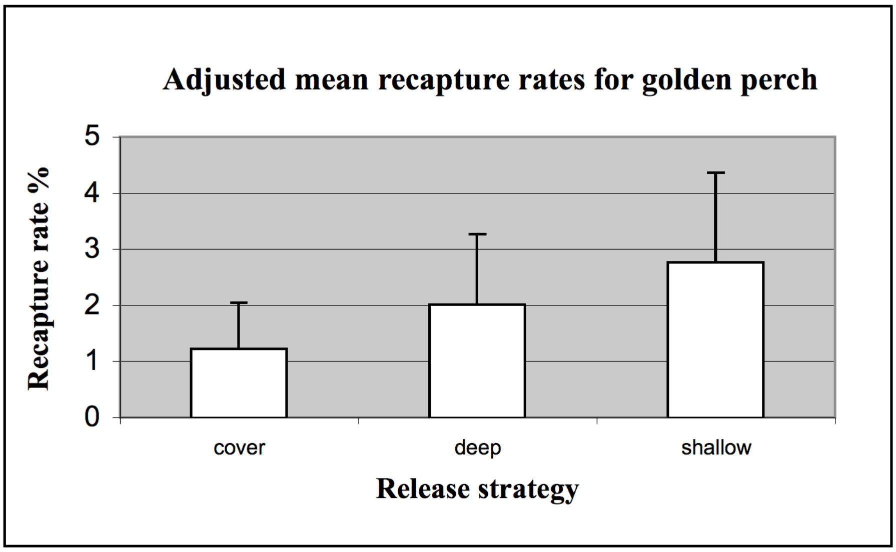
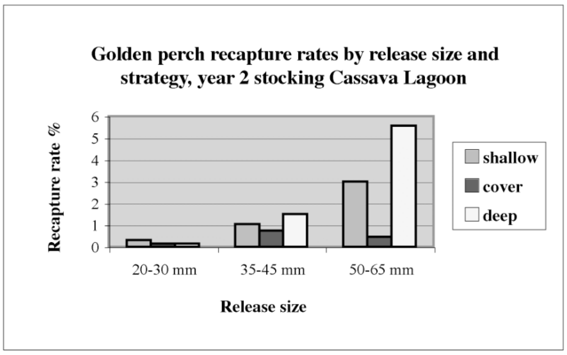
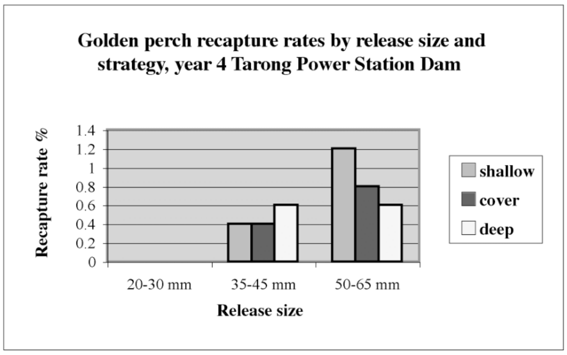


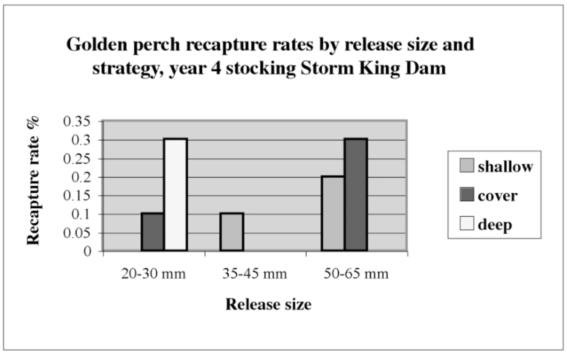
Figure 2.14 Adjusted mean recapture rates of golden perch released by different strategies. Values have been standardised by averaging over the levels for the factors 'dam name', and 'size at release'. The value for the variate 'number of sampling trips' has been fixed.



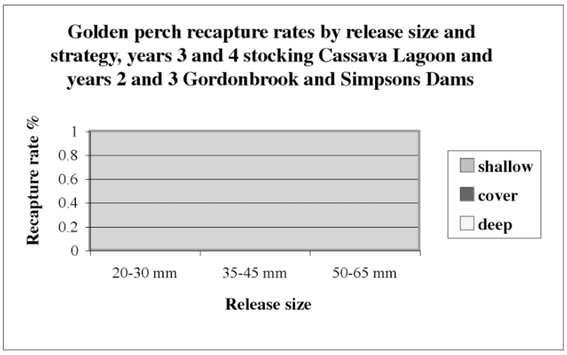
A



B



C



D

Figure 2.15 Recapture rates (as per cent of number stocked) of golden perch by release size and release strategy. Recaptures are shown in each dam by release year. A: Cassava Lagoon year 2. B: Tarong Power station Dam Year 4 C: Storm King Dam Year 4. D: Cassava lagoon years 3 and 4, Gordonbrook Dam Years 2 and 3 and Simpson’s Dam Years 2 and 3. Note zero catch rate across several dams and years.

2.2.4 Silver perch release size and release strategy

Figures 2.16 and 2.17 show adjusted mean recapture rates for silver perch by ‘size at release’ and by ‘release strategy’ respectively. Figures 2.15A to 2.15D show recapture rates for silver perch by ‘dam’ and ‘year’. For dams and years that silver perch were recaptured, 50–65 mm fish had the highest recapture rates. In Storm King Dam the recapture rates of 50–65 mm fish and 35–45 mm fish were equivalent. There were no recaptures of any silver perch stocked into Simpson’s Dam, Gooburrum Balancing Storage in Years 2 or 3 or into Cassava lagoon in Year 3.

The GLM containing the factors and variates ‘size at release’, ‘release strategy’, ‘dam name’ and ‘number of sampling trips’ was significant (see Table 2.11). The term ‘year’ was not run in the model due to aliasing with the term ‘number of sampling trips’. Running either term in the model gave similar results.

Analysis of the data by a GLM of binomial proportions showed that ‘release strategy’ had no significant effect on recapture rates of silver perch.‘Size at release’ had a significant effect with 50–65 mm fish and 35–45 mm fish recaptured at significantly higher rates than 20–30 mm fish (p<.001). Recapture rates at Storm King Dam and Tarong Power Station Dam were significantly different to those at Cassava Lagoon (p<.001 and p=.028) but recaptures at other dams were not significantly different to those in Cassava Lagoon (see Table 2.12). ‘Number of sampling trips’ was also a significant variate (p<.001) influencing recapture rates.

Overall, silver perch stocked at 50–65 mm were recaptured at higher rates than the other size classes. Table 2.13 shows relative survival ratios of the different size classes based on the adjusted means and also shows cost ratios based on current hatchery price structures. On this basis, it is currently most cost effective to stock silver perch at 50–65 mm.

Table 2.11 GLM for silver perch stocking experiment. Constant + size at release + release strategy + dam name + sampling trips.

	d.f.	deviance	Mean deviance	Deviance ratio	Approx chi probability
Regression	9	2742.8	304.755	304.76	<.001
Residual	70	300.7	4.296		
Total	79	3043.5	5.8483		

Table 2.12 GLM of silver perch stocking experiment showing significance levels for the variate ‘sampling trips’ and for factors compared to the reference levels size at release 20–30 mm, release strategy cover, Dam name Cassava.

Factor or variate	Estimate	t probability
Size at release 35–45 mm	0.7727	<.001
Size at release 50–65 mm	0.9134	<.001
Release strategy deep	–0.0731	0.330
Release strategy shallow	–.0556	0.459
Dam name Gooburrum	–11.0	0.286
Dam name Simpson’s	–11.0	0.294
Dam name Storm King	4.184	<.001
Dam name Tarong	1.934	<.001
Sampling trips	0.3581	<.001

Table 2.13 Adjusted mean relative survival ratios of different size classes of silver perch compared with relative cost ratios based on current hatchery prices. The most cost effective size is in bold type for each paired comparison. An inverse survival ratio is shown in parentheses. Overall 50–65 mm is the most cost effective size to stock and 20–30 mm the least. This table is based on a flat price rate for all three sizes.

Size class comparison	Relative survival ratio	> or <	Cost ratio
50–65 mm: 35–45 mm	1.098 (0.911)	>	1
50–65 mm: 20–30 mm	1.961 (0.510)	>	1
35–45 mm: 20–30 mm	1.786 (0.560)	>	1

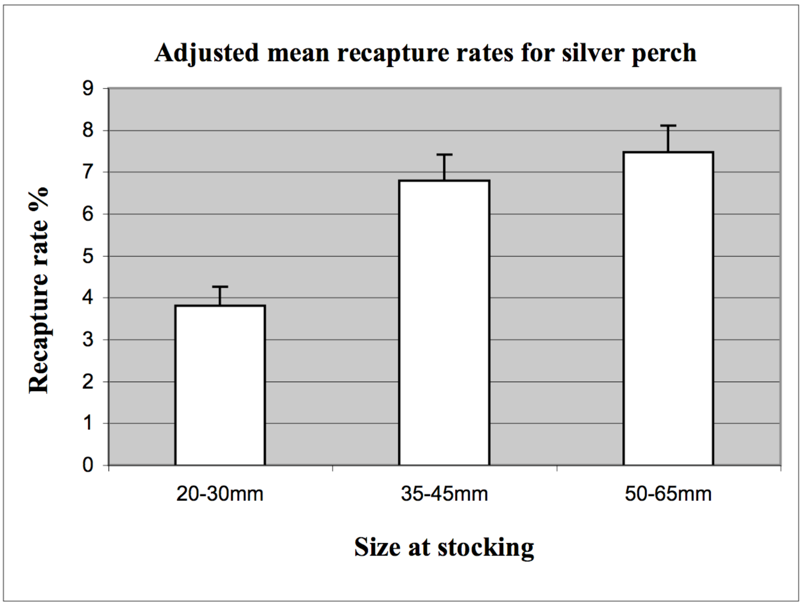


Figure 2.16 Adjusted mean recapture rates of silver perch stocked at different sizes. Values have been standardised by averaging over the levels for the factors ‘dam name’, and ‘release strategy’. The value for the variate ‘number of sampling trips’ has been fixed.

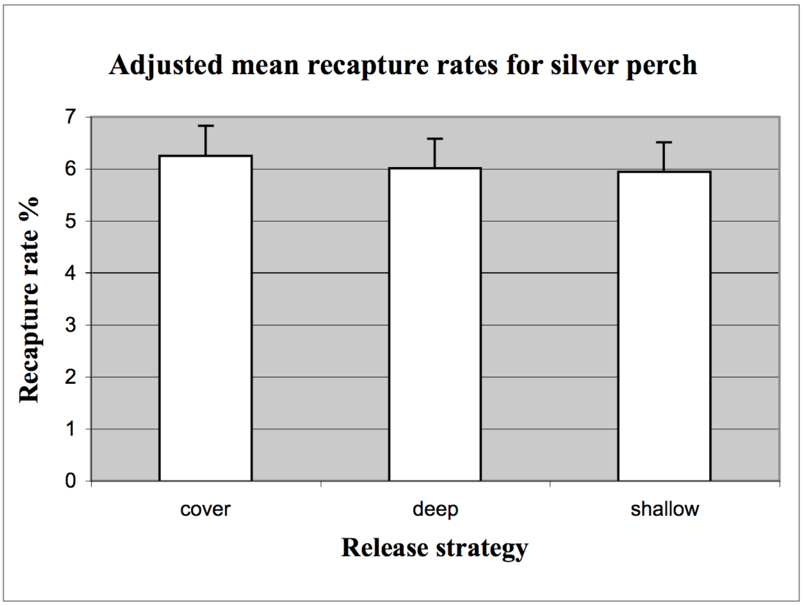
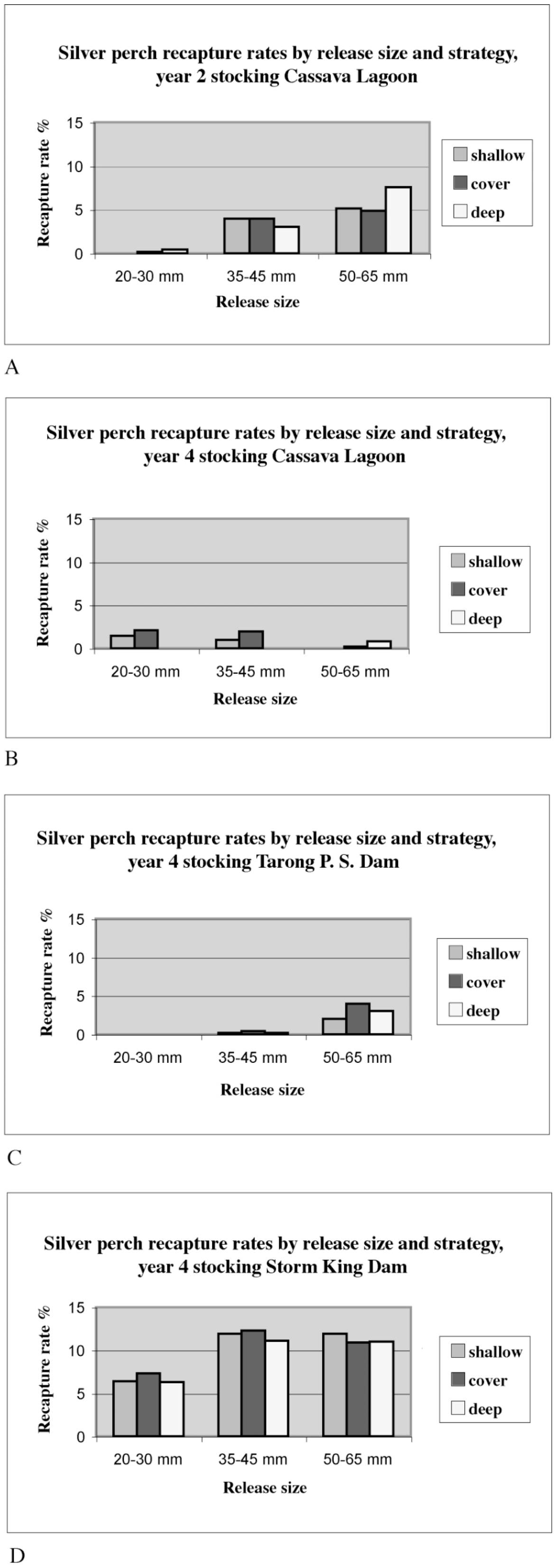


Figure 2.17 Adjusted mean recapture rates of silver perch released by different strategies. Values have been standardised by averaging over the levels for the factors ‘dam name’, and ‘release size’. The value for the variate ‘number of sampling trips’ has been fixed.


Silver perch recapture rates by release size and strategy, year 2 stocking Cassava Lagoon

Silver perch recapture rates by release size and strategy, year 4 stocking Cassava Lagoon

Silver perch recapture rates by release size and strategy, year 4 stocking Tarong P. S. Dam

Silver perch recapture rates by release size and strategy, year 4 stocking Storm King Dam

Figure 2.18 Recapture rates (as per cent of number stocked) of silver perch by release size and release strategy. Recaptures are shown in each dam by release year. A: Cassava Lagoon Year 2. B: Cassava Lagoon Year 4. C: Tarong Power Station Dam Year 4. D: Storm King Dam Year 4. Note, no silver perch were recaptured from Gooburrum Balancing storage or Simpson's Dam for release Years 2 and 3 or from Cassava Lagoon for release Year 3.

2.2.5 Growth

Figures 2.19 to 2.25 show the growth of Australian bass, silver perch, golden perch and barramundi in different years and different dams. In Queensland, the legal size for bass, golden perch and silver perch is 30 cm TL. For barramundi legal size is 58 cm TL. All species except bass showed potential to reach legal size in under 18 months. Given the poor survival of golden and silver perch in dams other than Cassava Lagoon in Years 2 and 3, and the poor survival of both species in Cassava Lagoon in Year 3, only limited comparisons between dams can be made for these species in Year 4.

Barramundi from Gooburrum Balancing Storage had the fastest growth rates, reaching legal size (58 cm) in just 14 months. Barramundi from Simpson's Dam grew much slower, and had still not attained legal size two years after stocking. A slowing of growth in winter was evident in barramundi — Figure 2.24 shows that stocking barramundi later in the season will lead to smaller size classes by winter than early season stockings. Slowing of growth in winter was less apparent in the other species. Winter minimum water temperatures in the dams varied between 12.5°C and 16.5°C.

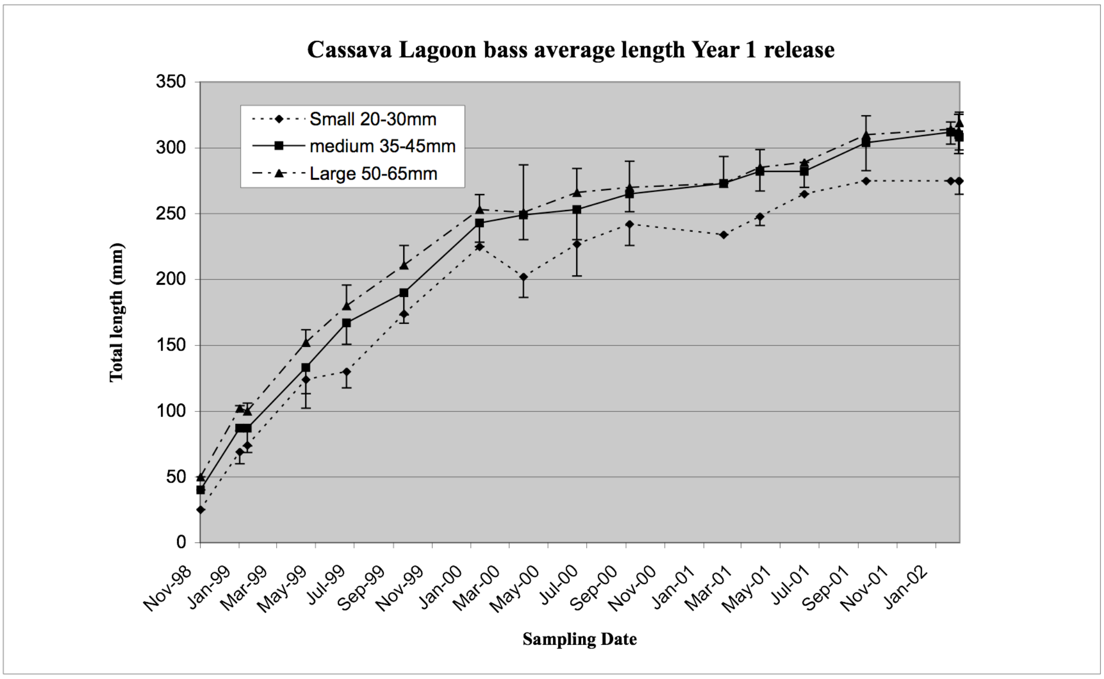


Figure 2.19 Mean total length at recapture (growth) of Australian bass released into Cassava Lagoon at 20–30 mm, 35–45 mm and 50–65 mm in Year 1 of the project. Error bars represent one standard deviation.

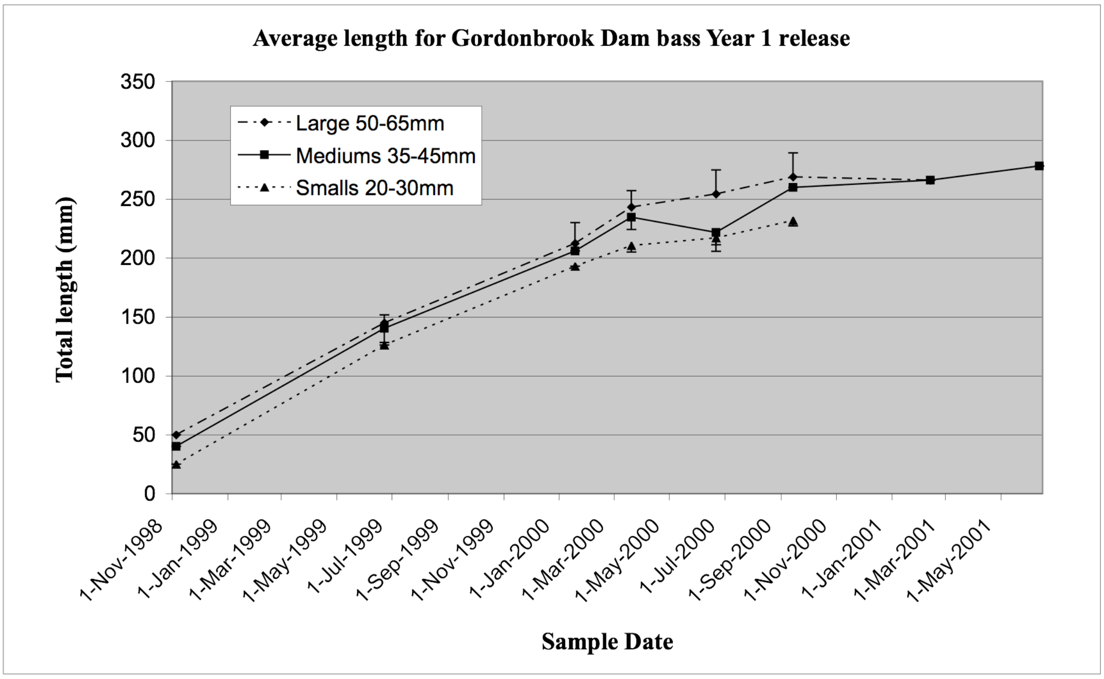


Figure 2.20 Mean total length at recapture (growth) of Australian bass released into Gordonbrook Dam at 20–30 mm, 35–45 mm and 50–65 mm in Year 2 of the project. Error bars represent one standard deviation.

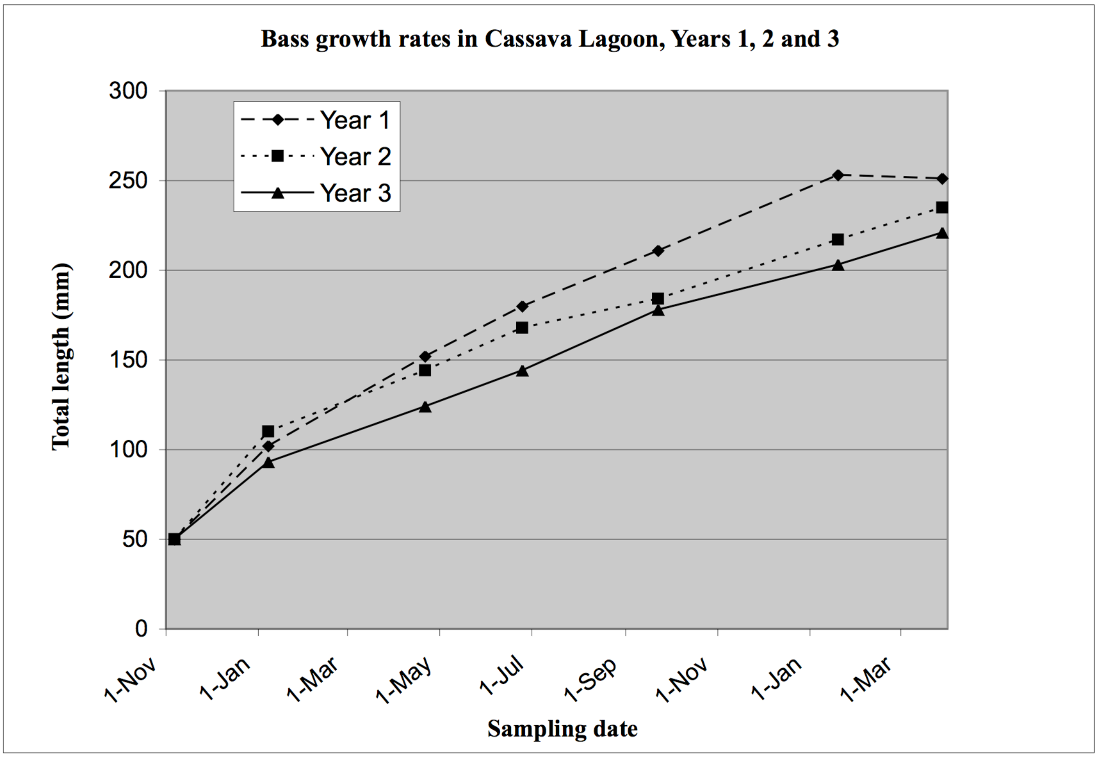


Figure 2.21 Comparison of growth rates of bass stocked at 50 mm into Cassava Lagoon in Years 1, 2 and 3 of the project.

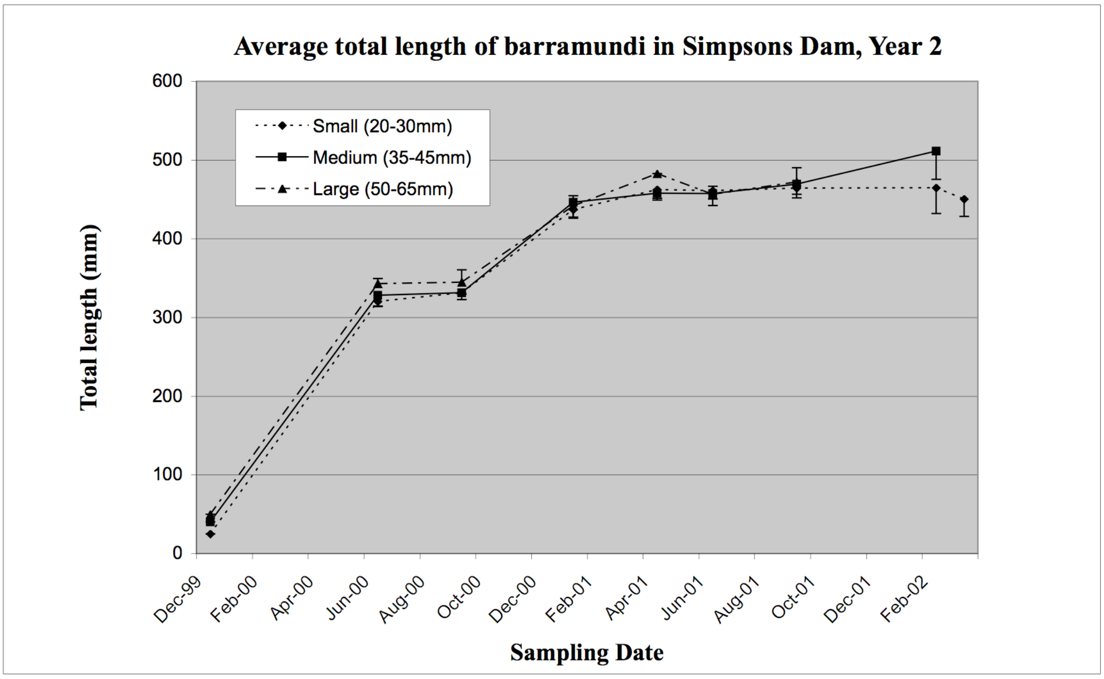


Figure 2.22 Mean total length at recapture (growth) of barramundi released into Simpson's Dam at 20–30 mm, 35–45 mm and 50–65 mm in Year 2 of the project. Error bars represent one standard deviation.

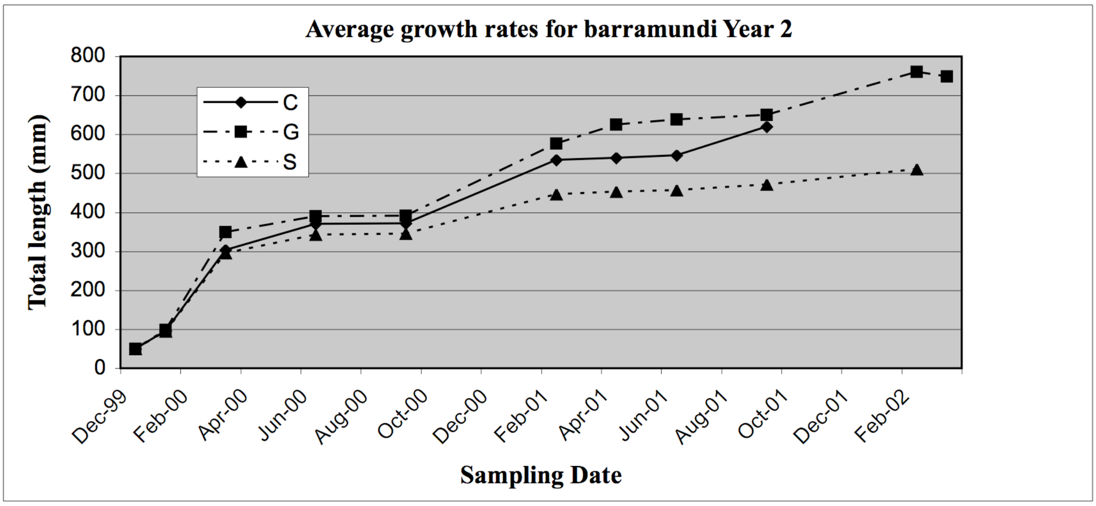


Figure 2.23 Comparison of growth rates of barramundi stocked at 50 mm into Cassava Lagoon (C) Gooburrum Balancing Storage (G) and Simpson's Dam (S) in Year 2 of the project.

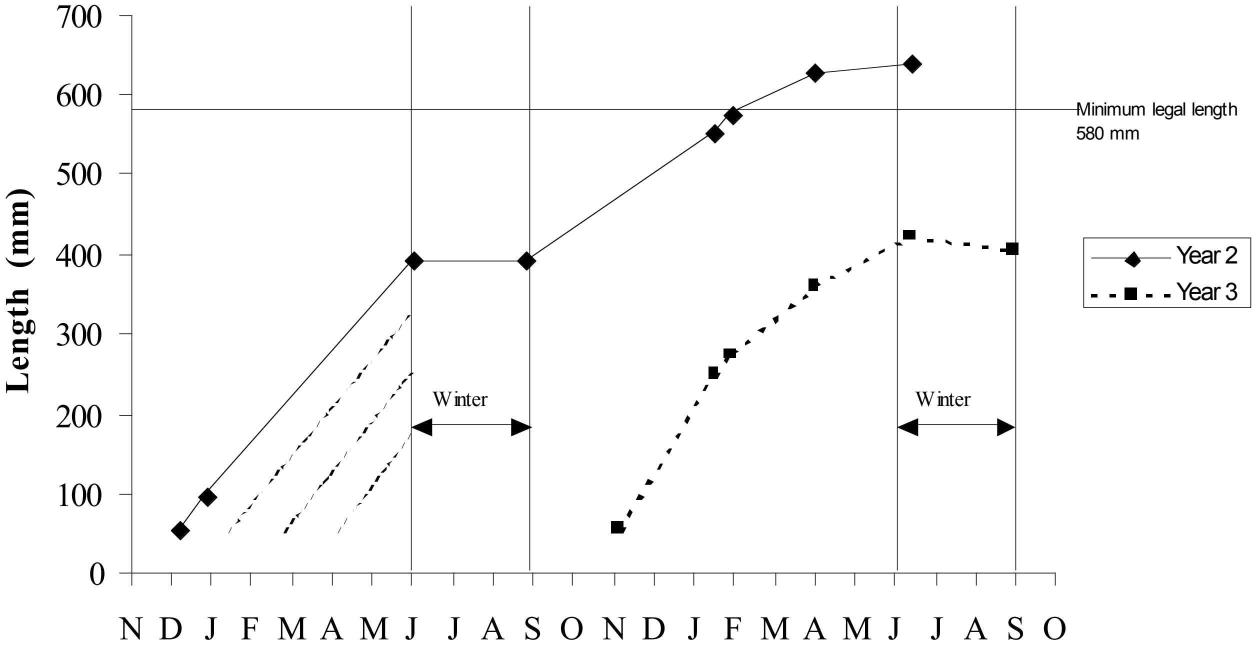


Figure 2.24 Growth rates of barramundi stocked at 50 mm into Gooburrum Balancing Storage in Years 2 and 3 of the project. Fine dashed lines show projected growth to winter of hypothetical later stockings. Note slowing of growth in winter of both the Year 2 and 3 stockings.

