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SURVIVAL OF STOCKED BARRAMUNDI, *LATES CALCARIFER* (BLOCH), IN A COASTAL RIVER SYSTEM IN FAR NORTHERN QUEENSLAND, AUSTRALIA

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ABSTRACT

As part of an ongoing study to investigate the efficacy and cost-benefit ratio of stock enhancement of barramundi, *Lates calcarifer* (Bloch), in coastal river systems, about 69,000 fingerlings have been released into the Johnstone River in northern Queensland, Australia, since 1993. All stocked barramundi were marked with coded wire tags to allow their discrimination from naturally recruited fish and to allow subsequent determination of fish size, release site, and release year class. The initial experimental design used two size classes of fish (30–40 mm and 50–60 mm total length), which were released into freshwater, estuarine and upper tidal habitats. The stocked barramundi took about three years to reach the minimum legal size of 580 mm total length. Stocked fish comprised about 20% of barramundi from the relevant size classes in research catches. No significant difference was found in the numbers of fish returned from the two different stocking size classes. Most stocked fish (62%) were recaptured within 3 km of their release site, but 38% undertook intrariverine movements of up to 37 km. Angler record cards and commercial catch data are being used in an effort to detect measurable increases in catch