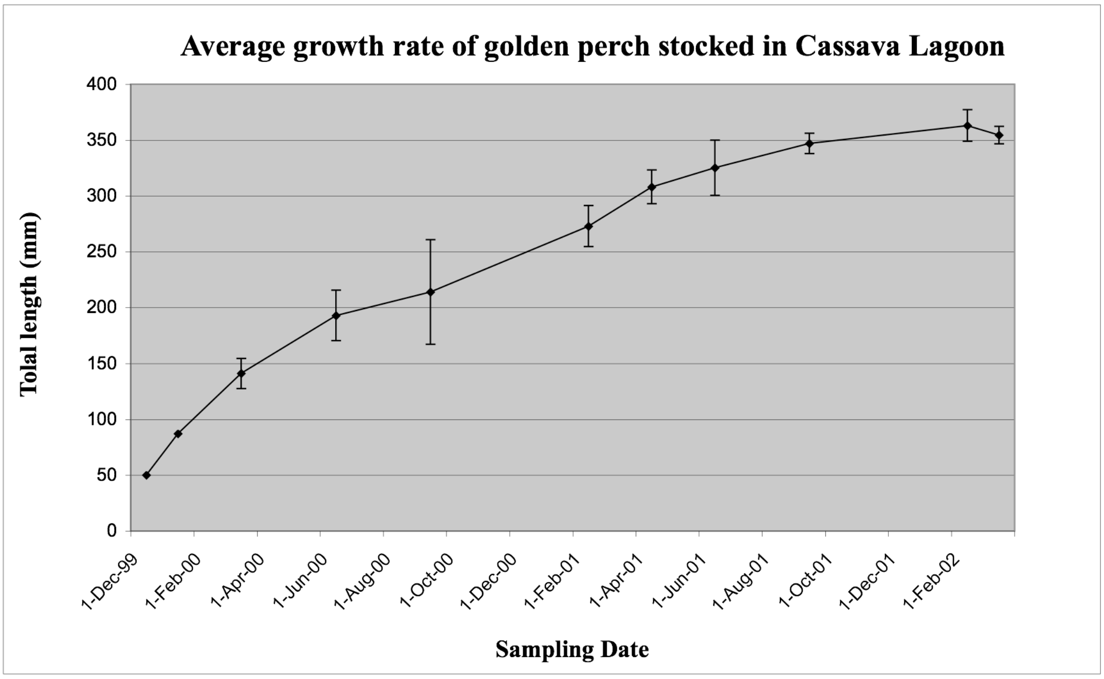


Figure 2.25 Mean total length at recapture (growth) of golden perch released into Cassava Lagoon at 50–65 mm in Year 2 of the project. Error bars represent one standard deviation.

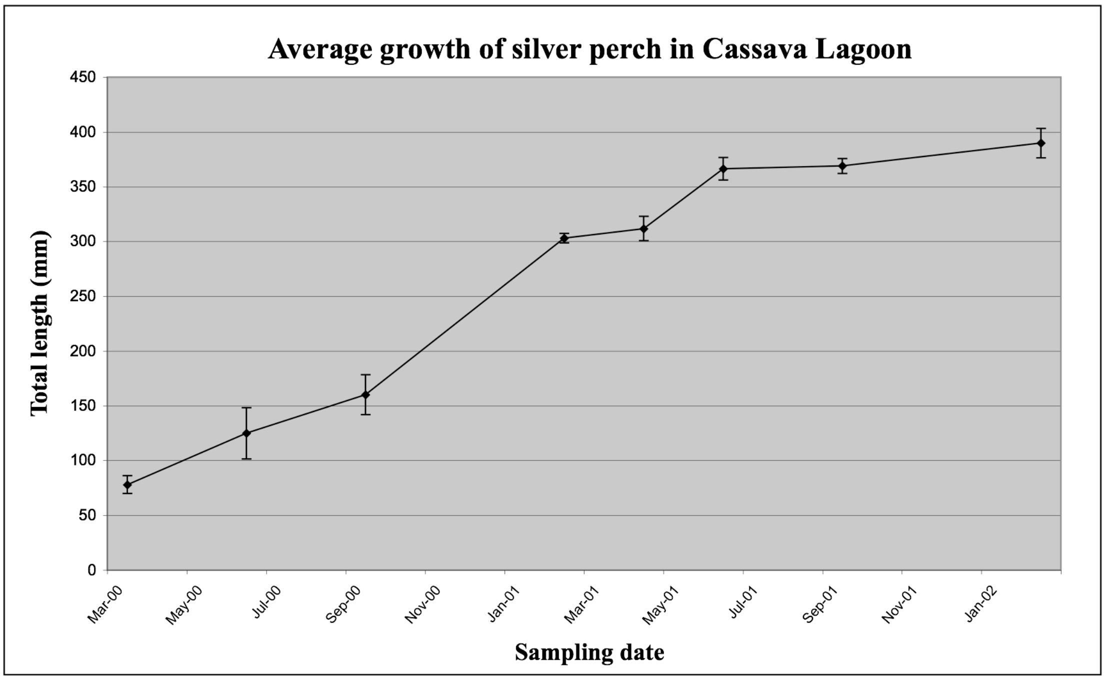


Figure 2.26 Mean total length at recapture (growth) of silver perch released into Cassava Lagoon at 50–65 mm in Year 2 of the project. Error bars represent one standard deviation.

2.3 Discussion

2.3.1 Stocking size

For all species, size at release was identified as a significant factor affecting survival. Overall the largest size class used in this study (50–65 mm) had the highest mean relative survival across all species. Adjusted mean recapture rates of fish stocked at 50–65 mm were between 2 and 8 times higher than those for the 20–30 mm size class and 1.1 to 2.3 times higher than those for the 35–45 mm size class. Nevertheless for each species there were considerable variations in actual recapture rates of the different size classes between years and dams (Figures 2.9, 2.12, 2.15 and 2.18).

A positive relationship between release size and survival is consistent with many overseas studies. For example, marine-stocking trials with red drum in Texas USA resulted in recapture rates more than three times higher for larger fish than smaller fish (Willis et al. 1995). Survival of mullet released into Hawaiian coastal waters in summer was skewed in favour of fish larger than 70 mm at the time of release (Leber 1995). Greater length at stocking also resulted in increased survival for muskellunge *Esox masquinongy* stocked in a New York Lake (McKeown *et al*. 1999) and for largemouth bass *Micropterus salmoides* stocked in experimental ponds (Miranda and Hubbard 1994).

Apart from a knowledge of which size classes survive best, an evaluation of the cost effectiveness of stocking a given size class is also important for a stocking program. For example research by Larscheid (1994) found walleye sac fry more cost effective to stock in a Minnesota lake than 100–150 mm walleye. Conversely Hoff and Newman (1995) found yearling trout more cost effective to stock than fingerlings in Wisconsin Lakes. For the four species trialled in this study, cost effectiveness of stocking is dependent on the current hatchery price structure, but relative survival of each size class enables stocking groups to estimate when price structures are favourable for stocking a particular size class.

In recent years, barramundi and Australian bass fingerlings have been priced on a per millimetre average length basis (e.g. a 50 mm fish would cost 50 cents if the price is set at 1c/mm). Golden and silver perch, on the other hand, have been sold at a set price irrespective of size, and both species are currently cheaper than bass and barramundi. The recommendations below are based on the relative survival of the three size classes of fingerlings (20–30 mm, 35–45 mm and 50–65 mm) of Australian bass, barramundi, golden perch and silver perch as compared to their relative cost at current hatchery prices.

Tables 2.4, 2.7, 2.10 and 2.13 compare the relative survival ratio and relative cost ratio between size classes for each stocked species. If the survival ratio is greater than the cost ratio, then the first of the two size classes being compared is the most cost-effective to stock. For example, in the comparison between 50–65 mm Australian bass and 35–45 mm bass (Table 2.4):

Survival ratio (S) = 1.16
Cost ratio (C) = 1.44
S<C, therefore it is more cost-effective to stock 35–45 mm bass.

The inverse relative survival ratio gives an indication of how cheap the smaller size class in a paired comparison would have to be before it became more cost-effective to stock that size class. So for the above example:

Inverse survival ratio = 0.862,

Therefore, 35–45 mm bass would have to cost less than 86.2% of 50–65 mm bass to be more cost-effective to stock compared to 50–65 mm bass. Obviously it would be preferable for the cost to be several percentage points lower to gain any real advantage.

Australian bass

As stated in the example above Australian bass of the 35–45 mm size class appear to be the most cost effective to stock based on current hatchery price structures (Table 2.4). A 35–45 mm bass currently costs approximately 70% the cost of a 50–65 mm bass and is therefore a good stocking option. Based on the mean relative survival ratios, 20–30 mm bass would need to be around 41% the cost of 50–65 mm bass, and 47% the cost of 35–45 mm bass, before they could be considered an equivalent stocking option to those larger size classes (Table 2.4). Currently 20–30 mm bass are not a viable stocking option. We consider 35–45 mm bass to be a more viable stocking option than 50–65 mm bass based on the assumption that stocking groups will spend a fixed amount of money rather than buy a fixed number of fingerlings. If groups spend a fixed sum of money then they can buy proportionately greater numbers of the 35–45 mm fish than the 50–65 mm fish.

Bass of all size classes did poorly in Simpson’s Dam. We suspect this was because of the presence of barramundi, which did not occur in the other dams where bass were stocked (see chapter 3). Cassava Lagoon and Gordonbrook Dam, where the stocked bass survived considerably better than in Simpson’s Dam, were also free of other predators like mouth almighty and fork-tailed catfish, which we found to prey on juvenile barramundi. We believe that the presence of these predators would have led to much lower survival of stocked bass. For these reasons, we recommend stocking bass of 50–65 mm or larger in dams with populations of predatory species. If dams have relatively few predatory species then 35–45 mm bass should be considered if their cost is no more than 80% that of 50–65 mm fish.

Barramundi

In most cases, the largest size class of stocked barramundi had the highest relative survival rate. The exception was in the first round of barramundi stocking (Year 2) into Cassava lagoon, where the 20–30 mm fish survived better than the two larger size classes (Figure 2.12). However, this trend was reversed in the subsequent year’s stocking. Hogan *et al.* (unpublished report 1991) also found that barramundi stocked at 20–30 mm into Copplerlode Dam near Cairns did as well as or better than larger size classes. However, the different size classes in that work were not released simultaneously as in the current study, with 20 mm fish being released in different months or seasons to other size classes. The 20 mm fish batch that showed the best survival in Copperlode Dam were those fish stocked earliest in the season (November) versus larger fish stocked in March or April. Research on other species has shown that stocking earlier in the season can improve chances of survival (Sutton *et al.* 2000, Leber et al. 1996, Leber *et al.* 1997).

Possible explanations for the apparent better survival of 20–30 mm barramundi in the first release into Cassava lagoon include:

(i) higher mortality of larger size classes due to greater transport stresses;

(ii) size-selective predation of the larger size classes by Australian bass or some other predator in the dam shortly after stocking.

We have no reason to suspect that the larger size classes of barramundi released into Cassava Lagoon in Year 1 suffered greater transport stresses than either the small size class, or than other barramundi released at any other time throughout this study. We believe it is more likely that size-selective predation may have contributed to the observed result. The only common predators in Cassava Lagoon were Australian bass and eels, either of which may have preyed selectively on larger barramundi fingerlings, while small fingerlings remained relatively undetected. The issue of species interactions and predation is explored in more detail in chapter 3.

Total recapture rates for barramundi were lower in Cassava Lagoon than in either Gooburrum or Simpson's Dams. No recaptures were made of any size class of barramundi stocked into Cassava Lagoon in Year 4. It is possible that the habitat characterisitics in Cassava Lagoon may have been less suitable for barramundi than in the other dams.

Excluding the one stocking event in Cassava lagoon, survival of 50–65 mm barramundi was always higher than that of the other two size classes. This difference from other size classes was most marked in Gooburrum Balancing Storage (Figure 2.12). This was the only dam in the stocking trials with mouth almighty and fork-tailed catfish (see chapter 3), both considered major predators of stocked fingerlings. Taking into account all the data, the predicted values from the GLM suggest that stocking 50–65 mm barramundi will produce the best results. Based on the current price structure of barramundi, 50–65 mm is also the most cost effective size to stock of the three size classes we trialled.

It is not unreasonable to expect that even better results may be achieved by stocking larger fish (e.g. 100 mm), particularly in tropical areas where the northern sub-species of mouth almighty grows much larger and where additional predatory fish species such as freshwater long tom occur. This is worthy of further research. Recent stocking trials by Russell (unpublished) have suggested that in the case of river stocking, the stocking of even larger barramundi (e.g. 300 mm) is an economically viable option. Growth rates of river barramundi are about one third that of impoundment fish, with river fish reaching legal size in three years (Rimmer and Russell 1998). Therefore river stocked barramundi are likely to remain at a size susceptible to predation much longer than impoundment stocked fish.

Golden perch

Recaptures of golden perch were highly variable between dams and years. In Gordonbrook Dam and Simpson's Dam, no golden perch were recaptured and it would appear that either survival was very low or fish were lost from these dams. In the case of Gordonbrook Dam it is possible that fish may have moved upstream out of the dam into the Stuart River, or downstream over the dam wall during a flood event. In Simpson's Dam, neither of these scenarios was possible, and we suspect that low recaptures of golden perch were largely the result of heavy predation by the resident barramundi population. The Year 3 stocking of golden perch into Cassava Lagoon was a failure, possibly due to low water levels (see chapter 3).

The only stocking of golden perch that produced a substantial number of recaptures was Cassava Lagoon, Year 2. Most of these recaptures occurred more than 12 months after the stocking. It is likely the behaviour of juvenile golden perch makes them less susceptible to capture. Post stocking surveys conducted by QFS staff have recorded few captures of golden perch until at least one year after stocking (Brooks and Hamlyn, Queensland Fisheries Service, pers. comm.). Nevertheless, stockings in Year 4 in Tarong Power Station Dam and Storm King Dam did produce recaptures of golden perch only two to three months after stocking, suggesting juveniles of golden perch may have been reasonably abundant in these two dams. Both of these dams are free of non-Murray Darling species, and it is possible that golden perch may not co-exist as well with species with which they have not co-evolved (see chapter 3). It is proposed that future sampling take place at Cassava Lagoon, Storm King Dam and Tarong Power Station Dam in 2003 to target golden perch at an age where they are likely to be more susceptible to capture.

The recapture data we have collected suggests that 50–65 mm golden perch survive better than the two smaller size classes. The poor recapture rates in some dams and years has increased the standard error of our results, but based on current hatchery price structures in Queensland, where hatcheries charge little, if any less in price for the smaller size classes, the 50–65 mm size class is the most cost effective to stock. Our results suggest that 35–45 mm golden perch would have to cost approximately 40% or less of the price of 50–65 mm fish (Table 2.10) before they could be considered in an impoundment stocking program. Given the variability of the recapture rates, until further recapture data becomes available it would be prudent to stock only the 50–65 mm size class.

Silver perch

Like golden perch, silver perch stockings appeared to fail in some dams and years. Silver perch were not recaptured from Simpson’s Dam or Gooburrum Balancing storage. We believe that predation by, or competiton with, some non-Murray-Darling species may have contributed (see chapter 3) to these failures.

The highest recapture rates of silver perch came from Storm King Dam in the Murray-Darling Basin. Overall trends suggest that 50–65 mm and 35–45 mm fish have higher survival than 20–30 mm fish. In Storm King Dam, where there are few predatory fish species other than golden perch and Murray cod, 35–45 mm fish did as well as 50–65 mm fish. In Cassava Lagoon which has a population of eels and bass and in Tarong Power Station Dam which has a population of spangled perch, 50–65 mm silver perch had the highest survival.

Based on the current hatchery price structure in Queensland, where there is little or no difference in price between 20–30 mm and 50–65 mm silver perch, it is best to stock 50–65 mm perch. If 35–45 mm fish drop in price below the level of 50–65 mm fish, then it is probably acceptable to stock 35–45 mm fingerlings if bass and spangled perch are absent from a dam. The issue of predation and species combinations is covered in more detail in the next chapter.

2.3.2 Release strategy

Contrary to our expectations, floating artificial cover appears not to have provided any significant survival advantage for the stocked fingerlings. The adjusted mean recapture rates for bass, silver perch and barramundi released into artificial cover were marginally higher than those for shallow and deep-water releases respectively, but the differences were not statistically significant. In the case of golden perch, the recapture rates of fish released into artificial cover were significantly lower than for the other two release strategies, but given the generally low recapture rates of golden perch in some dams and seasons, there must be some question as to whether or not this was biologically meaningful. If there was a real effect, then the possibility that predators wait outside the cover where fingerlings are clustered and prey on them as they emerge needs to be considered.

We had expected cover would confer a considerable advantage by providing a predator free refuge for fingerlings immediately after stocking. For example, Okumura (2002) found that use of artificial shelters enhanced the survival of stocked red spotted grouper. Brush shelters were also found to enhance the survival of stocked largemouth bass juveniles stocked into ponds containing predators (Miranda and Hubbard 1994). It is possible that our cover devices (each just under 2 cubic metres) were not large enough to have a significant effect. In the case of brush covers set in ponds for largemouth bass (Miranda and Hubbard 1994), the devices covered up to 26% of the area of the pond. However, increasing the number or size of cover devices would make their use less attractive or viable for fish stocking groups, as considerable effort would be required to transport and set up the devices.

For most of the release strategies there was considerable variation in the success of each strategy between size classes, dams and years, such that no statistically significant difference between release strategies could be detected overall.
In chapter 3 we explain some of the likely reasons for this variability. However, in the case of Australian bass, deep-water releases usually had less success, regardless of the size class, dam or year. Large adult bass school in the open mid-waters of impoundments, thus it is possible that adult bass may have been taking juvenile bass released into deep water. Adult bass were frequently captured in the course of this study near the deep water release zone in Cassava Lagoon. Therefore in the case of Australian bass we caution against releasing fingerlings into open deep waters of impoundments.

2.3.3 Dams and years

For all species, the GLM identified ‘dam’ as a significant effect on recapture rates. Dams served as pseudo-replicates in this work, as each dam had differences in habitat, species composition and temperature regime. The underlying causes of some of the differences in recapture rates between dams are explored in the next chapter.

For bass and barramundi, ‘year of release’ was also identified as a significant factor. Various conditions varied between years, including water level at time of stocking, and distribution of predatory species at the time of stocking. These factors are also explored in the next chapter. It is likely that similar variations between years would also influence the success of stocking silver perch and golden perch, but as we changed dams in year four (because of failed stockings in two out of three dams) we could not run the factor ‘year’ in the model without aliasing with the factor ‘dam’.

2.3.4 Growth

Growth of fish can be influenced by various factors, including temperature, food availability, salinity, oxygen, and intra and interspecific competition (Wootton 1990). Therefore one should not expect consistent growth rates between impoundments. Nevertheless the growth data collected in this work can provide a guide as to how soon fish could be expected to reach legal size and what effects timing of stocking may have on potential for survival and growth.

Australian bass

Australian bass had the slowest growth of the four species we stocked, reaching the legal size of 300 mm around three years after stocking. In exceptional circumstances bass have been known to reach legal size in 28 months (Hamlyn and Brooks 1992). Growth rates were slightly lower in Gordonbrook Dam than Cassava lagoon (Figures 2.19 and 2.20), and may relate in part to the lower winter minimum water temperatures in Gordonbrook Dam (12.5℃) compared to Cassava Lagoon (16.5℃). Growth rates of all three size classes appeared similar at first, with mean size differences between the three groups remaining approximately constant, but eventually in Cassava Lagoon the growth of fish stocked at 20–30mm began to lag behind that of the other two size classes. We speculate that one possible explanation is intra-specific competition for resources between the three size classes, with competitive advantage going in favour of the two larger size classes (Figure 2.19).

There is not much evidence of a winter slow down in growth rates. This may be due to the relatively mild winter water temperatures experienced in these two dams. Temperatures below 13℃ were only experienced for a few days in Gordonbrook dam, and temperatures were rarely below 17℃ in Cassava Lagoon. In more southern regions (e.g. NSW and Victoria) than in south-eastern Queensland we expect low winter growth would be evident and therefore annual growth less than in south-eastern Queensland.

Figure 2.21 is of particular interest as it shows a slowing of growth rates with subsequent stockings of bass in Cassava Lagoon. This could indicate early signs of overstocking and increased intra-specific competition for food. Alternatively, reduced growth rates may have been related to the general drop in water levels experienced during the course of this study, which acted to concentrate the fish and thereby effectively increase the stock density. Water levels were pumped critically low (2% full supply volume) in Cassava Lagoon in the period October 2000 to autumn 2001. A slowing of growth is evident in the bass population at that time (Figure 2.19), despite the fact that it spans the summer period when growth rates would normally be at their highest. The reduced area of the dam would be expected to have reduced total production and therefore food supply. Following filling of the dam in autumn an increase in growth rates is again evident. The importance of water levels to stocking success is explored further in the next chapter.

Bass growth data emphasise the importance of post-stocking monitoring. It is only by monitoring the growth and condition of stocked fish that managers can make informed decisions as to whether proposed stockings are likely to be beneficial to a fishery or not in a particular year.

Barramundi

Figure 2.22 shows the growth of the three size classes of barramundi stocked into Simpson's Dam in year two of the project. Compared to Australian bass, growth was rapid, and similar for all size classes, with fish reaching over 300 mm TL by the first winter. Growth then stalled in winter before increasing again to a fast rate over spring and summer. From late summer onwards until the end of the project growth was much slower. This may have been as a result of competition from subsequent stockings of barramundi (which showed similar early fast growth) and pre-existing populations of large barramundi and bass. Shrimp, gudgeons and hardyheads, suitable food for small barramundi, were relatively abundant in Simpson's Dam, but there were comparatively few forage species suitable for large fish. However, toward the end of the project we did note an increasing abundance of bony bream (*Nematalosa erebi*) in the dam, which may eventually lead to improved growth rates of stocked barramundi.

Again, we emphasise the importance of post-stocking monitoring. Our monitoring suggests that Simpson's Dam is near its maximum stocking capacity and further stocking is not recommended until growth rates of barramundi improve as a result of harvest of large fish or increased abundance of fodder species.

Growth rates of stocked fish will vary depending on the characteristics of the receiving environment. Figure 2.23 compares growth rates of barramundi in three dams. Growth was most rapid in Gooburrum Balancing Storage. This dam has relatively clear waters, with abundant weed growth and large populations of hardyheads, bony bream and snub-nosed garfish. Fish in this dam grew to 58 cm (legal size in Queensland) within 14 months of stocking. These rates are comparable to those recorded in north Queensland impoundments (Hogan, QFS, pers. comm.).

Growth rates of barramundi in the first few months were similar in all three dams, but declined in Simpson's Dam compared to the other two after the first winter. Growth was virtually zero in Cassava Lagoon from the summer of 2000–2001 until the end of winter. This was possibly due to the low water levels experienced in Cassava Lagoon (see bass above) during summer and then the effect of cooling during winter. Growth rates caught up with those in Gooburrum towards the end of the project and coincided with a boom in the snub-nosed garfish population in Cassava Lagoon.

Growth slowed to nearly zero during winter in all three populations of barramundi. Barramundi are essentially a tropical species and growth virtually ceases below 20°C. The winter minimum water temperatures logged in Cassava Lagoon, Gooburrum Balancing Storage and Simpson's Dam during the course of this project were 16.5°C, 15°C and 16°C respectively. Figure 2.24 gives an example of growth rates of juvenile barramundi stocked into Gooburrum Balancing Storage. Fish stocked in December of Year 1 grew steadily until the onset of winter, whereupon further growth virtually ceased until spring. A similar pattern can be seen with the fish stocked in November of Year 2.

The oblique dashed lines show hypothetical growth rates of barramundi stocked progressively later in Year 2. These suggest that fish stocked as late as April may remain at less than 200 mm throughout the winter period, and therefore remain highly susceptible to predation by fish and birds for a much longer period than fish stocked early in the season. We have recaptured barramundi stocked late in autumn into Awoonga Dam near Gladstone that had not attained any more than 100 mm TL by the end of winter, suggesting late autumn stockings may fare even worse in growth rates than is suggested by the projections.

Work by researchers overseas has also suggested that stocking early in the season improves the chances of survival (Sutton *et al.* 2000, Leber *et al.* 1996, Leber *et al.* 1997). Apart from reducing risks of predation, the other main advantage of stocking barramundi early in the growing season is that in productive impoundments they will reach legal size late the following summer. This is a time of the year when barramundi are active and easily caught by anglers. If stocking is delayed until later in the season, barramundi may not reach legal size until almost winter, when they become inactive and less available to anglers. Therefore, anglers must wait longer before seeing any returns from their stocking efforts. Similar low winter growth rates are likely for bass, golden perch and silver perch stocked in southern states, although winter slowing of growth in these temperate zone species is not as evident in coastal south-eastern Queensland, where milder mean winter temperatures are experienced.

Silver and golden perch

Silver perch and golden perch reached their legal size of 300 mm in 12 months and 16 months respectively. Only a small decrease in their growth rates was evident over the winter period. As suggested above, a more pronounced slowing of growth of these species is likely to occur in southern or inland areas where winter temperatures are more severe than in Cassava Lagoon. Consistent with the growth patterns of barramundi and bass, a slowing of growth is apparent in silver perch from Cassava Lagoon during the low water levels of the summer of 2000–2001. This pattern is not evident in the graph of golden perch growth, but is possibly masked by lack of golden perch captures during that summer period followed by good autumn growth rates.

2.3.5 Key recommendations and findings

1. Fish stocked at 50–65 mm have higher relative survival rates than fish stocked at 35–45 mm or 20–30 mm in the majority of cases.
2. It can be more cost effective to stock 35–45 mm Australian bass and silver perch in dams with low diversity or abundance of predators (for further details see next chapter).
3. If in doubt stock 50–65 mm fingerlings.
4. Shallow water releases around lake margins will suffice for all species.
5. Outcomes will vary between impoundments and years (see next chapter for further details).
6. Stock as early in the season as possible to maximise growth during the summer period and minimise risk of predation over the winter period.
7. Monitoring growth rates post-stocking is important in order to avoid future overstocking or stocking during periods when fish populations are under stress.

Chapter 3: Predation and other factors that may influence the success of stocking

Objective

Identify differences between impoundments that may influence the survival and growth of fish stocks.

3.1 Methods

This chapter deals with biotic and abiotic factors that may influence the success of stocking activities, including outcomes for different release sizes and release strategies.

3.1.1 Predation experiments

Predation experiments were initially set up in response to concerns by stocking groups that fork-tailed catfish (*Arius* spp) and mouth almighty (*Glossamia aprion*) may severely impact on the survival of barramundi fingerlings. These two predators are prevalent in many dams where barramundi are stocked. Both fork-tailed catfish and mouth almighty occur in Gooburrum Balancing Storage, as do several other potential predators, including long-finned eels, spangled perch and barred grunter. Barramundi that were stocked in the early stages of this study also became potential predators of later stocked barramundi. For these reasons, Gooburrum Balancing Storage was selected as a site to conduct predation experiments on stocked barramundi fingerlings. The predation experiments also provide supporting evidence for the approach outlined in 3.1.2 on page 45.

Field procedures

Experiments were conducted to compare the amount of predation — shortly after release — on different size classes of barramundi stocked by different strategies. Predation experiments for barramundi were run three times over a three-year period. They were conducted on the same day as the release of barramundi fingerlings into Gooburrum Balancing Storage as outlined in chapter 2. Coded wire-tagged barramundi fry of three size classes (20–30 mm, 35–45 mm and 50–65 mm) were released into deep water, shallow water and into floating artificial cover (see chapter 2). The deep-water release site was marked with a buoy and also recorded as a global positioning system (GPS) waypoint at time of release.

Approximately two hours after release of fingerlings, potential predators were collected within 50 m of each release point by electrofishing and gill netting. Sampling continued for approximately four hours. Captured predators were put into an ice slurry immediately after capture. When torpid, the fish were transferred into plastic bags, dated and labelled according to the catch zone, and the bags returned to the ice slurry. As well as euthanasing the fish, the ice slurry acted to slow or stop digestive processes so that any recently ingested stomach contents remained recognisable. Predator samples were kept in ice until return to SFC, where they were stored in a blast freezer at –20°C until ready for processing.

Following failure to recapture any of the silver perch stocked into Gooburrum Balancing Storage in 1998 and 1999 (see previous chapter), it was thought that predation by species with which they do not naturally co-exist in the Murray-Darling Basin — particularly Australian bass and barramundi — may have been reducing their numbers. To investigate this, a silver perch predation experiment was carried out in the 2000–2001 stocking season using the same protocol as for the barramundi experiment described above. In the 2001–2002 stocking season, the predation experiment was expanded to look at predation of newly stocked golden perch and silver perch in Cassava Lagoon.

Analyses of stomach contents

The focus of stomach contents analysis was the presence of stocked fingerlings; however, data on other items present in stomachs were also recorded. Analysis of stomach contents was conducted as follows.

1. Frozen specimens were rapidly thawed under running water, then transferred to an ice bucket.
2. Each predator was identified, total length recorded and stomach removed with surgical scissors. Zone of capture was recorded on a data sheet.
3. Stomachs were classified as empty, ¼ full, ½ full, full or distended. Points were allocated to each stomach as per Hynes (1950).
4. Stomachs were cut open with surgical scissors and the contents emptied into a Petri dish with water for identification, counting and scoring.
5. Invertebrates were classified to order or family level and occasionally to genus or species level if they were well-known species. Fish were classified to species level where possible, and the stocked species (target of the experiment) were classified by size and release location. Release location was determined by colour and/or position of micro-tags (see chapter 2 for details).
6. All individual items in a stomach were counted (e.g. two Atyid shrimp, four *Hypseleotris* sp)
7. Each category of item was scored by the points method as outlined by Hynes (1950) with minor modifications as described by Hutchison (1991a). The points method gives an approximate volumetric estimation of each group of items in a gut.
8. Categories of items were also recorded by per cent frequency of occurrence in the number of guts examined for each predatory species.

The predation experiments provide supporting evidence for the approach outlined in 3.1.2 below.

3.1.2 The effects of selected biotic and abiotic factors on stocking success and growth

In each impoundment used for the stocking strategies experiments (chapter 2), the following data were recorded: water temperature (see 3.1.3), water level at time of stocking, relative abundance of potential predator and prey species (including other stocked species) and a range of habitat variables.

We collected water temperature data using a tidbit data logger. These data were also supplemented where possible with readings from the authority responsible for the water body. The water level at the time of stocking was rated on a five-point scale based on the % surface area full supply level. Predator and prey species were given ordinal values between 0 and 3, where 0 indicated a species was absent or not encountered, 1 present but rare, 2 moderately common, and 3 common. Rare species (1) were encountered on 25% or less of sampling trips in a given year, or less than two individuals were encountered on any trip. Moderately common species (2) were encountered on 50% or more of trips, or between 3 and 30 individuals were encountered per trip. Common species (3) were encountered on 100% of trips, or more than 30 individuals were encountered on at least 50% of trips.

Ratings for most species were based on estimated frequency of observation during electrofishing activities and catch rates during gill netting. Ordinal data were used because the main focus of electrofishing and netting activities was the recapture of tagged individuals. Precise recording of abundance of other species would have been too time consuming. For some smaller predator species (e.g. mouth almighty) and prey species, abundance levels were also based on trapping results (mean catch/trap effort) and converted to ordinal data in the same way as the netting and electrofishing data. Six traps were set randomly around the margins of the dam in one to two metres depth of water. Traps were set one hour before sunset and pulled approximately six hours after sunset.

Other data obtained for each dam were full supply surface area, maximum depth, relative proportion of edge substrates, proportion of in-storage woody debris cover within 10 m of banks (absent = 0, 1–5% = 1, 5–20% = 2, > 20% = 3), estimated proportion of shoreline with emergent vegetation at typical water levels (absent = 0, 1–25% = 1, 25–50% = 2, >50% = 3) and estimated modal width of emergent vegetation. Most variables were broken into categories and given ordinal values.

For a complete listing of variables and their types see Table 3.1.

3.1.2a Factors affecting relative survival of stocked fish

In chapter 2, ‘dam name’ and ‘year’ were identified as significant factors influencing the relative recapture rates of all four species. In this chapter, ‘dam name’ and ‘year’ are substituted for a range of other biotic and abiotic variables that characterise each impoundment. Statistical tests are used to identify which of these biotic and abiotic variables may have contributed to between-impoundment and between-year differences in relative survival/recapture rates of the different species and size classes stocked. The variables tested were those relating to water levels, predatory species and habitat features.

Statistical analyses

Screening of all variables was done in Genstat™ by forward stepwise multiple linear regression, with per cent recaptures of the stocked fish (recaptures/number stocked*100) as the dependent variable. In the first instance, stepwise regression was used to select variables without any forcing of variables into the regression. In cases where aliasing between variables was evident, various alternative models were progressed by stepwise multiple regression by removing alternate aliased variables of interest from the starting group of variables. For example, if variable A and B were found to be aliased, the regression was run first by excluding A and then excluding B from the starting set of variables.

Table 3.1 Variables used to assess for potential impacts on relative survival of stocked fingerlings and/or growth. # Denotes potential predators and *denotes potential prey species**.** Potential predators are also potential prey for stocked species sometime after stocking.

Variable	**Type of variable: continuous, ordinal or category**
Number of sampling trips	continuous
Size at release	category
Release strategy	category
Dam full supply surface area	continuous
Maximum depth	continuous
Maximum winter temperature °C	continuous
Maximum summer temperature °C	continuous
Minimum winter temperature °C	continuous
Minimum summer temperature °C	continuous
Water level at time of stocking	ordinal
Relative abundance of spangled perch #	ordinal
Relative abundance of *Tandanus #*	ordinal
Relative abundance of mouth almighty #	ordinal
Relative abundance of Australian bass #	ordinal
Relative abundance of barramundi #	ordinal
Relative abundance of silver perch #	ordinal
Relative abundance of golden perch #	ordinal
Relative abundance of long-finned eels #	ordinal
Relative abundance of fork-tailed catfish #	ordinal
Relative abundance barred grunter #	ordinal
Relative abundance of turtles #	ordinal
Relative abundance of *Hypseleotris* spp *	ordinal
Relative abundance of flatheaded gudgeon *	ordinal
Relative abundance of smelt *	ordinal
Relative abundance of hardyheads *	ordinal
Relative abundance of bony herring *	ordinal
Relative abundance of snub-nosed gar *	ordinal
Relative abundance of rainbowfish *	ordinal
Relative abundance of ambassids *	ordinal
Relative abundance of *Gambusia* *	ordinal
Relative abundance of Atyid shrimps *	ordinal
Relative abundance of *Macrobrachium* prawns *	ordinal
Prop. edge with fringing emergent vegetation	ordinal
Fringing emergent vegetation modal width m	continuous

Proportion of edge with woody debris	ordinal
Woody debris complexity	ordinal
Prop. of edge with submerged macrophyte	ordinal
Submerged macrophyte density	ordinal
Submerged macrophyte maximum depth m	continuous
Macrophyte height m	continuous
Proportion of edge with floating macrophyte	ordinal
Floating macrophyte density	ordinal
Proportion of shoreline with treed edge	ordinal
Modal treed edge width	continuous
Proportion of water with standing timber	ordinal
Standing timber density	ordinal
Proportion of rocky shoreline	ordinal

Following the above procedures, species identified as potentially significant predators of stocked fingerlings were forced into the model (unless already selected previously) along with the term ‘release size’. ‘Release strategy’ was also forced in the model for species for which it had been identified as significant in chapter 2. The stepwise multiple linear regression was then run again to assist screening of variables that may help explain the differences in relative survival identified in chapter 2. Aliasing of variables was treated as outlined in the previous paragraph.

Variables identified as potentially significant by the above screening process were then used in generalised linear models of binomial proportions with a logit link function (Genstat™). This method calculates actual recaptures as a proportion of the number of fish stocked in each category. Several alternative maximal models were run including models using variables selected without any forcing and models using forced variables identified as significant. Alternate models were also run to account for aliasing of variables as outlined above. The significance of main effects and interactions in the model was assessed by a forward stepping procedure. Significant main effects and interactions were kept in the model. Other factors were rejected. Adjusted mean recapture rates determined from the various alternative models were calculated using the predict function. Mean proportions and standard errors calculated using this function were adjusted for the effects of other terms in the model.

3.1.2b Factors affecting growth

Potential factors (temperature, abundance of prey species and intra specific competitors) that may have affected the growth of bass and barramundi in the different dams were assessed using forward stepwise multiple linear regression. Factors affecting silver perch and golden perch growth were not assessed as all of the data on these species in the first three years of the study came from Cassava Lagoon. In Year 4, even though silver and golden perch were stocked at alternative sites, insufficient time elapsed from time of stocking to final field sampling to adequately assess growth of golden and silver perch and winter minima temperature effects.

Table 3.2 Transformations of continuous variables used in the assessment of factors affecting growth of stocked species.

Variable	**Transformation**
Maximum winter water T	none
Minimum winter water T	none
Maximum summer water T	none
Minimum summer water T	none
CPUE bass	Log10+1
CPUE barramundi	SQRT
CPUE golden perch	SQRT
CPUE silver perch	Log10+1

The dependent variable ‘growth’ was expressed as mean recorded length at six months and at 12 months after stocking. Independent variables that were assessed and are listed in Table 3.1 included the continuous variables ‘minimum winter water temperature’, ‘maximum winter water temperature’, ‘minimum summer water temperature’, ‘maximum summer water temperature’ and the ordinal variables for the relative abundance of the various prey species. In addition to those variables listed in Table 3.1, the density of intraspecific and potential interspecific competitors based on CPUE data from our sampling trips were also included in the analyses. All continuous variables were checked for normality. Those that were not normally distributed were log or square root transformed as appropriate (see Table 3.2).

3.1.3 The relationship between success of past stocking programs and impoundment characteristics

The effects of impoundment characteristics on stocking success were also investigated across a wider range of impoundments and a wider geographical area using past DPI Fisheries fish stocking data, DPI post-stocking survey data and data on the water quality and physical characteristics of the impoundments. This was done to supplement information from our own stocking experiments (see 3.1.2) and to generate preliminary hypotheses and preliminary recommendations about the types of impoundments that suit different species.

Data used

Water quality data and impoundment physical characteristics data (including impoundment areas, volumes and mean depths) were sourced from the Department of Natural Resources and Mines, South-East Queensland Water and other organisations responsible for water supply and water quality. A major problem with the water quality data is that different variables have been collected for different dams and by different organisations. The number of variables recorded in common is relatively few, and insufficient data was available for many locations. Therefore, analyses were restricted to some of the more basic water quality parameters (See Table 3.3).

DPI Fisheries (currently QFS) officers have conducted post-stocking surveys of dams throughout Queensland since the state’s impoundment stocking program began in the 1980s. These surveys provide CPUE data on stocked species. The main survey methods used by DPI&F have been gill netting and electrofishing. Gill net types have not been consistent between regions; consequently only electrofishing CPUE data is assessed in this report. These surveys have also provided data on the presence of potential predators and prey of the stocked species. CPUE data would have been preferable for an analysis of the effects of these species, but methods of data collection have varied between locations. Therefore only presence—absence data has been assessed in this report. Reports from which the CPUE and presence absence data have been derived are listed in the Appendix.

Statistical analyses

All continuous variables were checked for normality. Variables that did not fit a normal distribution were log or square root transformed as appropriate. Variables were screened by stepwise multiple linear regression to produce a final multiple linear regression model for each of the four key stocked species (barramundi, Australian bass, silver perch and golden perch). Data on physical characteristics and prey species were available from all sites assessed in post-stocking survey reports. However, as noted above, water quality data was not available for all sites.

Table 3.3 Variables used in the assessment of the effect of impoundment characteristics on the stocking success of four key species (see four dependent variables). Not all independent variables were run with each dependent variable. For example, ‘CPUE sooty grunter’ (a northern species) were excluded from regressions where CPUE bass/5 year stocking rate ha was the dependent variable, as bass are not stocked into areas where sooty grunter occur. Independent variables for CPUE of each stocked species were only run in the regressions in which the dependent variable was not of the same species. For example, ‘CPUE bass’ was entered in regression models when ‘CPUE of barramundi’ was the dependent variable, but not when ‘CPUE bass/5 year stocking rate ha’ was the dependent variable in the model.

Variables	**Type**	**Transformations**
Dependent variables		
CPUE barramundi	continuous	SQRT
CPUE bass/5 year stocking rate ha	continuous	SQRT
CPUE golden perch/5 year stocking rate ha	continuous	SQRT
CPUE silver perch/5 year stocking rate ha	continuous	SQRT
Independent variables		
Silver perch 5 year stocking rate/ha	continuous	none
Golden perch 5 year stocking rate /ha	continuous	none
Barramundi 5 year stocking rate/ha	continuous	none
Bass 5 year stocking rate/ha	continuous	none
Sooty grunter 5 year stocking rate/ha	continuous	none
CPUE sooty grunter	continuous	SQRT
CPUE barramundi	continuous	SQRT
CPUE bass	continuous	SQRT

CPUE silver perch	continuous	SQRT
CPUE golden perch	continuous	SQRT
Minimum conductivity mS	continuous	SQRT
Maximum conductivity mS	continuous	Log10
Median conductivity mS	continuous	Log10
Minimum pH	continuous	Log10
Maximum pH	continuous	Log 10
Median pH	continuous	none
Minimum turbidity NTU	continuous	Log 10
Maximum turbidity NTU	continuous	Log 10
Median turbidity NTU	continuous	Log 10
Impoundment surface area ha	continuous	Log 10
Impoundment volume 1000 MgL	continuous	Log 10
Mean depth m	continuous	none
Fork-tailed catfish	presence-absence	NA
Spangled perch	presence-absence	NA
Mouth almighty	presence-absence	NA
Long-finned eel	presence-absence	NA
Freshwater long tom	presence-absence	NA
Tarpon	presence-absence	NA
Sleepy cod	presence-absence	NA
Mary/Murray cod	presence-absence	NA
Barred grunter	presence-absence	NA
Bony bream	presence-absence	NA
Rainbow fish spp	presence-absence	NA
Hardyhead spp	presence-absence	NA
Hypseleotris spp	presence-absence	NA
Smelt	presence-absence	NA
Snub-nose gar	presence-absence	NA
Ambassid spp	presence-absence	NA
Atyid shrimp	presence-absence	NA
Macrobrachium prawn	presence-absence	NA
Cherax crayfish	presence-absence	NA

For this reason analyses were first run for only those sites with data available for all variables and then run again for all sites but excluding water quality variables.
If water quality variables were not selected in the first stepwise procedure then only the results of the second procedure are presented. For a list of all variables used in the analyses see Table 3.3. The dependent variable in each model was ‘recapture rate’ (CPUE as fish caught per minute of electrofishing) expressed as a proportion of the mean stocking effort per hectare over the preceeding five years. However, in the case of barramundi, stocking rates were so low in some lakes it was considered inappropriate to express catch rates in this way. A zero catch rate could have been simply a function of low levels of stocking rather than poor survival. For this reason in the case of barramundi the dependent variable was ‘barramundi CPUE’ and ‘rate of stocking’ was forced into the model as an explanatory variable.

3.2 Results

3.2.1 Predation experiments

Barramundi

Predation experiments from 1999 and 2000 confirmed spangled perch, mouth almighty, fork-tailed catfish, and to a lesser extent barred grunter, to be predators of stocked barramundi fingerlings (Figures 3.1 and 3.3). Total numbers of barramundi found in the stomachs of predators were relatively low, but probably only a small proportion of the predators near the release sites were captured. The 2001 barramundi predation experiment recorded no predation on stocked fingerlings. Only 50–65 mm fish were stocked in 2001 and fewer predators were captured near the release sites than in previous seasons. No barramundi fingerlings were ever found in the stomach contents of *Tandanus tandanus,* barramundi or long-finned eels. However, a total of only seven eels were collected for stomach contents examination. That eels are piscivores was confirmed in the golden and silver perch predation experiments (see below). *Tandanus tandanus* showed no evidence of piscivory, with stomach contents consisting mainly of molluscs, aquatic insects and crustaceans. The single barramundi stomach examined in 2000 contained fish of various species but no barramundi.

Barred grunter were the most abundant potential predator in our catches, comprising 27 and 33 individuals in 1999 and 2000 catches respectively. This species was not collected in 2001, as its mouth gape was considered too small to consume the 50–65 mm size class of barramundi stocked in that year. Only one barramundi fingerling (20–30 mm) was found in the stomach of a barred grunter in 1999, and none in 2000. Overall for barred grunter, barramundi comprised less than 2% of the stomach contents by volume and were found in less than 4% of the stomachs sampled. Approximately 75% by volume of the stomach contents of barred grunter was filamentous algae.

Seventeen barramundi fingerlings were recovered from the stomach contents of eight fork-tailed catfish examined in 1999, and none from the single fork-tailed catfish caught in 2000. Twelve of the barramundi fingerlings were fish that had been released in deep water, and five had been released in cover. All the fork-tailed catfish were captured in the vicinity of the deep water stocking site. The lowest recapture rates of barramundi stocked in 1999 were fish released in deep water (Figure 3.2), whereas deep water releases returned the highest recapture rate in 2000 (Figure 3.4).

Barramundi comprised approximately 40% by volume of mouth almighty stomach contents in 1999 and 2000 and were found in just over 15% of stomachs examined in 1999 and in 10% of stomachs examined in 2000. All fingerlings recovered from mouth almighty stomachs were fish released in shallow water. All size classes of stocked barramundi fingerlings were found in mouth almighty stomachs (n=19) in 1999, but only the 35–45 mm size class of fish were recovered from mouth almighty stomachs (n=30) in 2000. No 50–65 mm fish were found in mouth almighty stomachs (n=11) in 2001.

Barramundi recovered from the stomachs of spangled perch came from both shallow water and artificial cover release sites. All size classes of stocked barramundi were found in spangled perch stomach contents in 2000 but only the 20–30 mm size class were recovered in 1999. No 50–65 mm barramundi were found in spangled perch stomachs (n=13) in 2001

Silver perch

The 2001 silver perch predation experiment in Gooburrum Balancing storage confirmed barred grunter, mouth almighty, long-finned eels and barramundi of the 251–400 mm size class as predators of stocked silver perch fingerlings (Figure 3.5). No silver perch were found in the stomachs of larger barramundi 401–600 mm (n=9), spangled perch (n=10) or fork-tailed catfish (n=4). Spangled perch did contain other fish species in their guts (50% by approximate volume) as did fork tailed catfish (55% by approximate volume) and larger barramundi (97.5% by approximate volume). All confirmed predators of silver perch were non-Murray-Darling Basin species. The silver perch found in the stomach contents were all released in shallow water or near cover. No deep-water released fish were recovered from stomach contents.

Of the seventeen silver perch fingerlings found in stomach contents, eight were recovered from long-finned eels, four from mouth almighty, three from 251–400 mm barramundi, and one from a barred grunter. Silver perch comprised approximately 77% by volume of mouth almighty stomach contents, 60% by volume of small barramundi stomach contents, and 59% by volume of long-finned eel gut contents.

As for the barramundi predation experiment, only a single 20–30mm silver perch was recovered from a barred grunter stomach (n=73). Overall, silver perch fingerlings were found to be a limited part of the diet of barred grunter, comprising just over 1% of the approximate volume of all stomach contents and occurring in just over 1% of stomachs examined. Filamentous algae comprised over 90% of barred grunter stomach contents. Only 20–30 mm silver perch were found in mouth almighty stomachs and only 35–45 mm and 50–65 mm silver perch in long-finned eel and barramundi stomach contents. No silver perch stocked into Gooburrum balancing storage were ever recaptured.

The number of potential predators captured in the silver perch predation experiment in Cassava Lagoon 2002 was relatively low, and included: barramundi 401–600 mm (n=3), Australian bass < 300 mm (n=3), Australian bass 300–450 mm (n=8), golden perch (n=2), silver perch (n=8) and long-finned eels (n=2). Nevertheless predation of silver perch fingerlings by non-Murray Darling species was confirmed. Silver perch were found in the stomachs of Australian bass of both size classes and in barramundi of the 401–600 mm size class (Figure 3.6). All size classes of stocked silver perch and all release strategies were represented in the predator stomach contents, although 35–45 mm and 50–65 mm size classes were more abundant than the 20–30 mm size classes across the limited number of samples examined. Few of the silver perch stocked in 2002 were recaptured in the trips following the predation experiment.

Of the few fish recaptured the majority were of the 20–30 mm and 35–45 mm size classes (see Fig 2.18B) and from cover and shallow water releases.

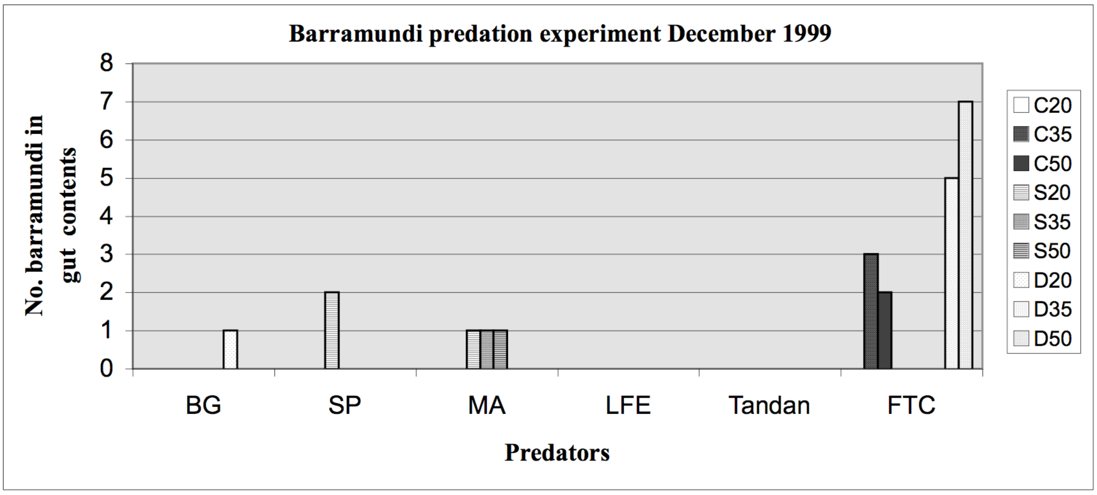


Figure 3.1 Number of barramundi of different size classes recovered from stomach contents of potential predators, Gooburrum, 24/12/1999.

Key: BG = barred grunter, SP = spangled perch, MA = mouth almighty, LFE = long-finned eel, Tandan = *Tandanus,* FTC = Fork tailed catfish. C = cover release, S = shallow water release, D = deep-water release. Numbers indicate size at release of stocked barramundi. 20 = 20–30 mm, 35 = 35–45 mm, 50 = 50–65 mm. Thus C20 = cover released 20–30 mm size class.

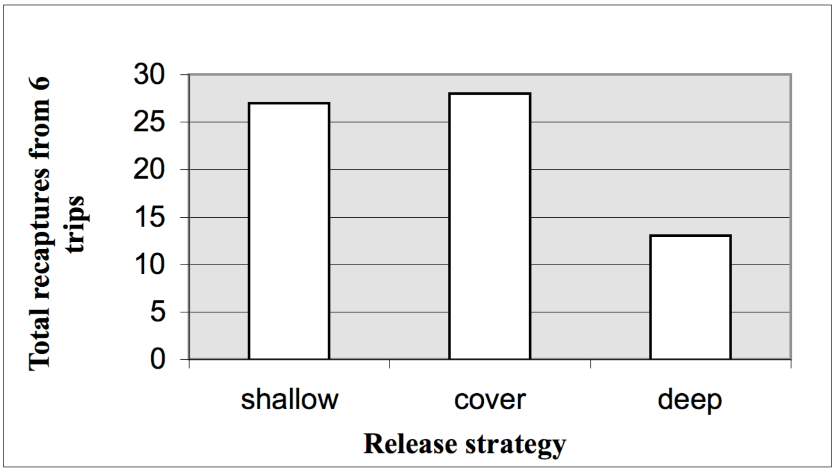


Figure 3.2 Recaptures by release strategy of barramundi stocked in Gooburrum balancing storage 1999. Recaptures represent totals from six sampling trips.

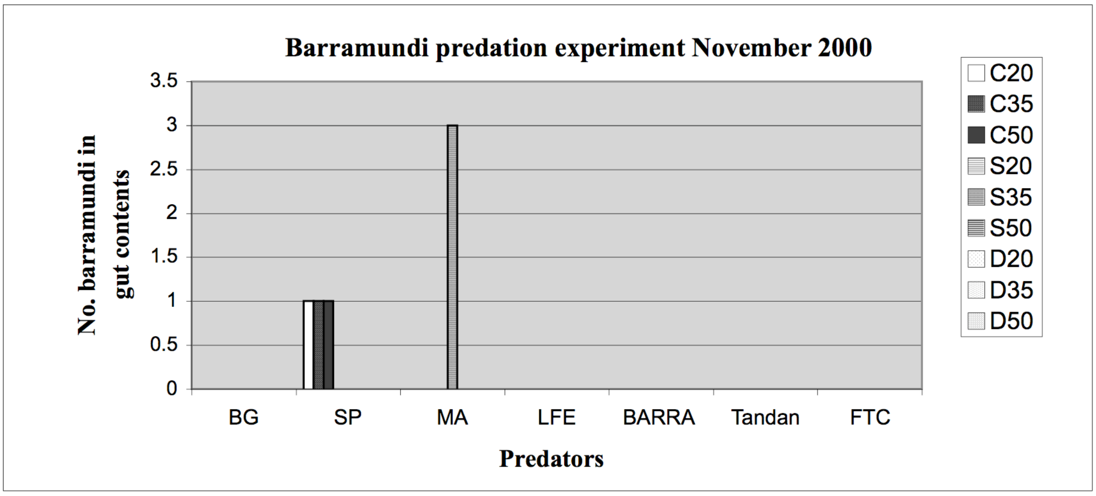


Figure 3.3 Number of barramundi of different size classes recovered from stomach contents of potential predators, Gooburrum, 14/11/2000.

Key: BG = barred grunter, SP = spangled perch, MA = mouth almighty, LFE = long-finned eel, BARRA = barramundi, Tandan = *Tandanus,* FTC = Fork tailed catfish. C = cover release, S = shallow water release, D = deep-water release. Numbers indicate size at release of stocked barramundi. 20 = 20–30 mm, 35 = 35–45 mm, 50 = 50–65 mm. Thus C20 = cover released 20–30 mm size class.

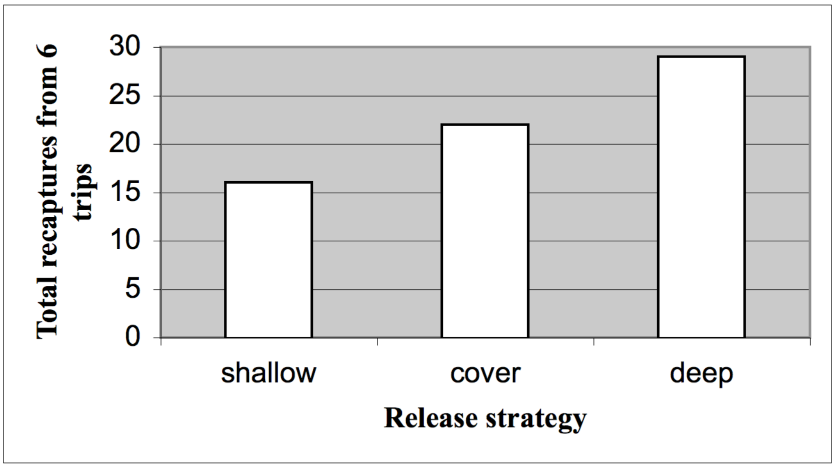


Figure 3.4 Recaptures by release strategy of barramundi stocked in Gooburrum balancing storage 2000. Recaptures represent total captures from six sampling trips.

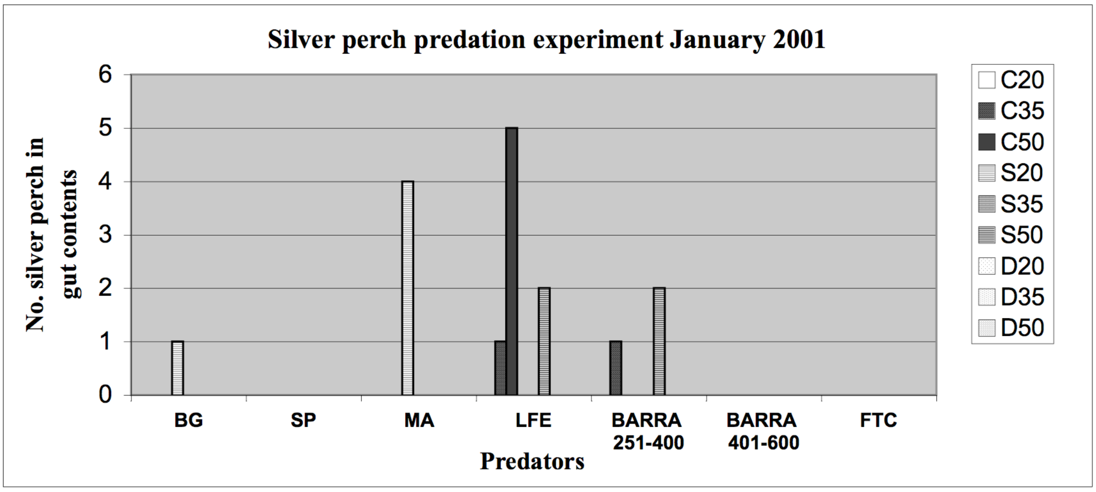


Figure 3.5 Number of silver perch of different size classes recovered from stomach contents of potential predators, Gooburrum, 24/01/2001.

Key: BG = barred grunter, SP = spangled perch, MA = mouth almighty, LFE = long-finned eel, Tandan = *Tandanus,* BARRA 251–400 = barramundi 251–400 mm size class, BARRA 401–600 = barramundi 401–600 mm size class, FTC = Fork tailed catfish.
C = cover release, S = shallow water release, D = deep-water release. Numbers indicate size at release of stocked barramundi. 20 = 20–30 mm, 35 = 35–45 mm, 50 = 50–65 mm. Thus C20 = cover released 20–30 mm size class.

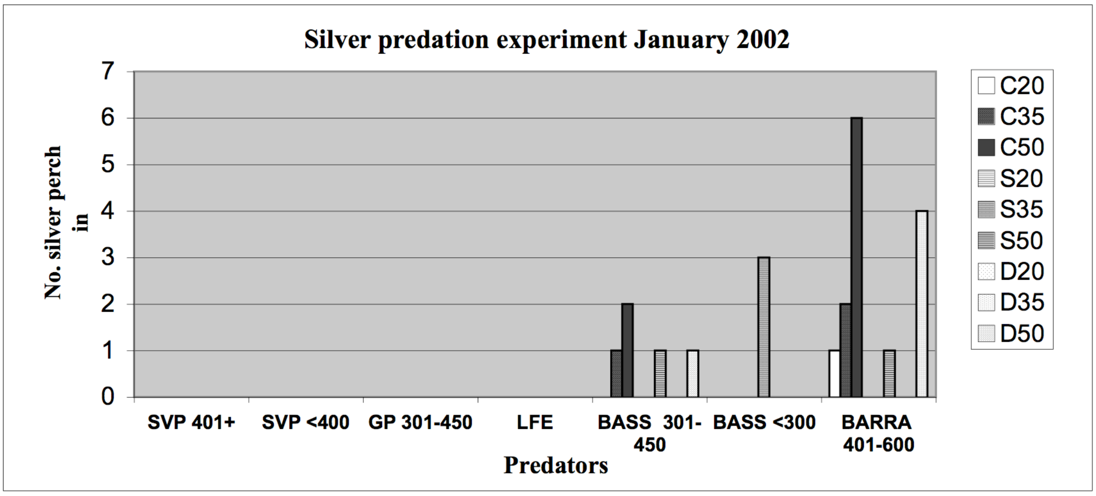


Figure 3.6 Number of silver perch of different size classes recovered from stomach contents of potential predators, Cassava Lagoon 29/01/2002.

Key: SVP 401+ = silver perch >401 mm, SVP <400 = silver perch <400 mm, GP 301–450 = golden perch 301–450 mm, LFE = long finned eel, BASS 301–450 = bass 301–450 mm size class, BASS <300 = bass <300 mm size class, BARRA 401–600 = barramundi 401–600 mm size class. C = cover release, S = shallow water release, D = deep-water release. Numbers indicate size at release of stocked barramundi. 20 = 20–30 mm, 35 = 35–45 mm, 50 = 50–65 mm. Thus C20 = cover released 20–30 mm size class.

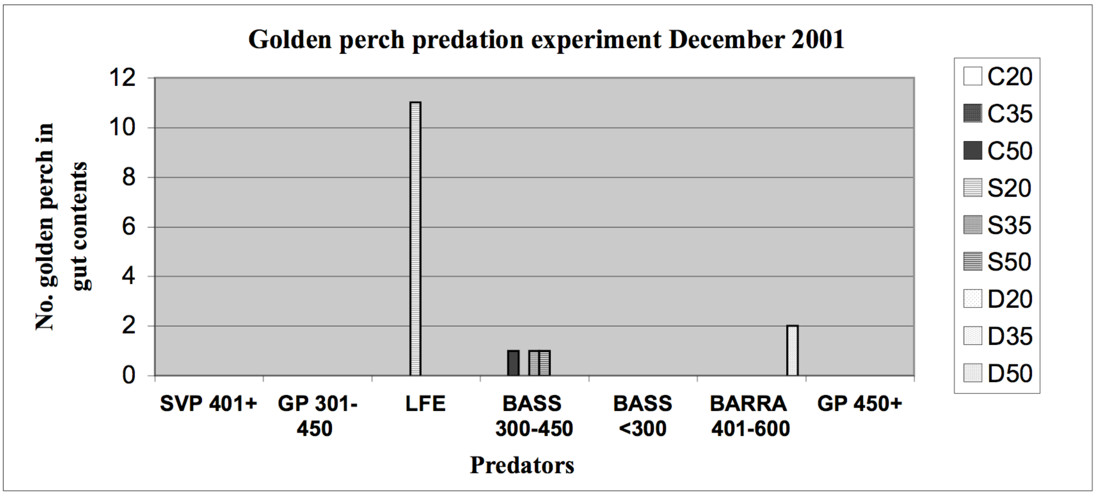


Figure 3.7 Number of golden perch of different size classes recovered from stomach contents of potential predators, Cassava Lagoon 29/01/2002.

Key: SVP 401+ = silver perch >401 mm, GP 301–450 = golden perch 301–450 mm size class, LFE = long-finned eel, BASS 300–450 = bass 300–450 mm size class, BASS <300 = bass < 300 mm size class, BARRA 401–600 = barramundi 401–600 mm size class, GP 450+ = golden perch > 450 mm size class. C = cover release, S = shallow water release, D = deep water release. Numbers indicate size at release of stocked barramundi. 20 = 20–30 mm, 35 = 35–45 mm, 50 = 50–65 mm. Thus C20 = cover released 20–30 mm size class.

Golden perch

For the golden perch predation experiment in Cassava Lagoon 2002, the total catch of predators near the release sites was low. Captures were silver perch (n=1), golden perch 301–450 mm (n=2), golden perch > 450 mm (n=1), long-finned eels (n=2), Australian bass 300–450 mm (n=13), Australian bass < 300 mm (n=6) and barramundi 401–600 mm (n=3). Nevertheless, non-Murray-Darling species were confirmed as predators of stocked golden perch fingerlings. Long-finned eels, Australian bass 300–450 mm and barramundi 401–600 mm all had some golden perch in their stomach contents.

The majority of golden perch fingerlings recovered from stomachs were 20–30 mm fish from shallow water found in the gut of an eel. The few golden perch recovered from the stomachs of bass and barramundi were 35–45 mm fish and 50–65 mm fish from shallow water, deep water and cover release sites (Figure 3.7).

Golden perch fingerlings comprised approximately 69% by volume of the stomach contents of the long-finned eels examined and 11% by volume for Australian bass larger than 300 mm. Aquatic and terrestrial insects comprised the bulk of the stomach contents of bass larger than 300 mm.

3.2.2 The effects of selected biotic and abiotic factors on stocking success

Australian bass

‘Macrophyte density’, ‘water levels at time of stocking’, ‘size at release’, ‘release strategy’ and ‘trips’ were unforced variables found to have a significant relationship with recapture rates of stocked Australian bass. ‘Water level at time of stocking’ is positively related to subsequent recapture rates, whilst macrophyte density has a negative relationship with recaptures. The Generalised Linear Model (GLM) of binomial proportions and the significance level of the terms and factors in the model are shown in Tables 3.4 and 3.5. Figure 3.8 shows adjusted mean recapture rates for Australian bass stocked at 50–65 mm. It is clear that fish stocked at high water levels survived better than those stocked at low water levels. The adjusted recapture rates are derived from the GLM and balanced for the effects of the other variables in the model across all sites. A similar relationship between water level at time of stocking and recapture rates can be seen in Figure 3.9. It shows the relationship between water level at time of stocking and recapture rates of bass stocked into Cassava Lagoon. Figure 3.9 is based on raw data and not adjusted for other factors.

Table 3.4 GLM of binomial proportions for recaptures of Australian bass. Model = Constant + macrophyte density +water level at stocking + size at release + release strategy + number of sampling trips. Variables used in the model were screened by stepwise multiple regression.

	d.f.	deviance	Mean deviance	Deviance ratio	Approx chi probability
Regression	7	3498.5	499.788	389.5	<.001
Residual	55	388.2	7.185		
Total	62	3893.7	62.802		

Table 3.5 GLM of binomial proportions for recaptures of Australian bass, showing significance levels for factors in the model ‘size at release’ and ‘release strategy’ are compared to the reference levels ‘size at release 20–30 mm’ and ‘release strategy cover’.

Factor	Estimate	t probability
Macrophyte density	–1.9657	<.001
Water level at stocking	0.8182	<.001
Size at release 35–45 mm	0.8115	<.001
Size at release 50–65 mm	0.9711	<.001
Release strategy deep	–0.4823	<.001
Release strategy shallow	–0.0254	0.659
Trips	0.06320	<.001

Tables 3.6 and 3.7 show an alternative GLM of binomial proportions that explains recapture rates of stocked Australian bass. This model was derived from a stepwise regression into which the term ‘relative abundance of barramundi’ was forced.

This also resulted in the selection of the term ‘relative abundance of spangled perch’. Both barramundi abundance and spangled perch abundance were shown to have significant negative relationships with recapture rates of Australian bass. No significant interaction effects between stocking size and the abundance of barramundi or spangled perch were detected in the GLM. Other potential predators of stocked

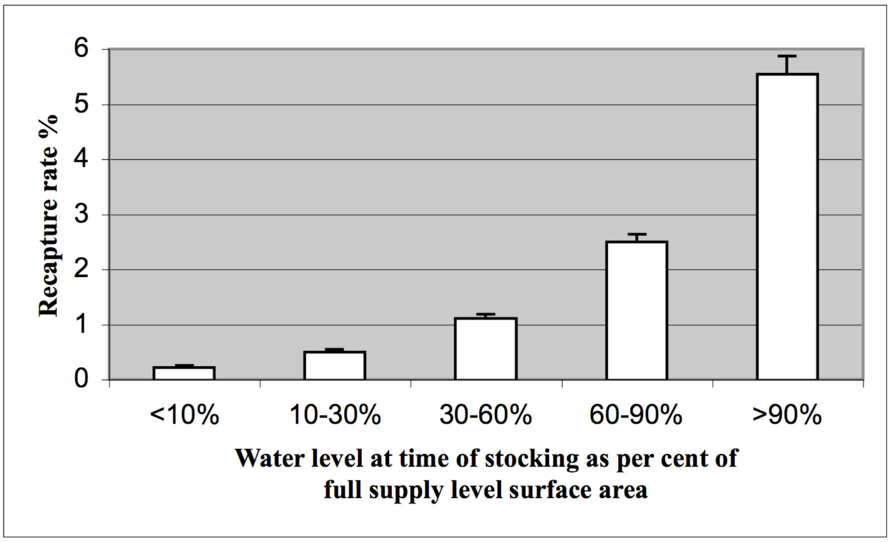


Figure 3.8 Adjusted mean recapture rates (%) for Australian bass stocked at 50–65 mm at different water levels. Means are balanced for fixed values of trips and macrophyte density; for release strategy marginal weights have been held constant. Error bars show one standard error of the mean.

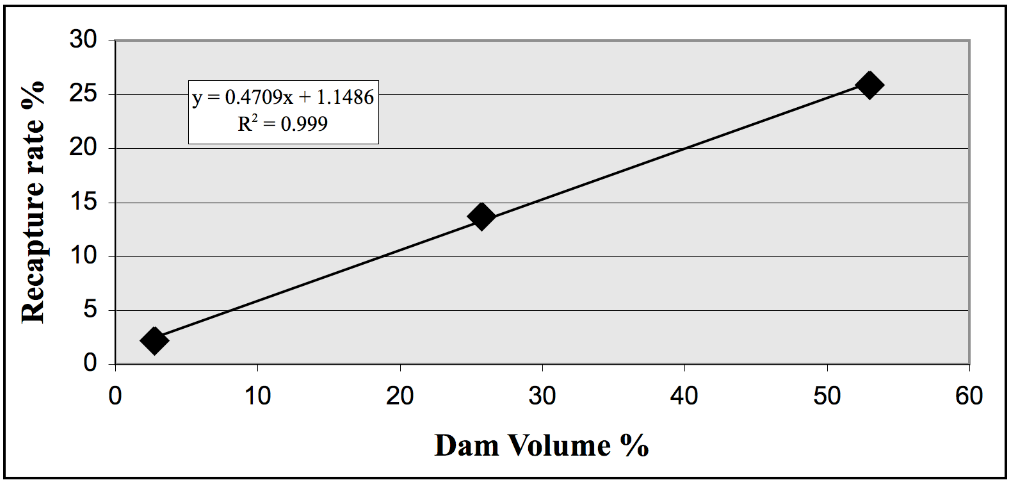


Figure 3.9 Recapture rates of bass (%) stocked into Cassava Lagoon at different water levels. Water level is expressed as per cent of full supply level volume. Water level data obtained from Hervey Bay Shire Council.

bass fingerlings were also forced in alternative models. The presence of a pre-existing population of Australian bass was found to have no significant effect on the subsequent success of bass stockings. No significant negative effect could be detected for long-finned eels, but in one case a significant positive relationship between eel abundance and bass recapture rates was shown. The effect of mouth almighty and fork-tailed catfish could not be assessed as they did not occur in any of our bass stocking sites. The relationship between recapture rates of Australian bass and the relative abundance of barramundi and spangled perch are shown in Figures 3.10 and 3.11 respectively.

Table 3.6 GLM of binomial proportions for recaptures of Australian bass. Model = constant + size at release + release strategy + number of sampling trips + relative abundance of barramundi + relative abundance of spangled perch. Variables used in the model were selected by stepwise multiple regression after forcing of relative abundance barramundi.

	d.f.	deviance	Mean deviance	Deviance ratio	Approx chi probability
Regression	7	3482.6	497.519	497.52	<.001
Residual	55	411.1	7.474		
Total	62	3893.7	62.802		

Table 3.7 GLM of binomial proportions for recaptures of Australian bass, showing significance levels for factors in the model. The factors ‘size at release’ and ‘release strategy’ are compared to the reference levels ‘size at release 20–30 mm’ and ‘release strategy cover’.

Factor	**Estimate**	**t probability**
Size at release 35–45 mm	0.8002	<.001
Size at release 50–65 mm	0.9442	<.001
Release strategy deep	–0.4805	<.001
Release strategy shallow	–0.0287	0.617
Trips	–0.0787	<.001
Rel. abund. barramundi	–1.6136	<.001
Rel. abund. spangled perch	–1.1299	<.001

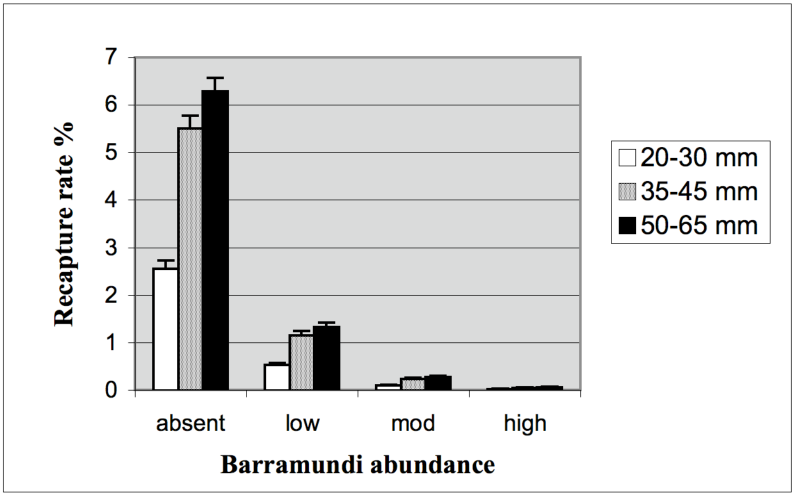


Figure 3.10 Effect of the abundance of barramundi on adjusted mean recapture rates for Australian bass stocked at different sizes. Means are adjusted for fixed values of spangled perch abundance and trips, with marginal weights held constant across factors for release strategy. Error bars show one standard error of the mean.

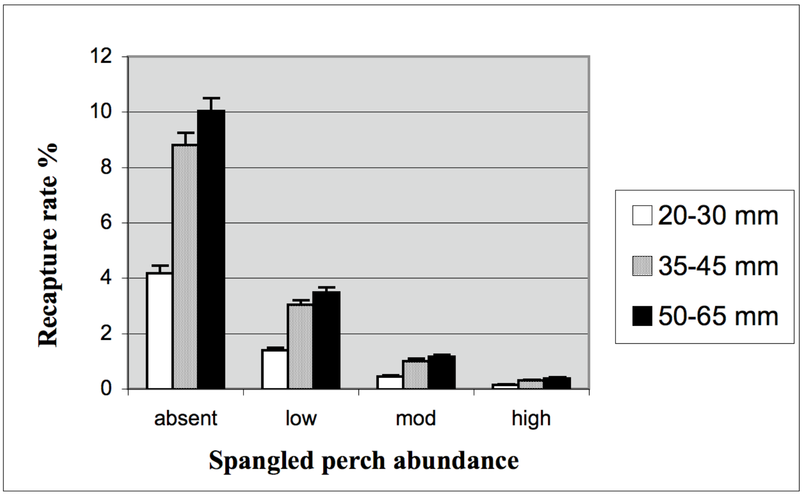


Figure 3.11 Effect of the abundance of spangled perch on adjusted mean recapture rates for Australian bass stocked at different sizes. Means adjusted for fixed values for barramundi abundance and trips, with marginal weights held constant across factors for release strategy. Error bars show one standard error of the mean.

Barramundi

Stepwise regression was used to select ‘fringing emergent vegetation’, ‘number of sampling trips’, ‘release size’, ‘relative abundance of long-finned eels’, ‘relative abundance of fork-tailed catfish’ and ‘water level at time of stocking’ as variables to enter into a GLM of binomial proportions for recaptures of barramundi. The GLM is shown in Table 3.8, with the significance levels of the variables shown in Table 3.9.

As for Australian bass recaptures, water level had a significant positive relationship with barramundi recaptures. This relationship is shown in Figure 3.12. Even though relative abundance of eels was selected by the stepwise regression procedure, the effect of eels on recapture rates was only weakly negative and not shown to be significant (see Table 3.9 and Figure 3.13). However, the relative abundance of fork-tailed catfish had a significant negative relationship with recapture rates of barramundi and there was a significant interaction effect with size at stocking. Recaptures of fish stocked at smaller sizes were significantly reduced as the abundance of catfish increased.

Table 3.8 GLM of binomial proportions for recaptures of Barramundi. Model = constant + prop. edge with fringing emergent vegetation + number of sampling trips + size at release + relative abundance of long-finned eels + relative abundance of fork-tailed catfish + relative abundance of fork-tailed catfish.size at release + water level at time of stocking. Variables used in the model were selected by stepwise multiple regression without forcing of any variables.

	d.f.	deviance	Mean deviance	Deviance ratio	Approx chi probability
Regression	9	437.2	48.631	48.63	<.001
Residual	56	188.6	3.367		
Total	65	626.3	9.635		

Table 3.9 GLM of binomial proportions for recaptures of barramundi, showing significance levels for factors in the model. The factor 'size at release' is compared to the reference levels 'size at release 20–30 mm'.

Factor	**Estimate**	**t probability**
Fringing emergent vegetation	0.297	<.001
Trips	0.2263	<.001
Size at release 35–45 mm	–0.011	0.939
Size at release 50–65 mm	0.241	0.077
Rel abund. long-finned eels	–0.027	0.847
Rel. abund. fork-tailed catfish	–.780	<.001
Ft catfish.size at release 35–45 mm	0.606	<.001
Ft catfish.size at release 50–65 mm	0.977	<.001
Water level at time of stocking	.3341	<.001

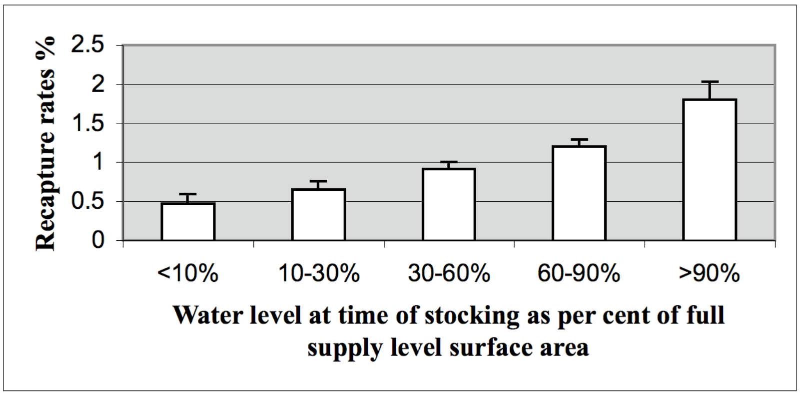


Figure 3.12 Adjusted mean recapture rates (%) for barramundi stocked at 50–65 mm at different water levels. Means are balanced for fixed values of abundance of long-finned eels, abundance of catfish, trips and fringing emergent vegetation. Error bars show one standard error of the mean.

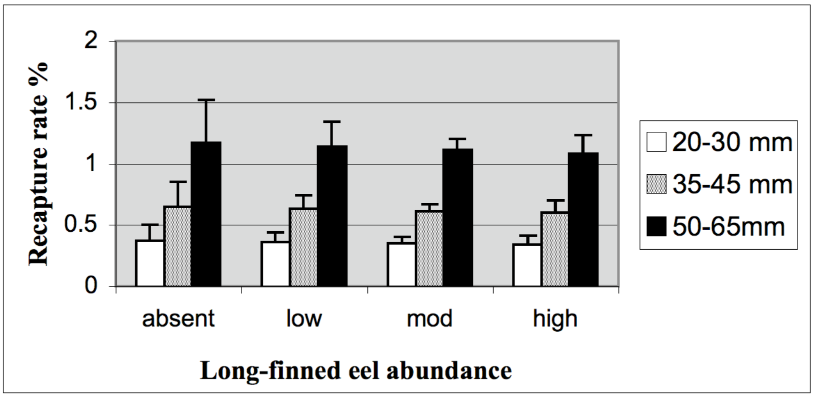


Figure 3.13 Effect of the abundance of long-finned eels on adjusted mean recapture rates for barramundi stocked at different sizes. Means are adjusted for fixed values of level at stocking, abundance of fork-tailed catfish, fringing emergent veg and trips. Error bars show one standard error of the mean.

The term ‘relative abundance of mouth almighty’ was aliased with the term ‘relative abundance of fork-tailed catfish’. When the stepwise regression was run excluding fork-tailed catfish, the following variables were selected: ‘proportion of edge with fringing emergent vegetation’, ‘number of sampling trips’, ‘relative abundance of mouth almighty’, ‘size at release’ and ‘water level at time of stocking’. The stepwise regression did not select ‘relative abundance of long-finned eels’. The selected variables were run in a GLM of binomial proportions. The model and significance levels of the variables are shown in Tables 3.10 and 3.11. As for the previous model, fringing emergent vegetation was positively related to barramundi recapture rates as was water level at the time of stocking. The estimated values for these variables are similar to those of the previous model. The estimated values for mouth almighty and interactions between mouth almighty and size at release are almost the same as those for fork-tailed catfish and interactions with size at release in the previous model. Relative abundance of mouth almighty has a negative relationship with barramundi recapture rates, with smaller size class recapture rates declining in the presence of mouth almighty, but those of the largest size class increasing (see Table 3.11 and Figure 3.14).

Table 3.10 GLM of binomial proportions for recaptures of Barramundi. Model = constant + prop. edge with fringing emergent vegetation + number of sampling trips + size at release + relative abundance of mouth almighty + relative abundance of mouth almighty.size at release + water level at time of stocking. Variables used in the model were selected by stepwise multiple regression without forcing of any variables.

	d.f.	deviance	Mean deviance	Deviance ratio	Approx chi probability
Regression	8	446.1	55.764	55.76	<.001
Residual	57	180.1	3.160		
Total	65	626.3	9.635		

Table 3.11 GLM of binomial proportions for recaptures of barramundi, showing significance levels for factors in the model. The factor ‘size at release’ is compared to the reference levels ‘size at release 20–30 mm’.

Factor	Estimate	t probability
Fringing emergent vegetation	0.3327	<.001
Trips	0.2501	<.001
Size at release 35–45 mm	–0.013	0.928
Size at release 50–65 mm	0.193	0.153
Rel. abund. mouth almighty	–.775	<.001
Mouth almighty.size at release 35–45 mm	0.607	<.001
Mouth almighty.size at release 50–65 mm	1.004	<.001
Water level at time of stocking	.2918	<.001

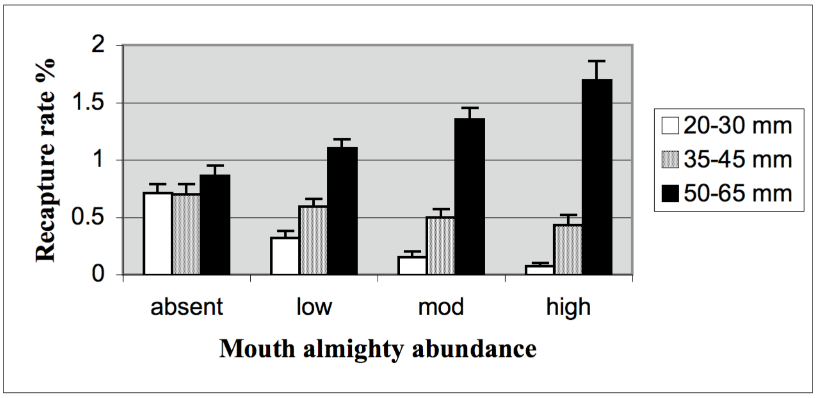


Figure 3.14 Effect of the abundance of mouth almighty on adjusted mean recapture rates for barramundi stocked at different sizes. Means are adjusted for fixed values of water level at time of stocking, number of sampling trips and fringing emergent vegetation. Error bars show one standard error of the mean. NB: Fork tailed catfish abundance levels were aliased with mouth almighty abundance levels. Substituting fork-tailed catfish for mouth almighty in the model gives an almost identical plot.

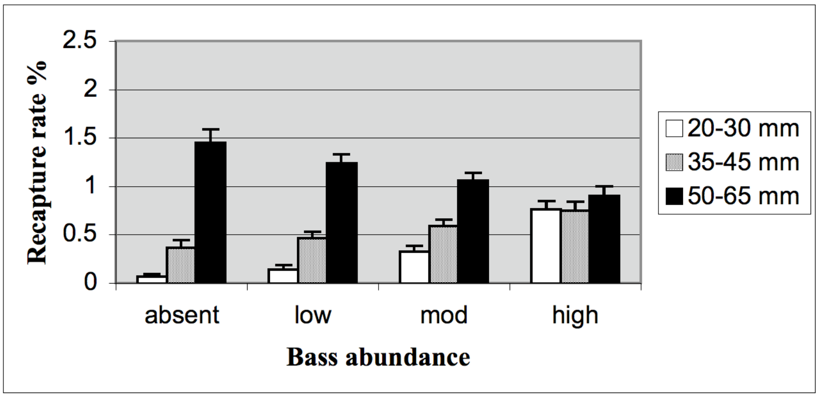


Figure 3.15 Effect of the abundance of Australian bass on adjusted mean recapture rates for barramundi stocked at different sizes. Means are adjusted for fixed values of floating macrophyte density, water level at time of stocking and number of sampling trips. Error bars show one standard error of the mean. This plot suggests size selective predation on the 50–65 mm size class.

Forcing of the relative abundance of Australian bass in the stepwise procedure resulted in the GLM of binomial proportions shown in Tables 3.12 and 3.13. ‘Water level at time of stocking’, ‘number of sampling trips’ and ‘size at stocking’ again all feature as in the previous models. ‘Fringing emergent vegetation’ has been replaced by ‘floating macrophyte density’, which shows a significant positive relationship with recapture rates of barramundi. There is a significant interaction between relative abundance of bass and size at stocking. The 50–65 mm size class show lower recapture rates at high densities of bass, whilst the smaller size classes of barramundi have increased recapture rates with increasing abundance of bass (see Figure 3.15).

Table 3.12 GLM of binomial proportions for recaptures of barramundi. Model = constant + floating macrophyte density + level at stocking + size at release + relative abundance of Australian bass + relative abundance of Aust bass.size at release + number of sampling trips. Variables used in the model were selected by stepwise multiple regression after forcing of the variable relative abundance of bass.

	d.f.	deviance	Mean deviance	Deviance ratio	Approx chi probability
Regression	8	443.6	55.449	55.45	<.001
Residual	57	182.7	3.205		
Total	65	626.3	9.635		

Table 3.13 GLM of binomial proportions for recaptures of barramundi, showing significance levels for factors in the model. The factor 'size at release' is compared to the reference levels 'size at release 20–30 mm'.

Factor	Estimate	t probability
Floating macrophyte density	0.801	<.001
Water level at time of stocking	0.3079	<.001
Size at release 35–45 mm	1.808	<.001
Size at release 50–65 mm	3.194	<.001
Rel. abund. Australian bass	0.845	<.001
Aust bass.size at release 35–45 mm	–0.608	<.001
Aust bass.size at release 50–65 mm	–1.007	<.001
Trips	0.2656	<.001

Substituting 'relative abundance of Australian bass' with 'relative abundance of spangled perch' did not greatly alter the effect of the other variables or the significance of the model (Tables 3.14 and 3.15). However, the interaction effect between stocking size and relative abundance of spangled perch was the reverse of that for bass. In the case of spangled perch the two smaller stocking sizes showed reduced recapture rates as abundance of spangled perch increased, whilst recaptures of fish stocked at 50–65 mm increased. This pattern is shown in Figure 3.16.

Table 3.14 GLM of binomial proportions for recaptures of barramundi. Model = constant + floating macrophyte density + level at stocking + size at release + relative abundance of spangled perch + relative abundance of spangled perch.size at release + number of sampling trips.

	d.f.	deviance	Mean deviance	Deviance ratio	Approx chi probability
Regression	8	438.3	54.782	54.78	<.001
Residual	57	188.0	3.298		
Total	65	626.3	9.635		

Table 3.15 GLM of binomial proportions for recaptures of barramundi, showing significance levels for factors in the model. The factor 'size at release' is compared to the reference levels 'size at release 20–30 mm'.

Factor	**Estimate**	**t probability**
Floating macrophyte density	0.988	<.001
Water level at time of stocking	0.2471	0.002
Size at release 35–45 mm	–0.334	0.083
Size at release 50–65 mm	–.400	0.021
Rel. abund. spangled perch	–0.884	<.001
Sp. perch.size at release 35–45 mm	0.708	<.001
Sp. perch.size at release 50–65 mm	1.333	<.001
Trips	0.2237	<.001

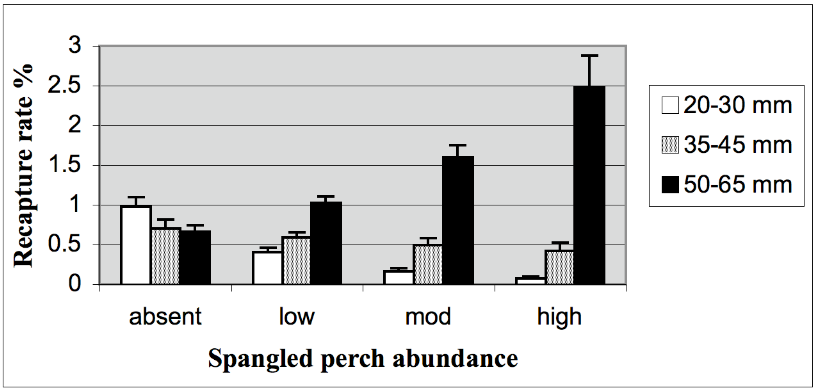


Figure 3.16 Effect of the abundance of spangled perch on adjusted mean recapture rates for barramundi stocked at different sizes. Means are adjusted for fixed values of number of sampling trips, floating macrophyte density and level at time of stocking. Error bars show one standard error of the mean. The plot suggests size selective predation on the 20–30 mm and 35–45 mm size classes. Low abundance where spangled perch are absent may be an artefact of project sampling sites where predators like bass were present where spangled perch were absent. The above model does not include the effects of other predators.

None of the other predators forced into the model were shown to have a significant relationship with recapture rates of barramundi except for the term 'relative abundance of barramundi'. Relative abundance of barramundi (i.e. pre-existing numbers at the time of stocking) was positively related to subsequent recapture rates of stocked barramundi ($p<.001$). There was no significant interaction between 'size at release' and 'relative abundance of barramundi', although the tendency was for fish stocked at 50–65 mm to have higher recapture rates than fish stocked at 20–30 mm and 35–45 mm.

Silver perch

Selection of variables by stepwise regression resulted in the GLM of Binomial proportions presented in Tables 3.16 and 3.17. As for Australian bass and barramundi, 'water level at time of stocking' has again emerged as a variable having a significant effect on stocking success (Figure 3.17). The terms 'macrophyte density' and 'modal width of the treed edge' were both found to have a significant negative relationship with silver perch recapture rates. As would be expected from the results presented in chapter two, size at release was also a significant factor. In support of our hypothesis that non-Murray Darling basin species have impacted on silver and golden perch stocking success a non-Murray-Darling species, the long-finned eel has a significant negative relationship with silver perch recapture rates. There was also a significant interaction between size at release and relative abundance of long-finned eels (Figure 3.18). Fish stocked at 20–30 mm had lower recapture rates than the larger size classes, but fish stocked at larger sizes also appear to do poorly in the presence of moderate to high abundance levels of eels.

Table 3.16 GLM of binomial proportions for recaptures of silver perch. Model = constant + modal tree width + macrophyte density + size at release + water level at stocking + relative abundance of long-finned eels + relative abundance of long-finned eels.size at release.

	d.f.	deviance	Mean deviance	Deviance ratio	Approx chi probability
Regression	8	2726.3	340.792	340.79	<.001
Residual	71	317.2	4.468		
Total	79	3043.5	38.526		

Table 3.17 GLM of binomial proportions for recaptures of silver perch, showing significance levels for factors in the model. The factor 'size at release' is compared to the reference levels 'size at release 20–30 mm'.

Factor	Estimate	t probability
Modal width treed edge	–0.0400	0.007
Macrophyte density	–2.604	<.001
Size at release 35–45 mm	0.6178	<.001
Size at release 50–65 mm	0.6350	<.001
Water level at time of stocking	0.8822	<.001
Rel. abund. long-finned eels	–3.028	<.001
Long-finned eels.size at release 35–45 mm	0.707	<.001
Long-finned eels.size at release 50–65 mm	0.959	<.001

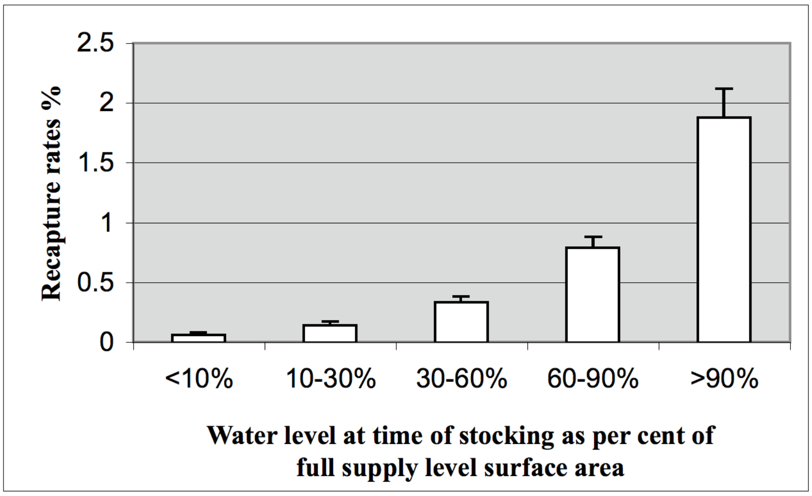


Figure 3.17 Adjusted mean recapture rates (%) for silver perch stocked at 50–65 mm at different water levels. Means are balanced for fixed values of modal riparian vegetation width, macrophyte density, and abundance of long-finned eels. Error bars show one standard error of the mean.

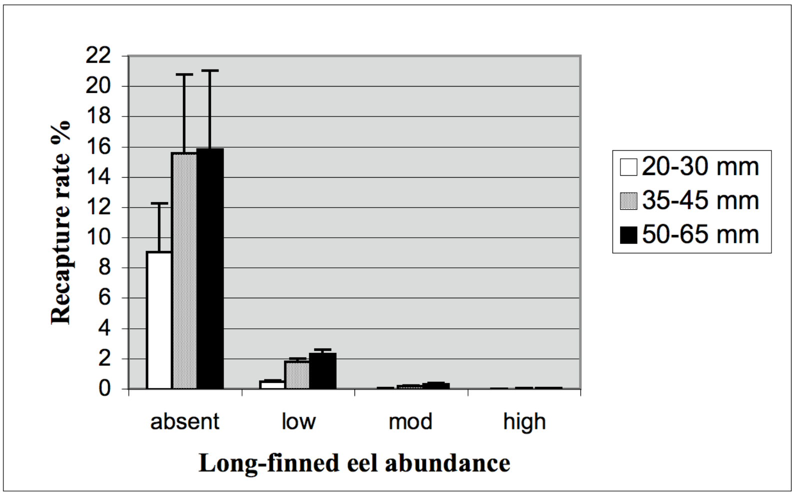


Figure 3.18 Effect of the abundance of long-finned eels on adjusted mean recapture rates for silver perch stocked at different sizes. Means are adjusted for fixed values of modal riparian vegetation width, macrophyte density and water level at time of stocking. Error bars show one standard error of the mean. Plot suggests all size classes do poorly at moderate to high abundance levels of eels.

Forcing the term ‘relative abundance of barramundi’ into the stepwise regression resulted in selection of the following additional terms or factors; ‘size at release’, ‘water level at time of stocking’, and ‘relative abundance of spangled perch’. These terms combined to produce a significant GLM of binomial proportions (Table 3.18). The effect of water level at time of stocking on subsequent recapture rates of silver perch is consistent with the previous model (Table 3.19). Spangled perch had a significant negative relationship with recapture rates of stocked silver perch, but there was no significant interaction between size at stocking and relative abundance of spangled perch detected (Table 3.19). However, data from Storm King Dam, where spangled perch are absent, and Tarong Power Station Dam, where spangled perch are the only significant predatory fish, suggests that there may be some interaction (Figure 3.19), with numbers of silver perch stocked at less than 50 mm being more severely impacted than fish stocked at larger than 50 mm (see discussion for further details).

Relative abundance of barramundi also had a significant negative relationship with recapture rates of stocked silver perch, but no interactions with size at stocking were detected (Table 3.19). Figure 3.20 shows that impact on silver perch of even moderate densities of barramundi can be severe.

Table 3.18 GLM of binomial proportions for recaptures of silver perch. Model = constant + modal + size at release + relative abundance of spangled perch + releative abundance of barramundi + water level at time of stocking.

	d.f.	deviance	Mean deviance	Deviance ratio	Approx chi probability
Regression	5	2653.9	530.778	530.78	<.001
Residual	74	389.6	5.265		
Total	79	3043.5	38.526		

Table 3.19 GLM of binomial proportions for recaptures of silver perch, showing significance levels for factors in the model. The factor 'size at release' is compared to the reference levels 'size at release 20–30 mm'.

Factor	Estimate	t probability
Size at release 35–45 mm	0.7746	<.001
Size at release 50–65 mm	0.9169	<.001
Relative abundance of spangled perch	–1.4190	<.001
Relative abundance of barramundi	–1.666	<.001
Water level at time of stocking	0.7162	<.001

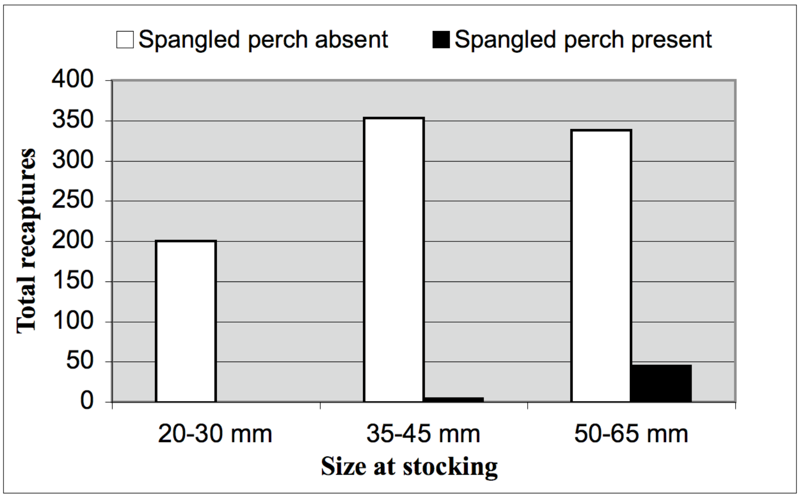


Figure 3.19 Comparison of recapture rates of different size classes of silver perch stocked into Storm King (SK) Dam and Tarong Power Station (TPS) Dam in Year 4 of the project. Spangled perch were present in TPS Dam (where they were the only predatory fish present in substantial numbers) and absent from SK dam.

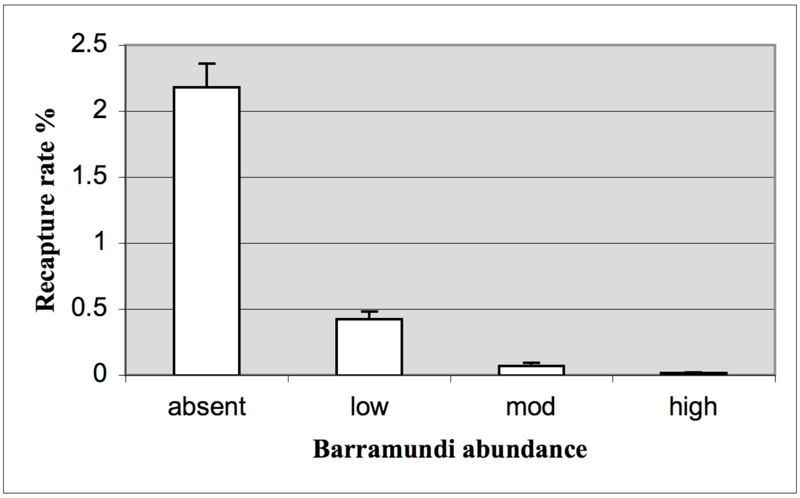


Figure 3.20 Effect of the abundance of barramundi on adjusted mean recapture rates for silver perch stocked at 50–65 mm. Means are adjusted for fixed values of abundance of spangled perch and water level at time of stocking. Error bars show one standard error of the mean.

Table 3.20 GLM of binomial proportions for recaptures of silver perch. Model = constant + size at release + relative abundance of Australian bass + relative abundance Australian bass.size at release + water level at time of stocking + relative abundance of spangled perch.

	d.f.	deviance	Mean deviance	Deviance ratio	Approx chi probability
Regression	7	2390.7	341.523	341.52	<.001
Residual	72	652.9	9.068		
Total	79	3043.5	38.526		

Table 3.21 GLM of binomial proportions for recaptures of silver perch, showing significance levels for factors in the model. The factor ‘size at release’ is compared to the reference levels ‘size at release 20–30 mm’.

Factor	Estimate	t probability
Size at release 35–45 mm	0.6256	<.001
Size at release 50–65 mm	0.7080	<.001
Relative abundance of Australian bass	–0.975	<.001
Rel. abund. bass.size at release 35–45 mm	0.434	<.001
Rel. abund. bass.size at release 50–65 mm	0.527	<.001
Water level at time of stocking	0.7162	<.001
Relative abundance of spangled perch	–1.7603	<.001

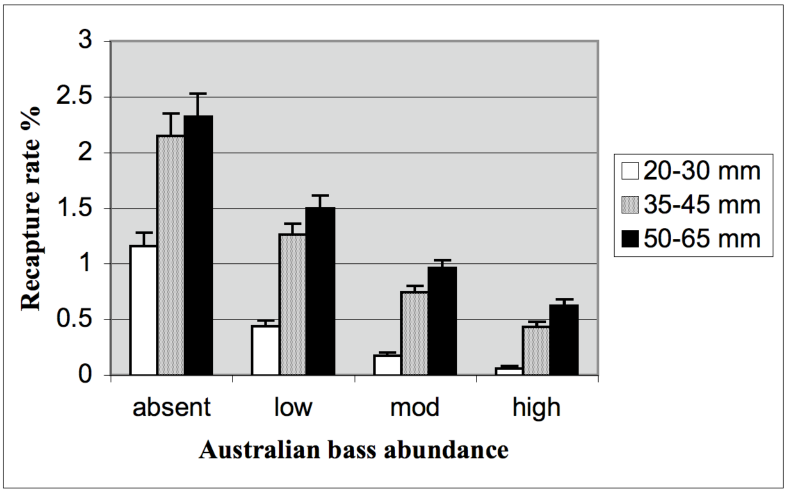


Figure 3.21 Effect of the abundance of Australian bass on adjusted mean recapture rates for silver perch stocked at different sizes. Means are adjusted for fixed values of abundance of spangled perch, and level at stocking. Error bars show one standard error of the mean. Plot suggests predation of all size classes with preference for 20–30 mm size class.

Forcing the term 'relative abundance of bass' into the stepwise regression procedure resulted in selection of the terms 'relative abundance of spangled perch', 'size at release' and 'water level at time of stocking'. These variables combined to produce another significant GLM of binomial proportions (Table 3.20). Bass were found to have a negative relationship with recapture rates of silver perch, although not as strongly negative as for barramundi (Table 3.21). This supports our hypothesis regarding the impact of non-Murray-Darling predatory species on silver perch. There was also a significant interaction between 'size at release' and 'relative abundance of bass', which may indicate selective predation of 20–30 mm silver perch (Figure 3.21).

Other potential predators did not have significant negative relationships with recapture rates of stocked silver perch. However, the relationships between recapture rates of silver perch and the relative abundance levels for both mouth almighty and fork tailed catfish were negative. In fact no silver perch were recaptured in the presence of these two predators. This actually led to a change in stocking sites and therefore fewer data points to assess the impact of these two species. The only other potential predator assessed was golden perch. Relative abundance of golden perch was positively associated with recapture rates of silver perch (estimate 1.939, $p<.001$).

Golden perch

The recapture rates of golden perch were the lowest of all four species stocked. Nevertheless some relationships between habitat variables and the relative abundance levels of different predator species are still apparent. Stepwise multiple regression selected the following variables as explaining variance in golden perch recapture rates: 'Macrophyte density', 'water level at time of stocking', 'size at release', 'maximum depth', 'release strategy', and 'relative abundance of spangled perch'.

However, the latter variable 'relative abundance of spangled perch' was dropped from the GLM of binomial proportions, as although a negative relationship with golden perch recapture rates was detected, it was not statistically significant $p = 0.128$.

The GLM of binomial proportions produced from the remaining variables was statistically significant (Table 3.22). As for the previous three species, water level at time of stocking was positively related to subsequent golden perch recaptures (Table 3.21, Figure 3.22). Macrophyte density was found to have a negative relationship with golden perch recapture rates. (Table 3.23). A similar relationship with macrophyte density was shown for bass recapture rates (Table 3.5). Maximum depth showed a positive relationship with golden perch recaptures (Table 3.23). Selection of size at stocking and release strategy is consistent with the results in chapter 2.

Table 3.22 GLM of binomial proportions for recaptures of golden perch. Model = constant + macrophyte density + water level at time of stocking + size at release + maximum depth + release strategy.

	d.f.	deviance	Mean deviance	Deviance ratio	Approx chi probability
Regression	7	384.66	54.952	54.95	<.001
Residual	73	83.2	1.140		
Total	80	467.86	5.848		

Table 3.23 GLM of binomial proportions for recaptures of golden perch, showing significance levels for factors in the model. The factor ‘size at release’ is compared to the reference levels ‘size at release 20–30 mm’ and the factor ‘release strategy’ is compared to ‘release strategy cover’.

Factor	Estimate	t probability
Macrophyte density	–2.976	<.001
Water level at time of stocking	1.686	<.001
Size at release 35–45 mm	1.323	<.001
Size at release 50–65 mm	2.325	<.001
Maximum depth m	0.3279	<.001
Release strategy deep	0.962	<.001
Release strategy shallow	0.581	<.001

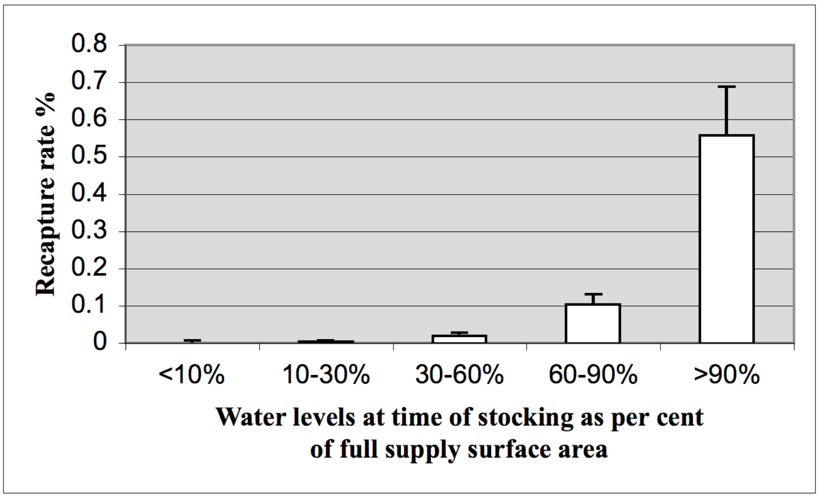


Figure 3.22 Adjusted mean recapture rates (%) for golden perch stocked at 50–65 mm at different water levels. Means are balanced for fixed values of macrophyte density and maximum depth, with marginal weights held constant across all factors for release strategy. Error bars show one standard error of the mean.

Forcing relative abundance of barramundi into the stepwise regression resulted in selection of relative abundance of eels and number of sampling trips in addition to the factors within 'size at release'. The resulting GLM of binomial proportions was significant (Table 3.24). 'Relative abundance of barramundi' had a significant negative relationship with recapture rates of golden perch (Table 3.25 and Figure 3.23) as did the 'relative abundance of eels'. There was also a significant interaction between 'size at release' and 'relative abundance of eels' (Table 3.25 and Figure 3.24) with recaptures of 20–30 mm golden perch apparently affected more than larger size classes. No interaction effect was found for size at stocking and relative abundance of barramundi.

Table 3.24 GLM of binomial proportions for recaptures of golden perch. Model = constant + relative abundance of barramundi + number of sampling trips + relative abundance of long-finned eels + long-finned eels.size at release.

	d.f.	deviance	Mean deviance	Deviance ratio	Approx chi probability
Regression	5	295.8	59.163	59.16	<.001
Residual	75	172.0	2.294		
Total	80	467.86	5.848		

Table 3.25 GLM of binomial proportions for recaptures of golden perch, showing significance levels for factors in the model. Factors in the model are compared with reference levels 'size at release 20–30 mm'.

Factor	Estimate	t probability
Relative abundance of barramundi	–2.231	<.001
Number of sampling trips	0.4120	<.001
Relative abundance of long-finned eels	–2.031	<.001
Long-finned eels.size at release 35–45 mm	0.952	<.001
Long-finned eels.size at release 50–65 mm	1.460	<.001

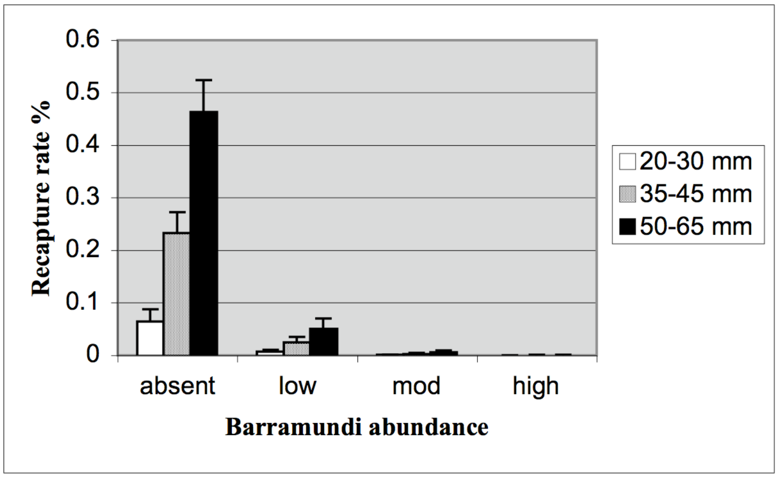


Figure 3.23 Effect of the abundance of barramundi on adjusted mean recapture rates for golden perch stocked at three sizes. Means are adjusted for fixed values of eel abundance and trips. Error bars show one standard error of the mean.

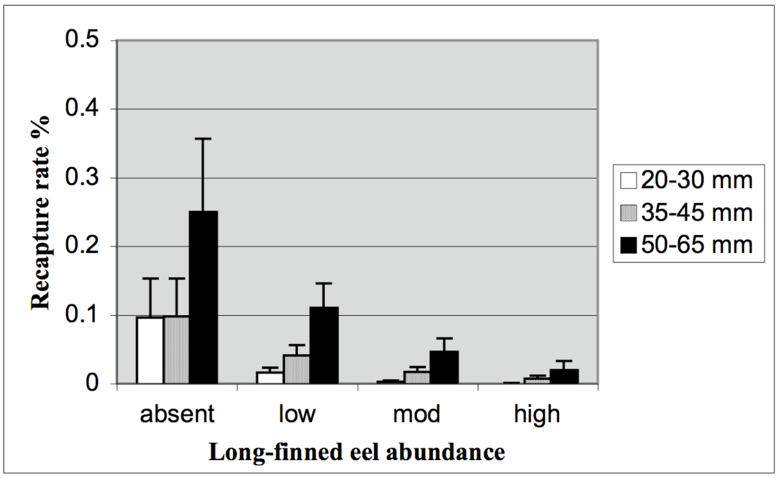


Figure 3.24 Effect of the abundance of long-finned eels on adjusted mean recapture rates of golden perch stocked at different sizes. Means are adjusted for a fixed abundance level of barramundi (present at low levels) and fixed number of sampling trips. Error bars show one standard error of the mean. Plot suggests all size classes do poorly at moderate to high abundance levels of eels, with greater pressure on the 20–30 mm size class.

When ‘relative abundance of Australian bass’ was forced into the stepwise procedure, the following variables were selected: ‘number of sampling trips’, ‘size at release’, and ‘release strategy’. These variables contributed to a significant GLM of binomial proportions (Table 3.26). Relative abundance of bass had a significant negative relationship with recapture rates of golden perch (Table 3.27 and Figure 3.25) although no significant interaction between size at release and release strategy was found (p>.05). There was a significant interaction between release strategy and relative abundance of Australian bass (Table 3.27 and Figure 3.26), with a substantial reduction in success of cover-released fish relative to the other strategies in the presence of bass. No interaction between size at release and relative abundance was found (p>.05).

Table 3.26 GLM of binomial proportions for recaptures of golden perch. Model = constant + relative abundance of Australian bass + number of trips + size at release + relative abundance of Australian bass.release strategy.

	d.f.	**deviance**	**Mean deviance**	**Deviance ratio**	**Approx chi probability**
Regression	6	244.9	40.819	40.82	<.001
Residual	74	223	3.013		
Total	80	467.9	5.848		

Table 3.27 GLM of binomial proportions for recaptures of golden perch, showing significance levels for factors in the model. Factors in the model are compared with reference levels ‘size at release 20–30 mm’ and ‘release strategy cover’.

Factor	**Estimate**	**t probability**
Relative abundance of Australian bass	–2.840	<.001
Number of sampling trips	0.975	<.001
Size at release 35–45 mm	1.293	<.001
Size at release 50–65 mm	2.330	<.001
Rel abund. bass.release strategy deep	0.534	<.001
Rel. abund bass.release strategy shallow	0.369	0.003

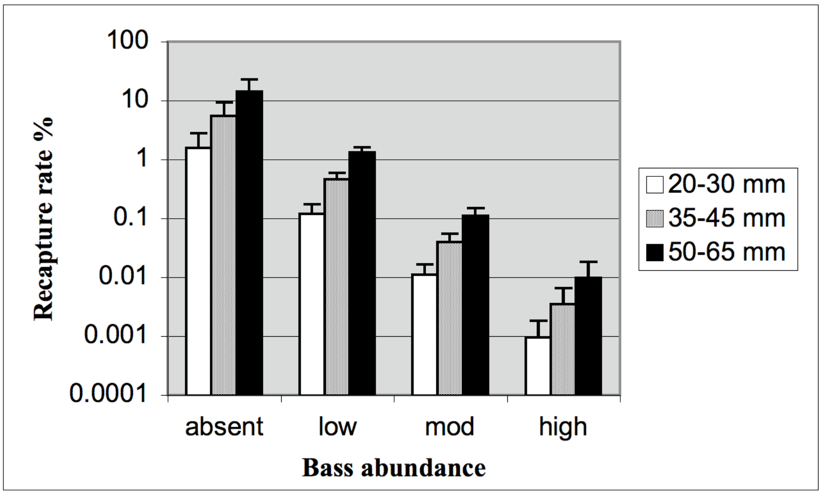


Figure 3.25 Effect of the abundance of Australian bass on adjusted mean recapture rates for golden perch stocked at different sizes. Means are adjusted for fixed values of trips, with marginal weights held constant across all factors for release strategy. The model excludes predators like barramundi and eels and also the effect of water level at time of stocking. Error bars show one standard error of the mean. Note y-axis is on a log scale. Adjusted mean recapture rates are very low at moderate to high densities of bass.

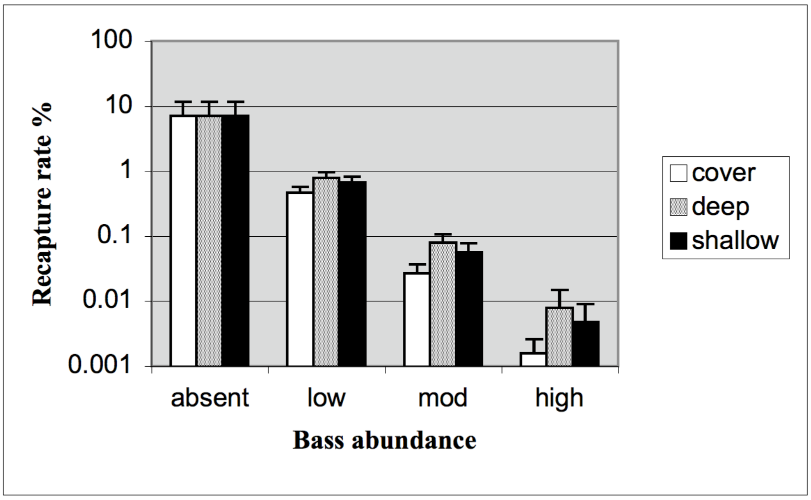


Figure 3.26 Effect of abundance of Australian bass on adjusted mean recapture rates for golden perch released by different strategies. Means adjusted for fixed values of trips with marginal weights held constant for factor size at release. Error bars show one standard error of the mean. Note y-axis is on a log scale.

3.2.3 Influences on growth of barramundi and bass

The number of data points used in analyses of factors that may affect growth is fewer than we would have preferred. This was due to occasional problems with the temperature data-loggers and also due to low recapture rates of bass and barramundi in some years at one or more of the sites (e.g. bass Year 3 at Gordonbrook Dam, bass Year 3 at Simpson's Dam and barramundi Year 4 at Cassava Lagoon). Recapture rates are shown in chapter 2. Low recapture rates meant that growth could not be adequately determined for some time periods at some sites.

In spite of these problems several multiple regressions relating to the dependent variable growth were statistically significant.

Growth of barramundi to six months was positively related to maximum summer water temperatures and relative abundance of snub-nosed garfish. The summary of the regression analysis and the estimates of the parameters in the regression are presented in Tables 3.28 and 3.29. The model accounted for 97.0% of the observed variance in barramundi growth to six months, and the standard error of observations was estimated to be 4.43.

Table 3.28 Summary of multiple regression analysis for the response variate, 'barramundi growth to six months', with terms constant, maximum summer water temperature and relative abundance of snub-nosed garfish.

	d.f	**s.s**	**m.s**	**v.r.**	**F prob.**
Regression	2	3255.30	1627.65	83.11	0.002
Residual	3	58.75	19.58		
Total	5	3314.05	662.81		

Table 3.29 Estimate for parameters in analysis of barramundi growth to six months.

Parameter	**Estimate**	**s.e.**	**t prob**
Constant	199.0	46.2	.023
Max summer water temp	4.43	1.43	.053
Relative abundance snub-nose gar	17.75	1.38	.001

Stepwise regression selected the variables 'relative abundance of hardyheads', 'Log10 CPUE of golden perch', 'SQRT of CPUE barramundi' and 'maximum winter water temperature' as those explaining most of the variance in barramundi growth by 12 months. However, the multiple regression produced from these variables was not statistically significant. Only one parameter in the model showed marginal significance and that was 'SQRT of CPUE barramundi' (p=.071). Forcing 'SQRT barramundi CPUE' into the first step of a stepwise regression resulted in selection of the variable 'relative abundance of bony bream'. Relative abundance of bony bream was positively related to barramundi growth to 12 months and CPUE of barramundi was negatively related to growth. Both these parameters were significant statistically. A summary of the analysis is shown in Table 3.30 and estimates and significance levels of the parameters in the regression are shown in Table 3.31. Total variance accounted for by the model was 87.8% and standard error of observations was estimated at 18.2.

Table 3.30 Summary of multiple regression analysis for the response variate, 'barramundi growth to 12 months', with terms constant, SQRT CPUE barramundi and relative abundance of snub-nosed garfish.

	d.f	**s.s**	**m.s**	**v.r.**	**F prob.**
Regression	2	12540	6270.2	18.94	0.020
Residual	3	992.9	331.0		
Total	5	13533.3	2706.7		

Table 3.31 Estimate for parameters in analysis of barramundi growth to 12 months.

Parameter	**Estimate**	**s.e.**	**t prob**
Constant	505.8	20.2	<.001
SQRT CPUE barramundi	–20.65	3.97	.014
Relative abundance of bony bream	21.88	5.97	.035

Stepwise regression of terms with the response variate ‘bass growth to six months’ resulted in selection of ‘relative abundance of gudgeons (*Hypseleotris* spp)’ and ‘SQRT CPUE golden perch’. Together these accounted for 67.2% of the variance. However, the regression was only marginally significant (F p=.087) and the parameter ‘SQRT CPUE golden perch’ although having a negative relationship with bass growth to six months was not significant statistically (t p=0.111) whilst ‘relative abundance of gudgeons (*Hypseleotris* spp) was positively associated with bass growth to six months (t p=.04).

For bass growth to 12 months the term ‘relative abundance of gudgeons (*Hypseleotris* spp)’ was again selected by stepwise regression and was the sole explanatory variable in the model, explaining 31.6% of the variance. However, the regression model was not significant (F p=0.143). Forcing the term ‘SQRT CPUE bass’ did not result in a significant model either, although CPUE of bass was weakly negatively related with ‘bass growth to 12 months’.

3.2.4 The relationship between success of past stocking programs and impoundment characteristics

Bass

Recapture rates of bass (balanced for stocking effort) could not be significantly related to any of the chemical parameters measured in the dams. These variables were subsequently dropped from the stepwise procedure enabling an analysis of the other variables from a greater number of dams. This resulted in the selection of the variables relative abundance of spangled perch, SQRT electrofishing (ef) catch of silver perch, mean stocking rate of silver perch/ha/5 years, presence–absence of gudgeons, presence–absence of snub-nosed garfish and mean stocking rate of barramundi/ha/5years. A summary of the regression model is presented in Table 3.32 and the estimates of the parameters and their t probability levels are shown in Table 3.33. Total variance accounted for by the model is 91.2%.

Table 3.32 Summary of multiple regression analysis for the response variate, ‘SQRT ef catch rate bass’, with terms constant presence–absence of spangled perch, SQRT ef catch rate silver perch, mean stocking rate of silver perch/ha/5 yrs, presence–absence of gudgeons (*Hypseleotris* spp) presence–absence of snub-nosed garfish and mean stocking rate of barramundi/ha/5 yrs.

	d.f	**s.s**	**m.s**	**v.r.**	**F prob.**
Regression	6	0.064491	0.0107485	21.78	<.001
Residual	6	0.002961	0.0004935		
Total	12	0.067452	0.0056210		

Table 3.33 Estimate for parameters in the analysis of SQRT ef catch rate bass.

Parameter	**Estimate**	**s.e.**	**t prob**
Constant	0.1894	0.0312	<.001
Presence–absence of spangled perch	–0.1118	0.0211	0.002
SQRT ef catch rate silver perch	0.0870	0.0316	0.033
Mean stocking rate silver perch ha/5 yrs	0.002178	0.000689	0.020
Presence–absence gudgeons (*Hypseleotris* spp.)	–0.0865	0.0244	0.012
Presence–absence snub-nosed gar	0.0505	0.0163	0.021
Mean stocking rate barramundi/ha/5yrs	–0.00170	0.0010	0.142

Barramundi

No significant relationship was found between any of the water quality variables and ‘SQRT ef catch of barramundi’. For reasons outlined in the methods section above, electrofishing catch of barramundi was not adjusted for stocking rate. Stocking rate of barramundi was forced into the stepwise regression procedure. This resulted in selection of only one other variable, ‘presence–absence of mouth almighty’, which was positively related to barramundi electrofishing catch rates. ‘Mean stocking rate of barramundi’ and ‘mouth almighty’ accounted for only 36.2% of the variance. The summary of the regression analysis and the estimates of the parameters are in Tables 3.34 and 3.35 respectively.

Table 3.34 Summary of multiple regression analysis for the response variate, ‘SQRT barramundi ef catch rate’, with terms constant, mean stocking rate of barramundi/ha/5 yrs and presence–absence of mouth almighty.

	d.f	**s.s**	**m.s**	**v.r.**	**F prob.**
Regression	2	0.3808	0.19038	6.38	0.009
Residual	17	0.5070	0.02982		
Total	19	0.8878	0.04672		

Table 3.35 Estimate for parameters in the analysis of SQRT barramundi electrofishing catch.

Parameter	**Estimate**	**s.e.**	**t prob**
Constant	0.0637	0.0675	0.358
Mean stocking rate barramundi/ha/5 yrs	0.00442	0.00231	0.073
Presence–absence mouth almighty	0.1886	0.0829	0.036

Silver perch

Inclusion of water quality and biotic variables in the stepwise regression for silver perch electrofishing catch rates (adjusted for stocking) resulted in selection of ‘maximum oxygen levels mg/l’ as an explanatory variable accounting for 63.2% of the variance. This variable was positively related to silver perch electrofishing catch rates but it was only marginally significant (p=.068). Dropping water quality variables from the stepwise procedure to include more dams in the analysis resulted in selection of ‘presence–absence of sleepy cod’ which was negatively related to silver perch electrofishing catch rates. This variable accounted for only 21.1% of the variance. The summary of the regression analysis is in Tables 3.36 and 3.37.

Table 3.36 Summary of multiple regression analysis for the response variate, ‘SQRT ef catch rate silver perch’, with terms constant and relative abundance of sleepy cod.

	d.f	s.s	m.s	v.r.	F prob.
Regression	1	0.0344	0.0034437	6.60	.018
Residual	20	0.1043	0.005217		
Total	21	0.1388	0.006609		

Table 3.37 Estimate for parameters in the analysis of SQRT ef catch rate silver perch.

Parameter	Estimate	s.e.	t prob
Constant	0.1026	0.0170	<.001
Presence–absence of sleepy cod	–0.1026	0.0399	.018

Golden perch

No water quality variables were significantly correlated with golden perch electrofishing catch rates. However, stepwise regression selected the following variables when water quality variables were dropped from the analysis: ‘presence–absence of spangled perch’, ‘presence–absence of Atyid shrimps’, ‘presence–absence of barred grunter’, ‘SQRT ef catch Australian bass’, ‘log10 impoundment surface area’ and ‘SQRT ef catch of silver perch’. Of these only banded grunter and impoundment surface area were negatively related to golden perch electrofishing rates although the former is not significant. A summary of the analysis and estimates of the parameters are shown in Tables 3.38 and 3.39 respectively. The result for spangled perch and bass contradicts those reported earlier in the chapter at 3.2.2.

Table 3.38 Summary of multiple regression analysis for the response variate, ‘SQRT ef catch rate golden perch’, with terms constant, presence–absence of spangled perch, presence absence of Atyid shrimp, presence–absence of barred grunter, SQRT ef catch rate Australian bass, log10 impoundment surface area, and SQRT ef catch rate silver perch.

	d.f	s.s	m.s	v.r.	F prob.
Regression	6	0.019052	0.0031754	7.22	<.001
Residual	15	0.006596	0.0004938		
Total	21	0.025649	0.0012214		

Table 3.39 Estimate for parameters in the analysis of SQRT ef catch rate golden perch.

Parameter	**Estimate**	**s.e.**	**t prob**
Constant	–0.0418	0.0341	0.239
Presence–absence of spangled perch	0.0568	0.0174	0.005
Presence–absence Atyid shrimp	0.0669	0.0226	0.010
Presence–absence barred grunter	–0.0388	0.0158	0.027
SQRT ef catch rate Australian bass	0.0597	0.0165	0.003
Log 10 dam surface area	–0.0058	0.0123	0.646
SQRT ef catch silver perch	0.0339	0.0128	0.018

3.3 Discussion

3.3.1 Predators and other influences on stocking outcomes

Predators of stocked fish and interactions with release strategies size at stocking

The predation experiments reported in this chapter were able to confirm predation of stocked fingerlings of silver perch, golden perch and barramundi by a range of species. This information combined with the analyses of relative abundance of predators in relation to recapture rates of the four species stocked provides information on the likely impacts of the different predators on fingerling survival and interactions with stocking size and stocking strategies. The outcomes from the analyses by GLM's of binomial proportions are interpreted in the following discussion as useful indicators of significant trends but not as absolute predictors of survival.

a) Predators of Australian bass

We did not stock bass into any dams containing mouth almighty or fork-tailed catfish (*Arius* spp.). However, our results from barramundi and silver perch stockings into such situations would indicate that it is highly probable that these species would also prey on bass. We suggest it would be prudent to stock 50–65 mm fish or larger into dams containing these predators. Smaller more abundant size classes of these predators would not have the mouth gape size to take 50–65 mm bass. Nevertheless, larger size classes, particularly of mouth almighty and fork-tailed catfish, certainly could ingest 50–65 mm bass. Large fork-tailed catfish would be capable of ingesting considerable numbers of these fish. Gape size alone does not determine success of predators in taking prey. As prey increase in size, their capacity to evade predators is also enhanced by increased swimming abilities (Brooking, *et al.* 1998). Thus, in the absence of alternative information, stocking 50–65 mm or larger fish would be the precautionary option in waters with these predators.

We did not conduct predation experiments following release of bass, but our analyses of relative abundance levels of various predators and recapture rates of micro-tagged bass provide evidence of probable predation by barramundi and spangled perch.

The effect of barramundi on bass abundance appears to be far more severe than that of spangled perch. The evidence that this negative relationship is most likely due to predation, rather than competition comes from observations of fish in Simpson's Dam. In this dam a population of Australian bass was successfully established before any barramundi were stocked. Several years after this initial stocking, and prior to our stocking experiments commencing, barramundi were also stocked in the dam. By this stage most bass were of a size too large to be preyed on by anything but a very large barramundi. When our experiments commenced there were already adult bass and adult barramundi present and the bass were still abundant. However, in the presence of stocked barramundi, our experimental stockings of bass failed. Only a very small number of our fish were ever recaptured. It is highly likely that, owing to the slow growth rates of bass, our stocked fish could not reach a size quickly enough where they were safe from predation by 60–100 cm barramundi. We did not experience the same problems in other dams with abundant bass, and where barramundi were absent. The natural distributions of barramundi and bass only have a small zone of overlap in the vicinity of Tin Can Bay and the lower Mary River (Allen *et al.*, 2002). It is quite likely that bass have not evolved to cope with a predator-like barramundi.

No interaction between size at stocking of Australian bass and relative abundance of barramundi was detected, but the 50–65 mm size class performed better than other sizes at all barramundi densities, although it must be stated that all size classes did poorly at moderate to high densities of barramundi. Therefore, we caution against stocking barramundi into bass fisheries. If a multi-species fishery for bass and barramundi is considered desirable, we suggest it would only be possible if barramundi densities and stocking rates were kept at a low level. If barramundi densities are too high then there is a risk of failure of bass stockings and the fishery would almost certainly become a 'barramundi only' fishery in the longer term.

In more southern areas, where barramundi fisheries shut down in the cooler months, this may be considered economically and socially undesirable. In contrast, existing bass fisheries offer angling opportunities throughout the year. It is possible that in larger lakes than our test locations the impact of barramundi on bass would not be as drastic as our data suggests, but with bass taking several years to reach the legal size of 30 cm, and with barramundi capable of reaching 90 cm in the same time period, there will be numerous opportunities for barramundi to prey on bass before they enter the fishery.

Spangled perch also seem to have a negative effect on stocking success of Australian bass; however, the abundance of bass does not appear to be reduced as severely by spangled perch as it is by barramundi. Indeed a number of successful bass fisheries have been established in impoundments containing spangled perch. No interaction between size at stocking of Australian bass and relative abundance of spangled perch was detected. Nevertheless, the model indicates (Figure 3.11) that bass stocked at 35–45 mm and 50–65 mm survive relatively better than those stocked at 20–30 mm across all densities of spangled perch.

As for barramundi no evidence of significant negative impacts on the stocking success of Australian bass by long-finned eels was detected. In the 1980s permits were issued to harvest eels from impoundments in Queensland. One of the justifications for this program was to enable development of fish stocking programs. It was assumed that eels were a major predator of stocked fingerlings. At least in the case of barramundi and bass stockings this assumption may have been flawed. Similarly we found no evidence for a negative impact of pre-existing bass populations on the survival of bass fingerlings, although it is possible that there may have been some impacts on growth rates at higher densities. It is quite likely that bass fingerlings have evolved strategies to minimise predation by their own species.

b) Predators of barramundi

The predation experiments provided direct evidence that spangled perch, fork-tailed catfish and mouth almighty are all predators of stocked barramundi fingerlings. Barred grunter were also found to be very minor predators of barramundi, but because of their small mouth gape were only capable of taking the 20–30 mm size class. This species does not appear to be a major piscivore.

It has often been suggested by stocking groups that eels may be major predators of stocked fingerlings. However, we found no direct evidence of predation of barramundi fingerlings by long-finned eels. Even though the possibility that eels may sometimes take barramundi cannot be discounted, stepwise regression followed by GLM of binomial proportions provided no statistical evidence for major impacts of eels on stocked barramundi.

Figures 3.1 to 3.4 suggest that distribution of predators at the time of stocking may have had an influence on the success of different stocking strategies for barramundi in Gooburrum Balancing Storage. For example, in Figure 3.1 it can be seen that the bulk of the predation recorded in 1999 was by fork-tailed catfish in deep water. Subsequent relative survival (Figure 3.2) was lowest for fish released in deep water that year.

In the year 2000 few predators were captured in the vicinity of the deepwater release site and no predation of fish released in the deep zone (Figure 3.3) was recorded. Relative survival for fish released in deep water zone in 2000 was higher than the other two strategies. From this it can be concluded that chance distribution of schools of predators at the time of stocking can influence relative survival. It also suggests that the few hours after stocking may be a particularly critical period. In order to minimise risk of dumping stocked fish onto a school or aggregation of predators we suggest releasing barramundi fingerlings in large batches at several different locations around an impoundment, rather than releasing all fish at a single point.

Cowx (1999) after examining mainly European fisheries data suggests that trickle stocking (frequent planting on a continuous basis of small numbers of fish throughout the water body) improves stocking success through reduced competition with, or predation by resident fish stocks. Cowx (1994) also states that scatter stocking (as we have suggested above) and trickle stocking are generally more successful than single point stocking. Unfortunately stocking groups may often opt for point stocking because it is more easily carried out.

The key predators of barramundi fingerlings (spangled perch, mouth almighty and fork-tailed catfish) in the predation experiments were also shown to have significant negative correlations with barramundi recapture rates. We conclude that these predators do have a potential impact on the success of barramundi stocking programs. There was also an interaction between stocking size and abundance of these predators shown by the GLMs of binomial proportions. This suggests that there is size-selective predation on the smaller size classes. Therefore, it is recommended that stocking groups only stock fish of 50 mm or larger in the presence of these species.

One interesting outcome is that the larger size class stocked (50–65 mm) actually seems to do better in the presence of these predators. Whether this is a function of our simultaneous stocking of the three size classes, whereby the 50–65 mm size class are relieved of interspecific competition from the other two stocked size classes, or whether this is through some other ecological effect, is uncertain. However, the case for stocking 50–65 mm or larger fish in dams with these predators is strong.

In North Queensland and the Northern Territory the mouth almighty is a different sub-species to that which occurred in our study's test impoundments (Allen *et al.* 2002). The northern subspecies grows to a larger size than the southern sub-species (Pollard, 1996). Therefore, in areas north from Mackay and across to the Kimberley in Western Australia, there may be a case for stocking fish at a larger size than our 50–65 mm size class.

Australian bass was one species that did not occur in the site of our barramundi predation experiments. However, bass did occur in the other dams where we stocked barramundi. Our analyses of abundance data show that there is some evidence for size selective predation of 50–65 mm barramundi by Australian bass. This may account for better performances of smaller size classes of barramundi in Cassava Lagoon (see chapter 2). Figure 3.15 also shows an interesting effect, where smaller size classes do better in the presence of bass. This again is probably a function of our simultaneous release of three barramundi size classes, whereby predation of the 50–65 mm size class has lessened interspecific competition with or cannibalism of the two smaller size classes. It should be noted that the relative survival of 50–65 mm barramundi is generally still higher than the smaller size classes, even in the presence of bass. The impact of bass on 50–65 mm barramundi also seems to be far less severe than the impact of the other predatory species on the smaller barramundi size classes.

We would therefore still recommend stocking 50–65 mm or larger barramundi in the majority of situations. Growth rates of impoundment barramundi are so rapid, if they survive the initial stocking period they will quickly reach a size where they are invulnerable to the majority of predators. Recent work in river systems, where barramundi growth is much slower than in impoundments has shown that stocking of 300 mm barramundi gives vastly superior results to smaller sizes and is cost effective (Russell*, pers. com.).

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c) Predators of golden and silver perch

In support of our hypothesis that species that have evolved in isolation from a species of predator may not have developed sufficient avoidance mechanisms to cope with that predatory species, a number of non-Murray-Darling species were implicated in reduced survival rates of stocked golden and silver perch. Predation experiments confirmed long-finned eels as predators of both silver and golden perch. The GLMs of binomial proportions also showed a negative correlation between long-finned eel abundance and recapture rates of both species. This is in contrast to the result for Australian bass and barramundi, two species which have sympatric distributions with eels. The results of the GLMs suggest that eels preyed on all size classes of silver and golden perch that we stocked, but fish stocked at 20–30 mm appear to be at greater risk of predation (Figures 3.18 and 3.24). Certainly more 20–30 mm golden perch were recovered from the guts of the small number of eels we sampled during the predation experiments. The results of the GLMs may reflect a greater abundance of smaller eel size classes in the dams we sampled. In dams with populations of eels we recommend stocking 50–65 mm golden and silver perch ahead of smaller size classes. Translocated populations of these golden and silver perch have probably benefited from the impoundment eel fishery in south-eastern Queensland.

Barramundi are another non-Murray-Darling species we have shown to have an impact on stocking success of golden and silver perch. Both perch species were found in the stomach contents of barramundi during the predation experiments and GLMs of binomial proportions showed significant negative relationships between relative abundance of barramundi and recapture rates of both these species. We actually had no recaptures of either golden or silver perch in dams or years where these species were stocked into waters with abundant barramundi. In those situations where some stocked fish did survive at lower abundance levels of barramundi, it was the larger size classes that did best, but the GLMs indicate no interaction between size at stocking and relative abundance of barramundi. The tendency is for the larger size classes to do best, but recapture rates of all size classes drop off steeply with increasing abundance of barramundi.

In the United States, rainbow trout have traditionally been stocked in spring to take advantage of zooplankton blooms. This system generally works well, except when populations of predatory walleye (*Stizostedium vitreum*) are present. Walleye take a heavy toll on rainbow trout, particularly in the warmer months when their feeding activity is at a peak.

It was found that by stocking larger size rainbow trout later in the season (i.e. autumn) when the feeding activity of walleye was declining, returns to trout anglers in subsequent seasons improved (Yule, *et al.*, 2000). Perhaps a similar strategy could be employed for stocking golden and silver perch into dams dominated by barramundi.

Silver perch and golden perch have much faster growth rates than Australian bass (see previous chapter); therefore, it may be economically feasible to grow on some golden and silver perch for late stockings. We suggest trialling stockings of much larger golden and silver perch into barramundi dams (e.g. 250 mm fish) during late autumn, when barramundi feeding activity slows down. These late stocked fish would be able to continue to grow through the winter season in most barramundi dams and by the time barramundi feeding activity recommences in spring, most of these fish should be safe from predation by all but the largest of barramundi.

The Fitzroy River strain or subspecies of golden perch does co-occur naturally with barramundi in the lower part of the Fitzroy-Dawson system. It is, therefore, possible that stockings of this strain may succeed better in the presence of barramundi than the Murray-Darling strain of golden perch, which is currently stocked into south-east Queensland, including some dams containing barramundi. If the Fitzroy strain also fails in the presence of barramundi, then perhaps late stockings with large golden perch could be implemented for barramundi impoundments in the Fitzroy River Basin. Another option for south-east Queensland would be to phase out stockings of translocated species such as silver and golden perch into barramundi dams and replace these stocking with endemic species such as jungle perch or mangrove jack.

Australian bass are another non-Murray-Darling species that occurs in some dams where golden and silver perch are stocked. There is no doubt that Australian bass will prey on stocked fingerlings of golden and silver perch (Figures 3.6 and 3.7). GLMs of binomial proportions suggest that Australian bass have a negative effect on survival of both silver perch and golden perch (Figures 3.21 and 3.24). In the case of silver perch the impact of bass appears to be far less severe than that of barramundi. The impact of bass is also greatest if fish are stocked at 20–30 mm. Reasonable success rates can still be achieved if fish are stocked at 35–45 mm or 50–65 mm. The impact of Australian bass on golden perch appears to be quite severe (note Figure 3.25 has a log scale for the vertical axis). However, the severity of this effect is probably exaggerated. The GLM that produced this figure did not include effects of eels, barramundi or water level in the result, all of which could have led to reduced recapture rates of golden perch in the presence of bass. In addition our sampling methods had difficulty in capturing golden perch until they were around 12 months old. Post-stocking surveys by QFS have experienced similar problems (Brooks*, pers. com.).

This may relate to some behavioural trait of small golden perch which makes them difficult to detect by electrofishing and netting. This would have influenced our catch rates, especially in year 4 of the project. We suggest that bass do have a negative effect on golden perch survival but that the impact is much less severe than our data suggest. For example, there are a number of bass dams with successful golden perch fisheries. No doubt various other environmental features may influence outcomes in different dams. Our advice would be to stock 50–65 mm golden perch in dams containing Australian bass.

We also detected an interaction between relative abundance of Australian bass and stocking strategies for golden perch (Figure 3.26). In the presence of moderate to high abundance levels of bass, golden perch released into artificial cover seem to do significantly worse. Perhaps the behaviour of golden perch around these structures actually makes them more vulnerable to predation by bass. Thus, the cover devices appear to have had the opposite effect to that intended. It could be that our cover devices were not large enough to provide effective cover for golden perch, or alternatively the fact that the cover devices were suspended rather than benthic may have reduced their effectiveness. The floating cover could have acted as fish attracting devices (FADs) and actually aggregated bass.

*Steve Brooks, Fisheries Biologist, Queensland Fisheries Service.

Two other non-Murray-Darling predators are fork-tailed catfish and mouth almighty. We did not stock golden perch into any dam containing these species. However, based on outcomes for barramundi and silver perch, we suggest that these species almost certainly would prey on golden perch fingerlings. It would make sense to stock 50–65 mm or larger golden perch into dams containing these species. Predation experiment data show that both these species prey on silver perch. The GLM of silver perch data showed that abundance of fork-tailed catfish and mouth almighty were negatively related to recaptures of silver perch. However, as we were unable to recapture any silver perch in the test site with these species we changed our stocking site in Year 4 of the project. This meant we were not able to show a statistically significant effect. However, the presence of silver perch fingerlings in the stomachs of both these species and our failure to recapture any silver perch in Gooburrum balancing storage certainly supports the hypothesis that both these species have a negative impact on stocking success of silver perch. It seems likely that silver perch stockings will fail at locations with high densities of fork-tailed catfish and mouth almighty. If stockings are attempted in such locations we suggest stocking silver perch at 50–65 mm or larger.

Spangled perch are native to the northern Murray-Darling basin. Our predation experiment in Gooburrum Balancing storage revealed that this species does prey on silver perch and GLM of binomial proportions showed that a significant negative relationship existed between relative abundance of spangled perch and recapture rates of silver perch. The GLM did not detect any interaction effect with spangled perch and size at stocking. However, this may in part be explained by the fact that barramundi co-occurred with spangled perch at some sites and thus presumed decimation of silver perch by barramundi may have masked some interactions. Evidence for size selective predation of silver perch by spangled perch comes from a comparison of silver perch recapture rates at Storm King Dam (where spangled perch are absent) and at Tarong Power Station Dam (where spangled perch are the only substantial predator present). Recapture rates of silver perch were much lower at Tarong Power Station Dam than at Storm King Dam, but the 20–30 mm and 35–45 mm size classes faired far worse than the 50–65 mm size class in the presence of spangled perch (Figure 3.19). Therefore, we conclude that in the presence of spangled perch it is best to stock 50–65 mm silver perch and smaller size classes should be avoided.

Spangled perch abundance also had a negative relationship with golden perch recapture rates, but this relationship was not statistically significant. As outlined previously our recapture rates of golden perch were relatively low compared to the other species. Further sampling when the Year 4 stocks increase to a more catchable size may reveal some further significant results. In the absence of evidence to the contrary we suggest stocking 50–65 mm golden perch in dams that contain spangled perch.

Golden perch and silver perch abundance levels were significantly and positively associated. This probably indicates that waters suitable for one species are also suitable for the other, rather than any direct causal and effect relationship. Thus in waters with few non-Murray-Darling predatory species, abundance levels of both silver perch and golden perch can be expected to be higher, but lower in waters where these predators are common.

Other predators

There are a number of other predatory species that occur in eastern and northern Australia that we have not assessed. For example, freshwater long tom, sleepy cods (*Oxyeleotris* spp) and various grunter species in northern Australia; and redfin perch, rainbow trout, brown trout and Murray cod in south-eastern Australia. The majority of these species did not occur at our test sites. Murray cod did, however, occur in Storm King Dam which was assessed only in year four of the project. This dam had our highest recapture rates of silver perch, so it is unlikely that Murray cod have a major impact on silver perch stocking success. We did not recapture many of the golden perch that we stocked, but as outlined previously catch rates may have increased once golden perch reached 12 months old or around 250 mm in size. We did capture numerous golden perch from earlier recreational stockings of 50 mm fish, suggesting that golden perch stocked at 50 mm can establish fisheries in dams with Murray cod populations.

Research by Baxter *et al*. (1985) and Hutchison (1991a) has shown that redfin perch *Perca fluviatilis* are major predators of stocked trout fingerlings. Hutchison (1991a) also showed evidence that survival of rainbow trout could be increased if stocked as yearlings into waters containing redfin perch. The gape size required to take relatively slender trout fingerlings would be less than that required to take a percoid shaped fish of similar total length. Nevertheless redfin perch are known to cannibalise juveniles of their own species and they have been implicated in the demise of small Australian native species (pygmy perch) of similar size and shape to stocked Australian native fish fingerlings (Hutchison, 1991a; Hutchison, 1991b and Morgan *et al*., 2002). To minimise predation risk in the presence of redfin perch and in the absence of any other data we suggest stocking fish at 50–65 mm or larger. It is likely that redfin perch may have a similar effect on stocked silver and golden perch to that of Australian bass or spangled perch in more northern waters.

Until research is done on the impacts of the other potential predators we suggest stocking 50–65 mm or larger fingerlings of Australian native species. For those predators for which we do have data on probable effects, in the majority of cases our data shows that the 50–65 mm size class has survived significantly better in their presence than the 20–30 mm or 35–45 mm size classes. Using the precautionary principle it would make sense to stock 50–65 mm or larger size classes in the presence of most predatory species. The possible impact of some of the other northern predators is touched on briefly in section 3.3.3 below.

Water level at time of stocking

The effect of water level at time of stocking was consistent across all four stocked species, with stocking success markedly better at higher water levels. Water level was selected as a key variable by each of the unforced stepwise procedures. Based on these results stocking at low water levels would appear to be a wasted effort for all species, especially when full supply surface area is less than 10 per cent. It is recommended that, where possible, stocking activities should seek to take advantage of high water levels to ensure greater returns. We suggest that reduced water levels would reduce available cover, potentially reduce available prey for fingerlings and effectively increase the density of potential predators and competitors. Foraging efficiency of predators is also likely to be increased (Miranda, 2001). Such effects are likely to be worse if the dam has recently been rapidly drawn down. In contrast, high water levels should provide greater access to a variety of habitats, have lower densities of predators and competitors and provide greater opportunity for predator avoidance.

Studies in the USA have found that recruitment of a range of reservoir sport fish species is positively related to the water level in the reservoir when the fish were age 0 (Sammons and Bettoli, 2000; Sammons *et al.* 1999). This is consistent with the results of our study, where survival of stocked fish (age 0) is positively related to water level at the time of stocking.

Other habitat variables

A number of other variables selected by stepwise regression were shown to be significant in subsequent analyses by GLM of binomial proportions. Fringing emergent vegetation emerged as a significant variable positively related to recapture rates of barramundi. Certainly in Simpson's Dam where our barramundi recapture rates were the highest, there were extensive beds of fringing emergent reeds (see Figure 3.27). We captured numerous barramundi in these reed beds. The majority of barramundi captured were between 20 and 40 cm total length, although we did find some barramundi up to one metre total length in that habitat. Gut analysis of some fish captured in that habitat suggested they were foraging for shrimp. We also observed recently stocked barramundi (Figure 3.28) using ambush predation on *Gambusia holbrooki* from the cover of emergent vegetation. These emergent reed beds probably suit the ambush predatory behaviour of barramundi. They may also provide cover for juvenile and sub-adult barramundi from larger potential predators, including large barramundi. Larger barramundi were more often found in the open waters or along the edge of the emergent vegetation where potential forage species such as bony bream occurred. Similarly large bass, another potential predator of juvenile barramundi, although occurring amongst the emergent vegetation were more common along the outer edges.

Figure 3.27 Simpson's Dam with fringing emergent vegetation in the foreground and midground (M. Hutchison, photo).

Figure 3.28 Barramundi fingerlings amongst emergent vegetation (K. Chilcott, photo).

Juveniles of Nile perch (*Lates niloticus*) a relative of the barramundi have also been found associated with inshore emergent vegetation in Lake Kainji, Nigeria, while larger Nile perch were generally associated with deeper open waters or areas of inflow (Balogun, 1987). Fringing emergent vegetation, similar to that in Simpson's Dam occurred to a lesser extent in Gooburrum balancing storage and, to a much lesser extent, in Cassava Lagoon, which had more extreme fluctuations in water level within a 12-month period. Relatively stable water levels are more conducive to the development of reed beds. Such habitat is, therefore, more likely to occur in domestic water supply dams in areas with high rainfall than in irrigation dams or areas with relatively low rainfall. Small private dams might be effectively managed for successful barramundi stocking by keeping water level fluctuations within a range that favours development of fringing emergent reed beds and making sure that these are inundated during the six months period after stocking.

Floating macrophyte density was also positively associated with recapture rates of barramundi. Floating macrophytes include *Nymphoides* and *Nymphaea* water lily species. This type of vegetation was most prevalent in Simpson's Dam, followed by Gooburrum and Cassava Lagoons. During electrofishing operations we regularly found barramundi associated with this type of habitat, including large barramundi around 1 metre in total length. As was the case for fringing emergent vegetation, dense stands of floating macrophytes probably suit the ambush predatory behaviour of barramundi. Floating macrophytes also provide cover from piscivorous raptors such as sea eagles and brahminy kites that are potential predators of barramundi in the first 12 months after stocking.

Macrophyte (submerged macrophyte) density was negatively associated with recapture rates of Australian bass, silver perch and golden perch. Dense, extensive beds of submerged macrophytes such as *Hydrilla* and *Ceratophylum* affect the efficiency of electrofishing and gill netting operations. During electrofishing operations stunned fish that sink into weed beds are difficult to see and recover with a dip net. It is even physically difficult to dip net those fish that can be seen from dense submerged macrophyte beds. Thus, it is likely that the negative effect of macrophyte density is at least partly related to effects on sampling efficiency. Although these beds often support shrimp, a potential food source of stocked species, we also observed mouth almighty and spangled perch in macrophyte beds. If dense weed beds favour these predatory species it may also explain why macrophyte density was negatively associated with recapture rates of bass, silver perch and golden perch.

The only other environmental variable selected by stepwise regression was the modal width of the treed edge. This variable was selected in conjunction with macrophyte density, water level at time of stocking and relative abundance of long-finned eels. This had a weak but significant negative relationship with recapture rates of silver perch. Thus recapture rates of silver perch tended to be slightly higher in dams with a narrower treed edge. We do not know if there is a direct causal link or some secondary feedback mechanism between the treed edge and catch rates of silver perch. Certainly anglers targeting silver perch in south-east Queensland impoundments report greater fishing success over muddy flats from relatively bare banks rather than in timbered areas with woody debris (R. Cheetham* pers com.).

It may be that these cleared areas are more conducive to Chironomid production. Examination of silver perch gut contents from south-east Queensland impoundments has revealed that large quantities of chironomid larvae are consumed by silver perch (R. Cheetham* pers com.).

3.3.2 Influences on growth

Barramundi

Growth of barramundi in the first six months after stocking was positively correlated with maximum summer water temperature and relative abundance of snub-nosed garfish. It is well known that high water temperatures promote barramundi growth rates, and indeed we heated tanks to 30ºC to speed up growth rates of some batches of barramundi (see chapters 2 and 4). Snub-nosed garfish are a potential prey species for barramundi. Our observations suggest that snub-nosed gar spawn in spring and early summer. Juvenile snub-nosed gars are abundant in summer and these could contribute substantially to the diet and growth of age 0+ barramundi. Breeding populations of snub nosed gar are present in a number of impoundments in south-eastern and central Queensland, but attempts to establish impoundment populations further north have to date failed. However, successful establishment of gar populations may be beneficial to early barramundi growth. Other species of fish or crustaceans not present in our test dams may also be significant contributors to barramundi growth rates in other waters.

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Catch per unit effort of barramundi (read barramundi population density) and relative abundance of bony bream were found to contribute significantly to growth outcomes in the 12 month period following stocking of barramundi. The CPUE of barramundi was negatively related to barramundi growth. This suggests a density dependent competition effect as barramundi increase in size. Density dependent effects on growth of fish due to intra-specific competition for food resources has been reported for a number of species including *Perca fluviatilis, Perca flavescens,* Tilapia (*Oreochromis niloticus*) and Kokanee salmon (*Oncorhynchus nerka*) (Ostazeski and Spangler, 2001; Hansson *et al.*, 1996; Persson *et al.*, 1996; Persson and Greenberg, 1990; Rothuis *et al.*, 1998 and Rieman and Myers, 1992).

Density dependent effects on growth can be more pronounced in lakes with lower productivity (Rieman and Myers, 1992) which in Queensland could be those lakes with small or no populations of bony bream (see below). We recommend that post-stocking monitoring of growth should be carried out at stocked impoundments to ensure that overstocking does not take place and that density dependent reductions in growth are avoided. Figure 2.23 in the previous chapter certainly suggests that stocking levels in Simpson Dam were leading to reduced growth rates.

The positive relationship between relative abundance of the bony bream, *Nematalosa erebi* (Clupeidae) and growth of barramundi is not surprising. This species is well recognised as prey of large barramundi. Pearce* (pers. com.) has found bony bream of 30–80 mm to be prevalent in the diets of large barramundi in Tinaroo Dam. We also found bony bream to be the main item in the guts of barramundi of the 40–60 cm size class captured in Gooburrum Balancing storage and fish from this impoundment were well conditioned (Figure 3.29).

Bony bream feed on benthic algae, detritus and small invertebrates and commonly reach 15–20 cm (Allen et al., 2002). Thus, bony bream are relatively near the base of the food chain, yet are an ideal sized prey species for a large predatory fish such as barramundi. In the USA threadfin shad and gizzard shad (Clupeidae), which are very similar to the Australian bony bream, are stocked into impoundments to optimise prey availability and to establish a dynamic forage base (Anonymous, Texas Parks and Wildlife, 1990).

Early in the Queensland State Government fish enhancement program, bony bream were transplanted into several impoundments in Queensland to provide forage for stocked species. Impoundments with large populations of bony bream are now generally recognised by the angling community as producing better conditioned fish than dams without bony bream or dams in which bony bream are scarce. These bony bream dominated impoundments are the subject of many popular magazine articles that allude to the role of bony bream (e.g. Schultz, 1999). We expect intraspecific competition effects on growth of barramundi to be less in dams with large populations of bony bream.

We recommend that the abundance of bony bream and the structure of bony bream populations and other forage species should be monitored as part of any ongoing fish stocking program in order to prevent overstocking that may lead to declines in bony bream abundance or size structure and a decline in quality of the fishery.

Figure 3.29 Well conditioned age 1+ barramundi from Gooburrum Balancing Storage, a bony bream dominated impoundment. Compare these fish to the 2+ barramundi (inset) from a dam with low abundance levels of bony bream (K. Chilcott photo).

Bass

Low recapture rates of bass in some years or at some sites resulted in less growth data points being available for bass than barramundi. This may in part explain why few significant relationships between growth and other variables were found. However, relative abundance of *Hypseleotris* spp. was positively related with bass growth to six months (p=.04). *Hypseleotris* gudgeon species are a recognised prey species of Australian bass. These planktivorous gudgeons can form vast schools in the open water of impoundments. Bass have been used in biomanipulation experiments to control these gudgeons in an effort to reduce blue green algae blooms through feedback mechanisms in the food-chain (Matveev, 2002). The fact these experiments were able to impact on gudgeon abundance levels does indicate the importance of this species to bass.

Although not significant, the negative relationship between growth of Australian bass and abundance of golden perch does suggest the possibility of some type of competitive interaction occurring between bass and golden perch. Such competition may also account for why golden perch stockings seemed to succeed better in our test dams with low abundance levels of bass.

No statistically significant relationship was found between any variable and growth of bass to 12 months. Relative abundance of *Hypseleotris* spp was selected by stepwise regression, but only explained 31.6% of the variance. As outlined above, *Hypseleotris* spp. are a significant prey item of bass. Many anglers believe that bony bream contribute to rapid growth and large maximum sizes in Australian bass (e.g. Schultz, 1999). Unfortunately the dams we selected for our bass stocking trials either had low abundance levels of bony bream or bony bream were absent.

Stepwise regression did not produce any evidence for intraspecific competition in bass, although growth rates of bass were weakly negatively correlated with CPUE of bass. Plots of growth rates for bass from Cassava Lagoon (Figure 2.21, chapter 2) show declining rates of growth in each subsequent year of stocking. These plots certainly suggest a density dependent decline in growth rates. The failure of regression analysis to detect such a trend may in part be related to low recapture rates of micro-tagged Australian bass in some of our test dams with high pre-existing abundance levels of bass due to either predation by subsequently stocked barramundi populations or loss of recently stocked bass over the dam wall in a major flood event. As for barramundi stocking programs, we recommend post stocking monitoring of bass growth and condition factors and monitoring of the abundance and structure of forage species populations in order to manage stocking programs to prevent overstocking.

3.3.3 Information from other dams

As outlined in the methods section, for the majority of non-stocked species in dams outside those used in our experiments we have had to rely on presence absence data to keep information standard between impoundments. It would have been preferable to use some type of abundance measure, but this type of data was not consistently available from the report data we used. The discussion that follows is in the context of this data limitation.

Australian bass

No physicochemical variables emerged as significant in explaining catch rates of Australian bass in Queensland impoundments. However, several species of fish emerged as significant explanatory variables. The negative relationship between presence and absence of spangled perch suggests that spangled perch may impact on bass survival. This is consistent with our findings from our stocking trial sites. We suggest the most likely impact is predation of bass fingerlings at the time of stocking.

The mean stocking rate of barramundi was weakly, but negatively associated with Australian bass catch rates. There were very few sites where both bass and barramundi had been stocked together, which may account for the weakness of the relationship, but the result is consistent with our earlier findings for a negative impact of barramundi stockings on recruitment of bass into a fishery.

‘Presence–absence of gudgeons (*Hypseleotris* spp)’ was negatively associated with recapture rates of bass. In section 3.3.2 we presented evidence that gudgeons were an important food source for bass and positively related with bass growth rates. At first this negative relationship may seem contradictory, but it is possible that large numbers of bass may adversely impact on the numbers of gudgeons, to the extent where they become rare or absent in an impoundment and not detected in post stocking surveys. As pointed out above bass have been used successfully to control gudgeon numbers.

The term ‘presence–absence of snub-nosed gar’ was positively associated with bass recapture rates. Snub-nosed gar are a prey species of Australian bass and occur naturally in a number of south east Queensland impoundments and have been stocked by the Queensland Department of Primary Industry and Fisheries into additional impoundments in south-east Queensland. Snub-nosed garfish are prolific breeders and founding populations of 300 adults have been able to establish large self-sustaining populations within two years of stocking. Garfish are microphagic omnivores, feeding on filamentous algae and plankton. They are therefore low down in the food chain and an ideal prey species for impoundment fisheries. This additional food source provided by juvenile gar may well be beneficial to bass populations. The high fecundity and fast growth of snub-nosed gar probably prevented bass having a significant impact on the gar populations.

Unexpectedly catch rates of silver perch were positively associated with Australian bass catch rates. Given the results from our test stocking sites we would have expected a negative association. The positive association between silver perch stocking rates and bass stocking rates probably reflects the fact that dams with high stocking levels of bass are also likely to receive high numbers of silver perch. However, the subsequent positive association between bass catch rates and silver perch catch rates suggests that the negative relationship we detected in our test stocking impoundments may not hold at all sites. One possible explanation is that in large impoundments (e.g. 100s–1000s hectares) there may be more opportunity for silver perch and bass to segregate by habitat type than was the case in our smaller test sites. Other possibilities include presence of more desirable alternative prey species, which may reduce predatory pressure from bass. We do not think that the silver perch populations themselves have had a positive effect on bass survival. It is more likely that impoundments with conditions that have been conducive to bass survival have also favoured silver perch. Whatever the explanation this outcome certainly suggests that a wide ranging detailed and controlled study on impoundment characteristics and their relationships with stocking success of different species is required. In our present assessment of Queensland impoundments we have been unable to include a wide range of habitat characteristics as such data was not recorded in any published reports.

Barramundi

As for Australian bass, no water quality variables were significantly related to catch rates of barramundi. The only significant explanatory variable to emerge from the analysis of Queensland post-stocking survey data was ‘presence–absence of mouth-almighty’. This variable was positively associated with barramundi recapture rates.

At first this may appear to contradict our findings earlier in the chapter. However, a closer examination of our data (See Figure 3.14) shows that the effect of mouth almighty was negative on fish stocked at 20–30 mm and 35–45 mm, but positive for fish stocked at 50–65 mm. Many (but not all) of the barramundi stocked in Queensland have been fish greater than 50 mm TL. As discussed earlier the result in Figure 3.14 may in part be explained by reduced intraspecific competition with the smaller size classes stocked simultaneously. Nevertheless the result using post-stocking survey data also suggests that there may be other reasons why mouth almighty might have a positive effect on barramundi survival. Perhaps mouth almighty reduce the abundance of other potential competitors or predators of stocked barramundi, or perhaps mouth almighty quickly become the prey of barramundi stocked at 50 mm or larger. This subject requires further investigation, but does not change our recommendation that barramundi should be stocked at 50 mm or larger in dams with mouth almighty present.

Silver perch

Silver perch recapture rates were not explained by any physico-chemical variables at the 5% significance level, however ‘maximum oxygen levels’ did account for 63.2% of the variance in those dams for which physicochemical data was available (p=0.068) and is worthy of some discussion.

Fish kills in impoundments consisting mainly of large silver perch are not uncommon in south-east Queensland following storms after a long dry period. These fish kills are generally attributed to low oxygen levels. Therefore, it is possible that silver perch, particularly large specimens, are less tolerant of low oxygen levels than the other stocked species. It may, then, be expected that silver perch are more abundant in dams that rarely experience low levels of dissolved oxygen. Contrary to this, however, is the fact that high oxygen levels (maximum oxygen levels) are often experienced in eutrophic impoundments during the daylight hours due to phytoplankton and macrophyte photosynthetic activity, but these same dams often experience very low oxygen levels at night. Nevertheless, without additional information on the habitat conditions in the impoundments monitored by post-stocking surveys it is difficult to draw any firm conclusions.

The only other variable of note to emerge from the analysis of silver perch post stocking survey data was ‘presence absence of sleepy cod’. This variable was negatively related to catch rates of silver perch. Sleepy cod *Oxyeleotris lineolata* have been illegally translocated into a number of impoundments where silver perch are currently stocked. Sleepy cod are an ambush predator and it is possible that this species could have an adverse impact on stocked silver perch fingerlings. Sleepy cod do not co-exist with silver perch within their natural range. This is a further example of a negative association between silver perch and a non-Murray-Darling Basin predatory fish species.

Golden perch

Analysis of data from our test sites found no significant relationship between relative abundance of spangled perch and recapture rates of golden perch, but the data did suggest a negative association. In the analysis of Queensland post stocking survey data, ‘presence absence of spangled perch’ is positively associated with catch rates of golden perch. This result may in part be influenced by the inclusion of surveys from various Murray-Darling Basin sites where spangled perch are present, but non-Murray-Darling predators are absent. If golden perch do survive better in the absence of non-Murray-Darling predators as our earlier data suggests, then this could account for the positive association between spangled perch and golden perch. Abundance data, rather than presence absence data would make these types of relationships a little clearer.

Silver perch catch rates were positively associated with golden perch catch rates, which is consistent with data from our experimental stocking sites. As outlined earlier we do not believe this relationship to be causal, but a reflection of the fact that dams that are suitable for silver perch are also likely to be suitable for golden perch. This probably reflects underlying factors such as the predatory species present or various habitat parameters. Given that both species are of Murray-Darling Basin origin, such an association is not surprising.

‘Presence–absence of barred grunter’ was negatively associated with golden perch recapture rates. Barred grunter were shown in our predation experiments to be minor predators of small barramundi and silver perch fingerlings. Given the small gape size of this species it is unlikely that they would take 50 mm or larger golden perch. This is the main size class stocked in south-eastern Queensland impoundments. However barred grunter is an aggressive species and will attack other species (Leggett and Merrick, 1987; Allen *et al.*, 2002). Such harassment could negatively impact on the survival of newly stocked fingerlings. Similarly, survival of golden perch has been found to be lower in dams containing *Gambusia*. *Gambusia* are too small to prey directly on golden perch fingerlings but their habit of nipping fins can cause stress and disease and eventually lead to the death of affected fish (Barlow, 1983).

Golden perch have been stocked into a number of impoundments within the natural range of barred grunter. Barred grunter have also been accidentally translocated to additional impoundments in south-east Queensland and to the Clarence River in NSW. Translocation of barred grunter could prove to be detrimental to stocking programs for golden perch. This is just one more example of a non-Murray-Darling species that can impact negatively on golden perch.

Golden perch catch rates were positively associated with presence absence of Atyid shrimp. Atyids are present in most waterways and impoundments in south-east Queensland. There is little published information on the diets of golden perch but their food is reported to consist mainly of crustaceans (Harris and Rowland, 1996). Therefore, it is reasonable to assume that Atyid shrimp are probably a prey item of golden perch and that their presence in an impoundment may have a positive outcome for golden perch survival.

The only other variable to emerge as significant in the analysis of factors affecting golden perch catch rates was the catch rate of Australian bass. Catch rates of Australian bass were positively related to golden perch catch rates. Despite evidence we have presented for bass being a potential predator of stocked golden perch fingerlings and further circumstantial evidence for possible competition between the two species, there must be certain situations where the two species can co-exist with minimum harm to each other. The contradictory outcomes from the post stocking survey data and our own experiments show the need for further research into the importance of impoundment characteristics. It is quite probable that different impoundment characteristics can result in different outcomes for the same species combinations.

We recommend development of a research project that quantitatively assesses a range of water quality, habitat and biotic characteristics of impoundments and investigates their relationship with outcomes from existing stocking programs. This has been done for a number of stocking programs in the USA (Anonymous, 1990; Gilliland and Boxrucker, 1995) and has led to species specific stocking guidelines based on physical and biological criteria.

3.3.4 Key recommendations and findings

Mouth almighty, spangled perch and fork-tailed catfish are key predators of stocked barramundi fingerlings. The impact of these species is severe on barramundi stocked at less than 50 mm TL. We recommend stocking barramundi and other species at 50 mm TL or larger in the presence of these species.

There is evidence that predation of stocked fingerlings is in part determined by chance distribution of schools of predators at the time of stocking. We recommend stocking fingerlings in three to four large batches around an impoundment to spread the risk.

There is evidence that non-Murray-Darling predatory fish species have an adverse effect on the survival of stocked golden and silver perch fingerlings. Silver perch and Murray-Darling strain golden perch stockings are likely to fail in the presence of barramundi. We recommend against stocking Murray-Darling strain golden and silver perch into dams containing barramundi and suggest stocking 50–65 mm fish or larger into dams containing other non-Murray-darling predatory species as there is some evidence for size selective predation.

There is evidence for poor survival of Australian bass fingerlings of all size classes stocked into dams with moderate to high densities of barramundi. We recommend against stocking bass into dams with barramundi, unless barramundi numbers are low.

Water level at time of stocking was positively related to stocking success for all species. We recommend stocking at high water levels and avoiding stocking when impoundments have been drawn down to less than 10% full supply surface area. Low water levels are likely to increase competition and opportunities for predators of fingerlings.

There is evidence that overstocking can lead to reduced growth rates in Australian bass and barramundi.

Survival of stocked barramundi fingerlings is likely to be higher in dams with extensive fringing emergent vegetation or floating macrophyte beds. There may be potential to manipulate conditions in some dams to favour development of this type of habitat.

Barramundi are more likely to achieve high growth rates in dams with high summer water temperatures and large populations of snub-nosed garfish and bony bream. It is likely that bony bream benefits the growth of other stocked species but this requires further research.

We recommend post stocking surveys of growth rates, condition factors and abundance of potential prey items to help managers make decisions that prevent overstocking and potential damage to a productive fishery.

There is evidence that growth rates of Australian bass in the first 6 to 12 months after stocking are higher in dams in which *Hypseleotris* gudgeon species are abundant.

Further quantitative research is required on the outcomes of stocking in relation to physical, chemical and biotic characteristics of impoundments. This work should be divided up into geographical regions and encompass as many dams that are in current stocking programs as possible. The aim of this research should be to provide species specific stocking guidelines for different regions based on known characteristics of an impoundment.

Chapter 4: Reliability of scale patterns as batch marks

Objective

To verify the reliability of scale pattern analysis as a means of identifying different batches of fish.

4. 1 Methods

Our investigation into cost-effective strategies for stocking barramundi fingerlings (*Lates calcarifer*) into impoundments (see chapter 2) provided the opportunity to verify the reliability of scale circulus patterns as discriminators between different batches of this species. Batches of barramundi fingerlings were micro-tagged with either VIE or CW tags and released into impoundments over a three year period.

Each batch represented a distinct size-class or release strategy of fingerling.
The tagged fingerlings were then recaptured up to two years after stocking, allowing us to compare the scale circulus patterns of barramundi from the different batches and assess whether they differed sufficiently to discriminate between batches.

4.1.1 Temperature manipulation

Approximately 30 000 barramundi larvae (18 mm; 27 days old) from the Gladstone Area Water Board Hatchery were received at the Southern Fisheries Centre (SFC) in each of three successive years (1998/9–2000/1). Each year, the larvae were divided into equal batches of 10 000, and placed into three aerated, flow-through holding tanks to which filtered seawater (35 ppt) was delivered. Tanks 1 and 2 (5000 L) were heated to 25 ℃ and 30 ℃ respectively using 3 kW titanium immersion heaters.

Tank 3 (2000 L) was maintained at 18–20 ℃ by circulating water through an in-line thermostatically controlled chiller unit (Aqualogic 1/3 hp with Aquadyne Octopus 3000 programmable computer monitoring system). This tank was fitted with a lid and insulated with high-density foam. In all three tanks, water temperature was maintained at the required level by adjusting the rate of seawater flow-through. Barramundi were held in the three tanks for up to 33 days, by which time they were within the required size ranges of 20–30 mm, 35–45 mm and 50–65 mm respectively.

In the fourth year of the project (2001/2), an estimated 23 000 barramundi larvae (18 mm; 29 days old) from the Gladstone Area Water Board Hatchery were divided equally among four tanks at SFC. The tanks were supplied with filtered seawater (35 ppt) and were well aerated. Tanks 1, 2 and 3 (5000 L) were each intermittently heated by two 3 kW titanium immersion heaters with thermostats set at 30 ℃. When not heated, the water temperature in each tank dropped to ambient levels.

The periods of heating in each tank were alternated in an attempt to induce differing scale circulus patterns among the three batches of barramundi. Temperatures were manipulated so that the three batches of barramundi were of a comparable size range (50–65 mm) by the end of the 30 day grow-out period. The barramundi in tank 4, which was maintained at approximately 20 ℃ using the cooling system outlined above, attained a size of 20–30 mm by the end of the grow-out period. This latter tank was not used in the discriminant analysis, its sole purpose being to produce a small size class for stocking experiments (see chapter 2).

Each year, barramundi to be used in stocking trials were tested for nodavirus when they were between 42 and 50 days old. A positive result to the test was obtained in Year 1, and all of that season's barramundi were humanely destroyed and disposed of. No further evidence of nodavirus was found in barramundi from the subsequent three years, and these fish were tagged with VIE (35–45 mm and 50–65 mm size classes) or CW (20–30 mm size class) and released as described in chapter 2.

4.1.2 Hatchery reference scale set

Each year prior to the commencement of tagging, 50–100 barramundi were randomly sampled from each tank and euthanased with a heavy dose of clove oil. Ten scales were removed from beneath the left pectoral fin of each fish with a pair of sharp forceps and placed on a glass slide so that they did not overlap. A second glass slide was then taped over the scales to hold them in place, and a label attached.

4.1.3 Recaptured barramundi scale set

Impoundments in which tagged barramundi had been released were sampled quarterly by electrofishing and gill netting until April 2002. Each barramundi captured was checked for VIE and CW tags (see 2.1.5), the length of the fish recorded, and between two and six scales removed from under the left pectoral fin. Scales were checked to ensure that they were original (i.e. not regenerated), and then sandwiched between two glass slides and labelled according to the tag carried by the fish. If no tag could be found, the fish was euthanased for later inspection (see 2.1.5). In the majority of cases a VIE tag was detected after dissection. All other barramundi in which a VIE or CW tag was detected were released alive after removal of scale samples.

4.1.4 Circulus data acquisition.

Scale circuli data were acquired using a digitised image-recording device and image analysis program. OPTIMAS was the program used in Years 2 and 3 of the project. However, this program became unstable in Year 4 of the project and was replaced by a new program IMAGE-PRO 4.1. Reference scale sets were compiled from the 50–100 samples taken from each hatchery tank before tagging commenced (see 4.1.2). Each sample was scanned to select the clearest example of an original, non-regenerated scale, an image of which was then acquired with OPTIMAS or IMAGE-PRO (100x magnification). A straight line was superimposed over this video image, originating within the first circulus and extending towards the anterior edge of the scale. The intersection of this line with each circulus received a digital mark (Refer to Figure 4.1).

A cumulative measure of distance between consecutive marks along this line were converted to an incremental measurement and recorded for that sample in an Excel data base file. These data were then converted into an index based on a relative distance measure. The index was used so as to minimise the effect of differences of actual circuli distances between scales within the same batch of fish (i.e. related to the different sizes of individuals, e.g. 50–65 mm) or variation between individual scales from a fish. The objective was to describe the scale pattern.

Figure 4.1 Barramundi reference scale from 35–45 mm fingerling, with line showing marked circuli along the radius they were measured.

Figure 4.2 Scale from a recaptured stocked barramundi.

4.1.5 Analysis of scale pattern data

Scale pattern data were exported from Excel into Genstat ™ for discriminant analysis (see Willett, 1996 and Palmer *et al.*, 2000). Discriminant analysis was used to allocate unknown (recaptured samples) to categories based on data derived from the reference set of scales. In essence the reference scales are used to train the program to discriminate between unknown samples. The maximum number of circuli that can be used in discriminant analysis is the least number of circuli laid down on the reference scales in any of the batches of fish to be compared. The data collected from hatchery and impoundment recapture samples allowed comparisons between recaptured fish and reference fish and permitted an evaluation of the effectiveness of scale patterns as a batch tag for barramundi.

Most studies have relied on the performance of discriminant analysis to reallocate reference sets of scales to their correct categories to estimate accuracy of allocation of unknowns to their correct categories (e.g. stocked and wild fish). However, our micro-tagging enabled us to know the true identity of recaptured fish and to assess the actual success rates of allocating recaptured fish to their correct category. In Years 2 and 3 the analysis examined success in discriminating between fish that had been released at different sizes (i.e. 20–30 mm, 35–45 mm and 50–65 mm) in the same year. We were also able to compare reference samples of the same release size, but released in different years. In Year 4, the comparison was extended to discriminating between batches of fish that had been released at the same size (50–65 mm) but grown under separate temperature conditions in the same year.

4.2 Results

4.2.1 Comparison of scale patterns between size classes

Barramundi of the same age (in days) put down different numbers of circuli according to their growth rate. The smallest size class had only 9–16 circuli. The number of circuli in the most slowly grown group (20–30 mm) was significantly less than the number in the two larger size classes (Figure 4.3). There was also considerable variation in the number of circuli laid down by fish within each size class. This is possibly related to the size range within each size class.

The variation in number of circuli meant that any discriminant analysis between all size classes was dependent on examination of only a small number of circuli, i.e. the least number present across all groups. Eleven circuli in Year 2 and only nine in Year 3. That is the least number of circuli in any sample (Figure 4.3).

Discrimination of “unknowns” was also dependent on this minimum number of circuli. Up to the first seven circuli were probably laid down under the same grow out conditions across all three groups. As few as two circuli may have been laid down by the 20–30 mm size group in the time in which fish were held in the laboratory.

However, the spacing of these two circuli can also change the relative measures of the other circuli in the scale. Nevertheless, additional circuli laid down by the two larger size classes, which may have improved discrimination, had to be eliminated from the analysis.

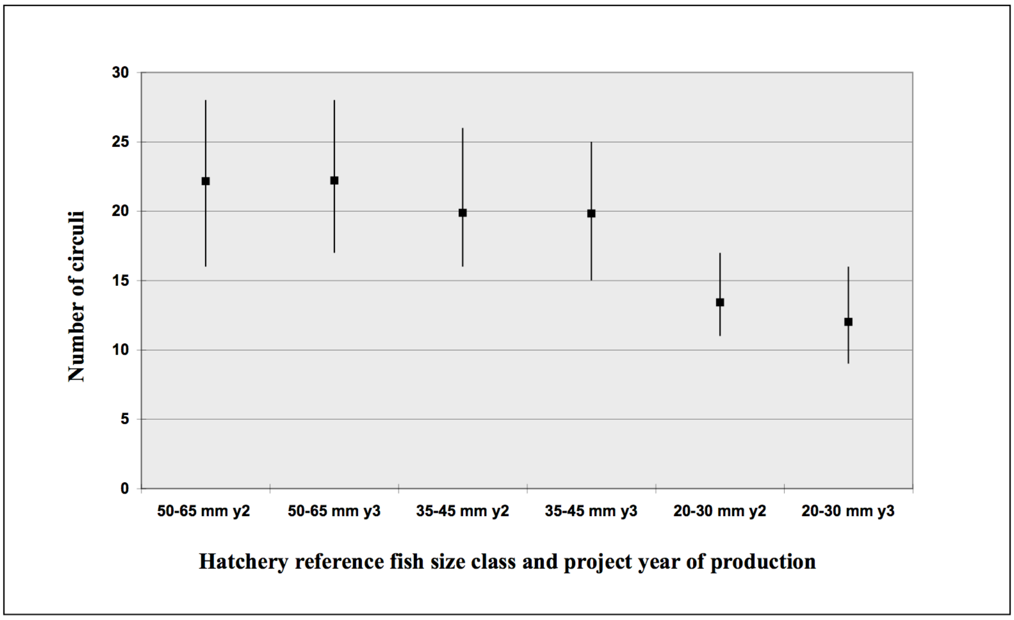

Figure 4.3 Comparison of the mean number of circuli recorded from scales of small (20–30 mm), medium (35–45 mm) and large (50–65 mm) barramundi released in Years 2 and 3 of the project. Error bars show the range of the number circuli recorded.

For fish stocked in 1999 (Year 2) and 2000 (Year 3), excluding the second circulus from the analysis gave the best result. Hatchery reference scales correct reclassification rates and correct classification rates of scales from recaptured fish are shown in Tables 4.1 and 4.2 for the 1999 and 2000 stockings respectively. The reclassification rates for hatchery reference scales were better than random (i.e. 33.33%) but still had a relatively poor level of accuracy. With two exceptions (the 35–45 mm size class (1999) and the 20–30 mm size class (2000)), the results for recaptured fish are much poorer than those from the hatchery reference fish and are near random reallocation levels (Tables 4.1 and 4.2). Including scales from fish at large for more than 12 months resulted in even poorer reclassification rates (Table 4.1).

Table 4.1 Discriminant analysis of three size classes of fish stocked in 1999.

Release size class	Correct classification rates % by discriminant analysis		
	Hatchery Reference fish	Recaptured 0+ fish	Recaptured 0+ and 1+ fish
50–65 mm	53.06	39.53	38.78
35–45 mm	53.57	56.76	52.50
20–30 mm	65.96	28.12	26.90

Table 4.2 Discriminant analysis of three size classes of fish stocked in 2000.

Release size class	Correct classification rates % by discriminant analysis	
	Hatchery Reference fish	Recaptured 0+ fish
50–65 mm	54.00	25.00
35–45 mm	57.14	33.33
20–30 mm	54.76	57.1

4.2.2 Discrimination of scale patterns between year classes

Scale circuli formation rates were found to vary little between the two years (Figure 4.3), However, as both early hatchery and laboratory conditions were unlikely to be identical between years there was potentially greater scope for different scale pattern formation. This enabled discriminant analysis between year classes of each size class to be investigated. Greater numbers of circuli could be used when comparing the 35–45 mm fish from each year class and also when comparing the 50–65 mm fish. Correct classification of each year class batch varied from 62 to 90 per cent (dependent on size class) of scale samples examined through discriminant analysis. Mean index values for circuli from 50–65 mm and from 35–45 mm hatchery reference fish are shown in Figures 4.4 and 4.5 respectively. For the 35–45 mm and 50–65 mm size classes, discriminant analysis was based on the first 15 and first 16 circuli respectively.

Reclassification of hatchery reference scales

Figures 4.4 and 4.5 suggest some difference between the year classes and reclassification of scales of large (50–65 mm) hatchery reference samples was successful for 90% of Year 2 samples and 86% of Year 3 samples. For the 35–45 mm size class, 90.9% of Year 2 reference scales and 87.8% of Year 3 reference scales were correctly reclassified. This is a much higher reclassification result than that between size classes stocked in the same year (see Tables 4.1 and 4.2) when fewer circuli were relied on for discrimination. The reclassification results of the small size class (20–30 mm) reference scale samples were poorer than for the two larger size classes, being 65.96% and 61.9% correct reclassification for Years 2 and 3 respectively. The analysis for these was based on fewer (9) circuli than was possible for the larger two size classes. A level of 62–66% correct reclassification is at a level higher than attributable by chance (i.e. 50%) but misclassification rates are still high, being 38% and 34% respectively.

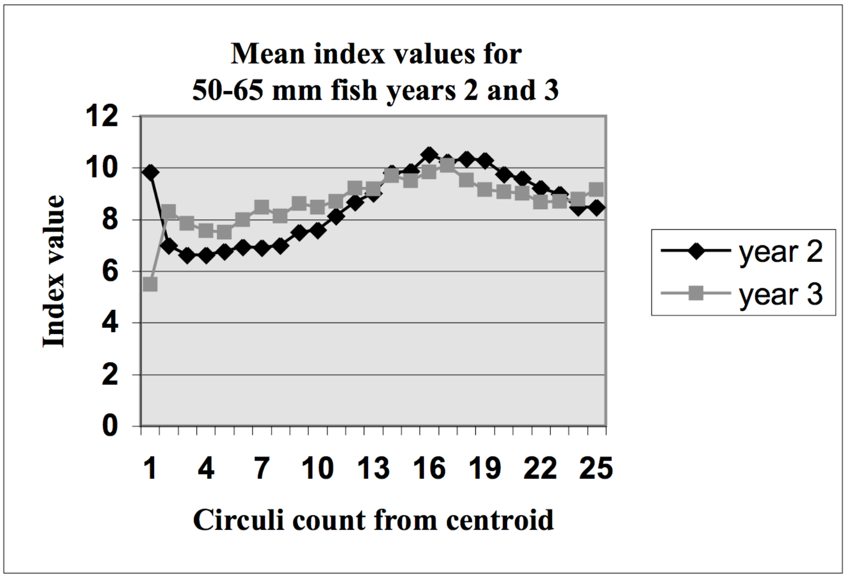

Figure 4.4 Comparison of the mean index values for circuli from 50–65 mm hatchery reference fish in Years 2 and 3. Only circuli 1–16 could be used in the analysis.

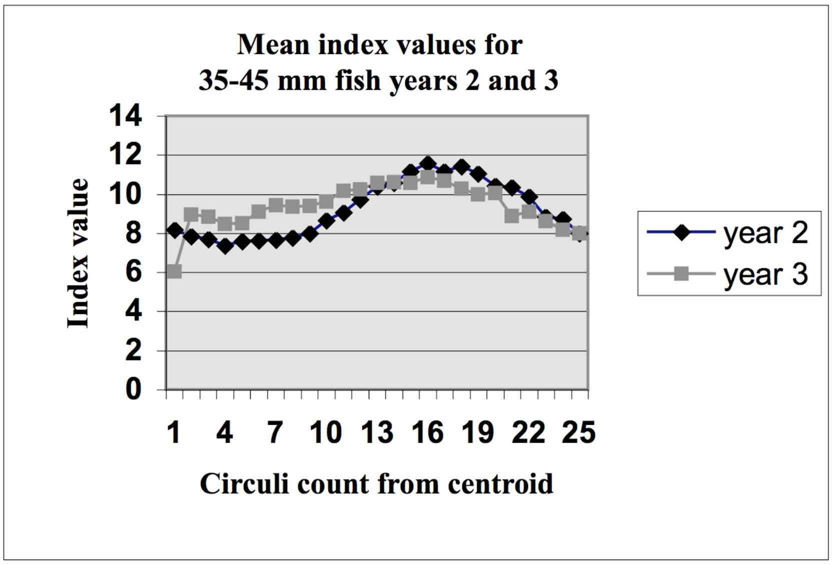

Figure 4.5 Comparison of the mean index values for circuli from 35–45 mm hatchery reference fish in Years 2 and 3. Only circuli 1–15 could be used in the analysis.

Discrimination of scales from recaptured fish

Correct batch identification of recaptured fish scale samples produced variable results. For the 35–45 mm size class, recaptured fish stocked in Year 3 of the project were correctly classified by scale pattern analysis at a rate of 85.6%. However, only 42% of recaptured fish stocked in Year two of the project were correctly classified. Of the 50–65 mm size class, 95.4% of recaptured fish stocked in Year 3 were classified correctly, but only 52.3% of recaptured fish stocked in Year 2 were classified correctly. For fish stocked at 20–30 mm correct classification of year classes for recaptured fish was only 25.6% for fish stocked in Year 2 and 52.2% for fish stocked in Year 3.

4.2.3 Discrimination of scale patterns of three batches of 50–65 mm fish from the same year class

As shown in Figure 4.6 we were able to create unique temperature signatures for the three tanks in which 50–65 mm barramundi were grown out in Year 4 of the project. Figure 4.7 shows the mean circuli growth patterns of the barramundi grown in these three tanks. Although some clear differentiation is apparent between circuli 22 and 28, these circuli had to be excluded from the final analysis as the minimum number of circuli present on an individual fish from each batch was 16. Between circuli 1 and 16 differentiation is poorer, and the first 5–7 circuli would have been produced under identical growing conditions. Conducting discriminant analysis with greater numbers of circuli meant excluding some reference fish from the analysis, resulting in larger proportions of unknowns. For example using 24 circuli produced correct reclassification of the three batches of hatchery reference fish at rates of between 65.8% and 84.4% for those fish with 24 or more circuli. However, 33% of fish (those with less than 24 circuli) had to be excluded from the analysis. The number of unknowns increased as the number of circuli above 16 was increased. Based on an analysis of 16 circuli correct reclassification of hatchery reference fish was 54.5% fish for the cover batch, 50% for the deep batch and 58.3% for the shallow batch. Random chance alone would be expected to reclassify fish correctly at a rate of around 33.3%.

Of the recaptured Year 4 released fish, correct classification by discriminant analysis was 60% for shallow water released fish, 57% for the deep water released fish and 29.6% for the cover released fish.

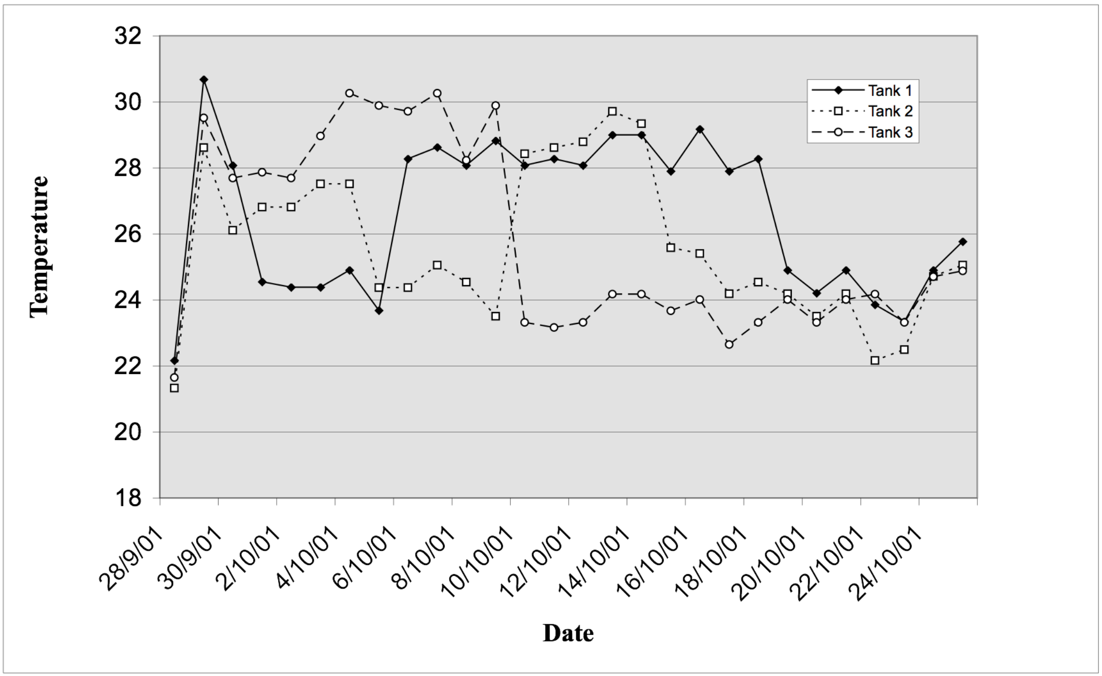

Figure 4.6 Water temperatures in degrees Celsius at 4:30 pm each day in the three tanks used to grow out three batches of 50–65 mm barramundi in Year 4 of the project. Temperatures were manipulated in order to produce different scale patterns.

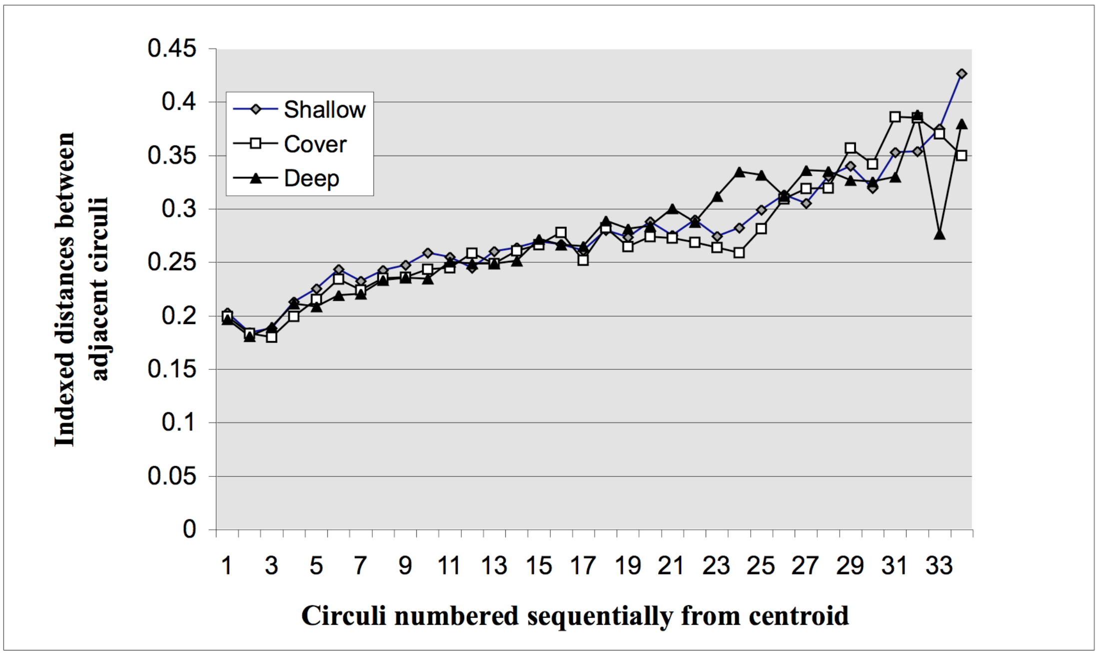

Figure 4.7 Comparison of the indexed distances between circuli for three batches (shallow release, cover release and deep water release) of 50–65 mm barramundi grown under different temperature conditions in Year 4 of the project. All fish had at least 16 circuli.

4.3 Discussion

4.3.1 Growth effects and the importance of validation

The use of scale pattern analysis has been used in the past in the classification of scale circuli patterns of hatchery reared and wild fish for a wide range of species, including Chinook salmon, striped bass, barramundi, silver perch, red drum, flathead and whiting (Schwartzberg and Fryer 1989, Humphreys *et al.,* 1990, Ross and Pickard, 1990, Barlow and Gregg, 1991, Willett 1993, Silva and Bumguardner 1998, Palmer *et al*., 2000 and Butcher *et al.,* 2000). Discrimination rates of hatchery reference scales in the above studies ranged from 41% to 99%. Scale patterns have also been used to compare survival rates of fish reared at different temperatures and released at different sizes (Willet, 1996). However, many of these past studies have assumed the correct reclassification rates of reference scales is transferable to the classification of the scales from recaptured fish. However, the current study suggests that this may not always be the case. By being able to identify recaptured fish with microtags we were able to validate whether scale circuli patterns resulting from this process can be used as discriminators long term. Our results have shown that a high level of correct reclassification of the reference set of scales does not always equate with a similar rate of correct classification for scales from recaptured fish.

Barlow and Greg (1991) showed that it was possible to distinguish hatchery barramundi from wild barramundi. In that study scales from wild and hatchery produced barramundi between 150 mm and 350 mm TL were compared. Discrimination rates as high as 83% were achieved. This is similar to the rates achieved in the current study (86–90.9%) with reference scale batches from 35–45 mm and 50–65 mm barramundi of two year classes. Barlow and Greg's analysis was based purely on a reference set of scales and unlike the current study did not stock hatchery fish in the wild and attempt to reclassify recaptured fish at a later date.

Barlow and Greg (1991) found scales from barramundi larger than 350 mm difficult to read and excluded these from their analysis. Similarly we found considerable thickening of the central area of the scale and the circuli in fish larger than 400 mm to cause some problems in reading and measuring of distances between circuli. In the case of comparison of release sizes, this thickening may have accounted for poorer discrimination of recaptured fish that were at large for more than one year. It also may explain the poorer result in discriminating recaptured 35–45 mm and 50–65 mm fish stocked in 1999 (Year 2), as compared to those stocked in 2000 (Year 3).

The discrimination rates for recaptured fish (86–95%) that were stocked in 2000 were actually comparable to the reclassification of the hatchery reference scales, suggesting that scale pattern analysis may have some value for fish that have been at large for less than a year. The batches of fish stocked earlier contained proportionately more older and larger fish in the recaptured samples than those stocked later. Thickening of the central part of the scale and the circuli themselves as the fish grow may actually alter the scale pattern to some extent or lead to inaccurate reading of the scales.

Silva and Bumguardner (1998) experienced similar problems in reading red drum scales from fish more than a year old. Decreasing readability with increasing age is likely to be less of a problem for small-scaled species such as silver perch, whiting or trout.

Impoundment barramundi grow particularly fast, and may reach 50 cm in under a year (see chapter 2). Riverine barramundi have generally slower growth rates and may take two to three years to reach an equivalent size (Russell and Rimmer, 1997). Therefore scale pattern analysis can probably be applied to riverine populations of barramundi for a longer sampling period than is possible for impoundment fish.

4.3.2 Number of circuli

It would also seem that a more reliable result could be achieved from discriminant analysis if more circuli are available for inclusion in the analysis. The best reclassification rates were obtained when comparing the two year classes of 35–45 mm fish and the 50–65 mm fish (see 4.2.2). In these cases 15 to 16 circuli were used in the analyses. In contrast comparison of the two year classes of 20–30 mm fish produced a much poorer result. In this case only nine circuli could be used in the analysis. This may also explain the poorer result in the comparison between the three size classes released simultaneously in 1999 and again in 2000. In the case of the three size class comparison, few of the circuli laid down by the larger sizes under different growing conditions were able to be used in the analysis.

Being dependent on fewer circuli in an analysis also seems to impact on the reliability of identification of scales from recaptured fish. It is the central part of the scale that seems to thicken up first. If more circuli are able to be included in the analysis of scales at the reference stage, then there is a greater chance of circuli lying outside the thickened zone in recaptured fish and giving better/more accurate discrimination. For example compare the classification rates of recaptured fish stocked in Year 3. The 20–30 mm fish were classified correctly at only just over ½ the rate of the 35–45 mm and 50–65 mm size classes.

One difficulty with scale pattern analysis is that fish from the same batch, of the same age reared under identical conditions can lay down variable numbers of circuli. For example 50–65 mm fish from Year 4 had between 16 and 34 circuli. This means some fish were laying down circuli at twice the rate of others. Therefore, if comparing circuli number 15 between fish, it does not necessarily mean that circuli number 15 was laid down on the same day or under the same conditions in each individual fish. The amount of variability is likely to influence the ability to discriminate between batches.

4.3.3 Manipulating scale patterns

Willet (1993) successfully differentiated between scales from silver perch reared in hatcheries from different geographical areas (with different temperature conditions) and silver perch reared in a tank indoors with controlled temperature conditions of 30°C. Hatchery origin could be identified with 91% accuracy and indoor reared fish could be identified from pond-reared fish with 99% accuracy. In further work by Willet (1994) six batches of silver perch were held for four weeks at three temperature regimes. Fish held at high temperatures (30°C) were classified with high accuracy (94–96%) and readily distinguished from other groups. Accuracy of classification decreased with decreasing temperature with fish held at 25°C classified at rates of 58%–72% and fish held at 20°C classified at 54%–58%. Most misclassifications were between the 25°C and 20°C groups.

The smallest silver perch (i.e. the 20°C group) were in the 20–25 mm size class range. In contrast to the barramundi in our experiment, these fish had laid down at least 18 circuli, compared with only 9 for barramundi. It is this lower number of circuli that probably explains the poor discrimination of the high temperature reared groups of barramundi from the low temperature reared groups of barramundi in Years 2 and 3 of our study when compared with Willet's results. However, discrimination between Willet's two lower temperature groups more closely resembles our barramundi result for size class comparisons. The result for Willet's 20°C group is also very similar to that of our temperature manipulated batches in Year 4 of the project.

Our fluctuating temperature manipulations in Year 4 of the project clearly produced unique temperature signatures in each of the three tanks (Figure 4.6) but this did not result in very distinctive scale patterns in the batches of barramundi held in each of these tanks (Figure 4.7). Better differentiation was achieved between reference scales from batches of same sized fish between years (86%–90.9%), than was achieved from manipulated batches in Year 4 (50%–58.3%).

It is possible that factors other than temperature may also influence scale pattern formation. Barber and Walker (1988) examined the pattern of circulus formation in two sockeye salmon stocks. They found that no significant variation in circuli spacing was explained by oceanic temperature. Instead they hypothesised that circuli spacing and annulus formation were related to photoperiod and food availability.

In our work, during the period of the manipulation where tanks were exposed to contrasting temperature regimes, temperatures ranged between approximately 23°C and 31°C. It was expected that fish would grow at varying rates according to temperature and lay down circuli at varying rates and intervals. Although variation in growth of fish was obvious to us, variation in circuli patterns were not as marked as we expected. During the course of the manipulation, fish were fed by automatic food dispenser and were not food limited. Perhaps this influenced the circuli formation. It is also possible that the periods of temperature fluctuation were too short to have much influence of the pattern formation.

Why did stocks from different years have greater differences in circuli patterns than the manipulated batches from the same year? It is possible that there were differences in early rearing conditions in the supplying hatchery and in the transport conditions for the fish from the hatchery to Southern Fisheries Centre. Fish supplied to us subsequently may have experienced variations in food quality and ambient temperature between years. Fish were also reared at slightly different times of the year and would therefore have been subject to slightly different photoperiods. Fish were received about three weeks earlier in Year three than in Year 2. All these possibilities are speculative. However, what is clear from the current work is that if it is desired to produce distinctive scale patterns in two or more batches of barramundi, then temperature manipulation alone may not be sufficient.

For two of the three batches of fish released and recaptured in Year four of the project, classification rates of recaptured fish were similar to the reclassification rates for the reference scales. However, the correct classification rate for cover-released fish was considerably lower and at random levels. The reason for this is unclear, as recaptured fish were mostly less than 35 cm TL.

4.3.4 Other options

A major advantage of using scale patterns as opposed to otolith patterns as batch tags is that scales can be removed from recaptured fish without the need to sacrifice the fish. Scales are also much easier to prepare for examination than otoliths. However, as shown in the current study the reliability of scale patterns, at least in barramundi is questionable. More so as the fish increase in size beyond 400 mm. Can reliability of scales as tags be increased? It has already been noted that the number of circuli laid down appears to be related to size of fish as opposed to age of fish. The work of Barlow and Greg (1991) supports this observation. It is, therefore, theoretically possible to introduce some type of fluorescent mark into the scales of fish at different stages of growth, and therefore recognise different batches of fish by the position of the mark relative to the scale circuli count from the focus. Creation of a mark may be achieved by fingerling immersion in such material as OTC or alizarine in hatchery tanks. Fluorescent marking is more commonly used for otoliths, but Brooks and Kind (2002) have successfully marked lungfish scales with OTC by intra-muscular injection. Marking of otoliths by immersion of fish in OTC has met with mixed success. For example Palmer *et al.* (2000) had difficulties in marking whiting and flathead otoliths. Much of the problem appeared to be effects of salinity on the uptake of the chemical. Greater success is likely with freshwater species.

Another way of increasing reliability of scales as tags, particularly for separating stocked from wild fish may be the use of a stocking check mark. Some species of fish are known to develop a check mark at the time of stocking. Humphreys *et al.* (1990) noted that hatchery reared striped bass could be separated from wild strip bass from stocking check mark formation. Hatchery bass were characterised by widely spaced circuli near the focus, corresponding to rapid hatchery growth, followed by an abrupt growth check relating to handling, tagging and adaptation to wild food sources in the river. Through recognition of stocking check marks, experienced scale readers (without using computer aided discriminant analysis) were able to identify hatchery origin young of the year fish and yearling fish 89% and 95% of the time respectively. Coded wire tags as for our current study provided verification of hatchery origin. Determining if stocking checks form in the scales of any stocked Australian native fish species is something that is worthy of investigation.

4.4 Conclusions and recommendations

A key finding of this study is that reliance on classification rates of reference sets of scales is not always a sufficient predictor for estimating correct classification rates of scales from recaptured fish. Before any studies embark on use of scale pattern analysis for a given species, verification of the methods suitability or limitations should be carried out. This could be done either by micro-tagging, marking of otoliths with alizarin or OTC, or stocking of reference fish into separate ponds to grow out. Without such verification, studies could end up with totally misleading results, particularly in the case of large scaled fast growing species like barramundi.

Scale pattern analysis as a method for barramundi has both potential and limitations. Scale pattern analysis may have some application with barramundi up to around 400 mm TL. Correct discrimination can reach levels above 90%. However, scale pattern analysis appears unsuitable for larger barramundi as thickening of the scales reduces readability. For fish less than 400 mm TL scale pattern analysis may be particularly useful for separating hatchery from wild stocks, as early conditions are likely to be dissimilar for these two groups. For scale pattern analysis to be effective, fish should be stocked at larger sizes (i.e. larger than 35 mm) so that more circuli are available for inclusion in any analysis. The more circuli available the greater the reliability of the method.

To produce several batches of fish with unique scale patterns, it would appear that for barramundi temperature manipulation alone is not enough. Variation in rearing techniques, e.g. pond vs tank and feeding regimes may also be required.

Our recommendations are as follows:

1. Scale pattern analysis should only be used after verification that classification rates of *recaptured* fish are comparable to classification rates of reference sets of scales.
2. Scale pattern analysis is suitable only for barramundi less than 400 mm TL.
3. To produce unique scale patterns in barramundi, temperature variation alone is insufficient. Other conditions should also be varied (e.g. hatchery source, feed, pond/tank type, rearing location, photoperiod etc) .
4. Greater success will be achieved if more circuli are available for the discriminant analysis. Therefore better discrimination results can be expected if batches of fish are released at larger sizes.
5. The potential to mark scales with fluorescent marks should be investigated.
6. Formation of stocking check marks in species used in Australian fish stocking programs should be investigated as an alternative to discriminant analysis of scale patterns.

Chapter 5: Benefits

5.1 Benefits and beneficiaries

The outcomes of this project will benefit freshwater fisheries management agencies, fish stocking groups, recreational anglers and regional communities. The research outcomes produced by this project will assist in development of successful fish stocking programs, result in higher survival rates of stocked fish, minimise wasteful stocking and enable community groups and fisheries management agencies to choose cost effective stocking options. It is not possible to make absolute statements or foolproof recommendations regarding fish stocking strategies that will apply equally to all impoundment scenarios. However, we have attempted to point out many of the factors that can lead to differing success rates among stocking programs, particularly in terms of the fish species being stocked, optimal release strategies, optimal release sizes, the number and variety of fish and other flora and fauna already present in the impoundment, and the physical and chemical characteristics of the impoundment. Given the almost infinite number of possible combinations and permutations of these factors that a particular impoundment might present, there can be no guarantee that strict adherence to the recommendations given in this document will always result in the best possible outcome.

We are, however, confident that a thoroughly planned fish stocking program that takes into account the findings outlined in this document will stand a much greater chance of success and being cost effective than one which is hastily conceived without due regard for potential influencing factors.

Quantifying the actual economic benefits of this program is difficult. Economic surveys carried out in the past have estimated the economic benefits of stocking programs to range from $18 to $31 for every dollar spent on fish stocking (Hamlyn and Beattie, 1993; Rutledge *et al.*, 1990). Given that groups which follow the advice provided by the current research program are likely to achieve more cost effective stocking, then the economic benefit for each dollar spent on stocking is likely to increase. If increased stocking success leads to better catch rates by anglers, this is also likely to increase angler participation and lead to further economic gains. It is estimated that 192 100 fishers fished in Queensland freshwaters in the twelve month period up to September–October 1996, (Roy Morgan Research, 1996). Visiting freshwater anglers help to contribute to the well being of regional economies in eastern and northern Australia. Most of the key impoundment fisheries are located away from the capital cities and help to draw visitors to regional areas. Apart from the savings resulting in more cost effective stocking programs, the improved survival of stocked fish and resulting higher angler catch rates will provide a social benefit.

The work we have done on evaluation of scale pattern analysis will help prevent future researchers and fisheries managers falling into the trap of evaluating the ability to discriminate stocks solely from a reference set of scales. Our work will help prevent future wasteful research that relies on scale pattern analysis to discriminate stocks without adequate verification. If scale pattern analysis is to be used long term as a tagging tool, it should be independently verified for each species by following tagged fish over the time or growth period that is of interest to the research program in question. We have demonstrated that subsequent growth and thickening of scales can render scale pattern analysis useless as a discriminating tool in barramundi that have grown to over 40 cm total length. For short-term projects of less than six months, scale pattern analysis may provide a cheap tool for marking barramundi stocks.

5.2 Intellectual property and valuable information

No patentable inventions or processes have been developed during this project.

5.3 Dissemination of research results

Presentation of research results has been made to a wide variety of audiences. During the project preliminary results were presented to a wide range of audiences through:

- Radio and television interviews including
  - Totally Wild, Channel 10, 2000
  - ABC Radio Rural Report, Radio National, 2001 and 2002
  - ABC Regional Radio, Bundaberg, Mackay, 2001
  - ABC Radio Kingaroy, 2000
- Presentations to fish stocking groups and hatcheries at annual northern and southern fish stocking workshops
  - 1999 Gin Gin and Mackay
  - 2000 Monto and Charters Towers
  - 2001 Maroon Dam and Ayr
  - 2002 Gladstone and Mission Beach
- Presentation of scientific paper at the Australian Society for Fish Biology Annual Conference, Cairns, 14–17 August 2002
- Scientific paper in press (2003) Proceedings of the Royal Society of Queensland
- Articles and stories in popular fishing magazines including
  - Courier Mail November 2001
  - Courier Mail July 2001
  - Courier Mail May 2000
  - South Burnett Times, November 2001
  - Queensland Fishing Monthly
  - Bush and Beach
  - Freshwater Fishing Australia
- Regular updates in the QFS Newsletter *Stocking Snippets.*
- Pamphlet on optimum stocking strategies sent to every Queensland stocking group and available via the DPI&F Notes series and on the Internet (Agdex 472/23).
- Best practice stocking manual for impoundments published and sent to all state fisheries agencies, DPI&F library and to over 180 community groups and individuals involved in fish stocking in Australia.
- Chapters 2, 3 and 4 of this report will form the basis of scientific papers that will be submitted to peer reviewed journals.

Chapter 6: Further Development

There is a range of research and monitoring activities that can be undertaken to further build on the outcomes and outputs of this project

6.1 Stocking sizes and release strategies

- Optimal stocking sizes and release strategies for sooty grunter and Murray cod stocked into impoundments are yet to be determined. Murray cod and sooty grunter are stocked less widely than the species covered by this project, but are increasing in popularity.
- More work is required on the timing of stocking. For example, how do daytime releases compare with night-time releases or how does survival of fish stocked in early spring compare with survival of fish released in early summer?
- The merits and economics of stocking much larger fish (e.g. 200–250 mm) late in the season requires investigating, particularly in dams dominated by barramundi.

6.2 Impoundment characteristics and fish stocking

The current project has shed light on the impact of key predators on stocked species, the influence of water levels at time of stocking and the importance of some key prey species for growth of stocked fish. However, it is clear that much more can be done with reference to the importance of key habitat parameters, biotic and abiotic influences on the outcomes of stocking. We suggest:

- A major project investigating the relationship between impoundment characteristics and stocking outcomes is required in order to develop guidelines as to which impoundments are most suitable for stocking of the different key species. Such work may best be conducted on a region-by-region basis.
- Implementation of research and monitoring programs to assess carrying capacity, optimal stocking densities and optimal harvest rates in different types of impoundments.
- Following from outcomes of the above, work could be done to improve impoundment habitats to improve the success of stocking or to increase carrying capacity. Such work has already been done for some species in the USA.

6.3 Scale patterns as tags

- Use of scale patterns as tags should not proceed for any new species without a validation trial that includes recapture of independently tagged individuals.
- Potential for the use of fluorescent marks as batch marks in the scales or otoliths of fish should be investigated. In the past such marks have been used to separate stocked from unstocked fish, *i.e.* the fish are either marked or unmarked. However, as the number of circuli in scales appears to be related to the size of fish, marks could be administered to different batches at different times during the growth period the hatchery. In this way the position of fluorescent marks could be related to the number of circuli from the focus of a scale. The stability of the position of these marks relative to daily increments in otoliths or to circuli in scales and the durability of these marks in scales should be investigated.

- Some species of fish form stocking check marks on their scales. This should be investigated for Australian species of stocked fish. If such stocking check marks do form it may be possible to separate stocked fish from wild fish downstream of impoundments or in open water stocking situations.

Chapter 7: Planned outcomes

The research proposal for this project listed five planned outcomes. These are addressed below.

1. **Identification of cost effective stocking practices and uptake of these by fish stocking groups and state fisheries organisations**

   This project has successfully addressed cost effective fish stocking practices. Chapter 2 of this document outlines the most cost effective strategies. The stocking manual produced as part of this project provides general advice and outlines ways for fish stocking groups to determine strategies that are most likely to be cost effective in their local impoundment. It is still too early to assess uptake of these practices by fish stocking groups, as the manuals have only been distributed recently. However, we are aware of some stocking groups modifying their stocking practices after we presented our preliminary results at fish stocking workshops. The Queensland Fisheries Service is using the results of this work as a basis to recommend stocking of 50 mm or larger fish in most circumstances.

2. **Increased production of the most cost effective size classes of fish for stocking by hatcheries**

   We believe most hatcheries are aware of our recommendations, yet again it is premature to assess whether hatcheries have altered the size of fish they produce. This should be driven by demand from stocking groups. We are aware of hatcheries supplying larger sized barramundi in north Queensland to a stocking group that previously concentrated most of its stocking effort on smaller sizes. Gladstone Area Water Board (GAWB) hatchery also has begun to change production to 50 mm or larger barramundi for its stocking program in Awoonga Dam, whereas previously only barramundi less than 20 mm were produced for stocking.

3. **Improved survival of stocked fish leading to improved recreational catches**

   As the final results of this program have only just been made available to the public it is too soon to assess whether catches have increased in most dams. However, Awoonga Dam is one location where changes to stocking sizes were made early on in the project. These changes were made partly in response to preliminary results from our project. In that dam there has been a measurable improvement in barramundi catches within 12 months of the changes to stocking practices. Researchers from GAWB estimate a nine-fold increase in survival.

4 Preliminary information on characteristics of impoundments which favour/hinder stocking success of different species, leading to more focused research and preliminary advice to stocking groups

Chapter 3 has provided some preliminary information on the characteristics of impoundments that favour or hinder the stocking success of different species. The key findings were the impacts of various predatory species and the importance of water levels at the time of stocking. These results have been incorporated into the advice in the stocking manual that was distributed to community groups and fisheries agencies. In turn this work has led to recommendations for further research on habitat characteristics and outcomes of stocking on a regional basis (see chapters 3 and 6).

5. Verification of scale patterns as a cheap batch tag for stocked fishes

This project was able to verify that scale patterns may be useful as cheap tags in the short term. However it also identified some shortcomings with the method. Unique scale patterns were not as easily produced in barramundi as was hoped through temperature manipulation alone. Also, it was found that growth and subsequent thickening of the scale could make correct discrimination of scale patterns more difficult in recaptured fish than in hatchery reference fish. Nevertheless, this information is useful and will help prevent invalid assumptions being made in future projects. It also shows the importance of independent verification of the method for recaptured fish on a species by species basis through use of a second tagging or marking system

Chapter 8: Conclusions

The key recommendations and findings of the project are outlined below in relation to Objectives 1, 2 and 3 of the study. Although Objective 4 (ensure adequate replication of stocking strategies for barramundi, golden perch and silver perch) is not addressed specifically in this chapter, neither Objective 1 nor Objective 2 would have been possible without achievement of Objective 4.

Objective 1: To determine optimal stocking size and release strategies to maximise the survival of four fish species (golden perch, silver perch, Australian bass and barramundi) in stocked impoundments.

1. Fish stocked at 50–65 mm have higher relative survival rates than fish stocked at 35–45 mm or 20–30 mm in the majority of cases.
2. In the majority of circumstances 50–65 mm fingerlings of all species were the most cost effective stocking option. However, it can be more cost effective to stock 35–45 mm Australian bass and silver perch in dams with low diversity or abundance of predators. In dams with low abundance of predators 20–30 mm barramundi can be more cost effective to stock than 35–45 mm and 50–65 mm fish. If in doubt it is best to stock 50–65 mm fingerlings. Also see point 1 under Objective 2 below.
3. Shallow water releases around lake margins will suffice for all species.
4. Outcomes will vary between impoundments and years.
5. Stock as early in the season as possible to maximise growth during the summer period and minimise risk of predation over the winter period.
6. Monitoring growth rates post-stocking is important in order to avoid future overstocking or stocking during periods when fish populations are under stress (also see point 9 under Objective 2 below).

Objective 2: Identify differences between impoundments that may influence the survival and growth of fish stocks.

1. Mouth almighty, spangled perch and fork-tailed catfish are key predators of stocked barramundi fingerlings. The impact of these species is severe on barramundi stocked at less than 50 mm TL. We recommend stocking barramundi and other species at 50 mm TL or larger in the presence of these species.
2. There is evidence that predation of stocked fingerlings is in part determined by chance distribution of schools of predators at the time of stocking. We recommend stocking fingerlings in three to four large batches around an impoundment to spread the risk.
3. There is evidence that non-Murray-Darling predatory fish species have an adverse effect on the survival of stocked golden and silver perch fingerlings. Silver perch and Murray-Darling strain golden perch stockings are likely to fail in the presence of barramundi. We recommend against stocking Murray-Darling strain golden and silver perch into dams containing barramundi and suggest stocking 50–65 mm fish or larger into dams containing other non-Murray-Darling predatory species as there is some evidence for size selective predation.

4. There is evidence for poor survival of Australian bass fingerlings of all size classes stocked into dams with moderate to high densities of barramundi. We recommend against stocking bass into dams with barramundi, unless barramundi numbers are low.
5. Water level at time of stocking was positively related to stocking success for all species. We recommend stocking at high water levels and avoiding stocking when impoundments have been drawn down to less than 10% full supply surface area. Low water levels are likely to increase competition and opportunities for predators of fingerlings.
6. There is evidence that overstocking can lead to reduced growth rates in Australian bass and barramundi.
7. Survival of stocked barramundi fingerlings is likely to be higher in dams with extensive fringing emergent vegetation or floating macrophyte beds. There may be potential to manipulate conditions in some dams to favour development of this type of habitat.
8. Barramundi are more likely to achieve high growth rates in dams with high summer water temperatures and large populations of snub-nosed garfish and bony bream. It is likely that bony bream benefit the growth of other stocked species but this requires further research.
9. We recommend post stocking surveys of growth rates, condition factors and abundance of potential prey items to help managers make decisions that prevent overstocking and potential damage to a productive fishery.
10. There is evidence that growth rates of Australian bass in the first 6 to 12 months after stocking are higher in dams in which *Hypseleotris* gudgeon species are abundant.
11. Further quantitative research is required on the outcomes of stocking in relation to physical, chemical and biotic characteristics of impoundments. This work should be divided up into geographical regions and encompass as many dams that are in current stocking programs as possible. The aim of this research should be to provide species specific stocking guidelines for different regions based on known characteristics of an impoundment.

Objective 3: To verify the reliability of scale pattern analysis as a means of identifying different batches of fish.

1. Scale pattern analysis should only be used after verification that classification rates of *recaptured* fish are comparable to classification rates of reference sets of scales.
2. Scale pattern analysis is suitable only for barramundi less than 400 mm TL.
3. To produce unique scale patterns in barramundi, temperature variation alone is insufficient. Other conditions should also be varied (e.g. hatchery source, feed, pond/tank type, rearing location, photoperiod etc).
4. Greater success will be achieved if more circuli are available for the discriminant analysis. Therefore, better discrimination results can be expected if batches of fish are released at larger sizes.
5. The potential to mark scales with fluorescent marks should be investigated.
6. Formation of stocking check marks in species used in Australian fish stocking programs should be investigated as an alternative to discriminant analysis of scale patterns.

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Appendix I

Project Staff

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Appendix II

DPI Post-stocking survey reports (published and unpublished) used as source data for evaluation of stocking success in relation to impoundment characteristics

Breddin, I. and Hamlyn, A. (2000) *Post stocking survey report Lake Monduran (Fred Haigh Dam) Gin Gin Survey 2, 18 November 1999.* Queensland Fisheries Service, Department of Primary Industries Queensland.

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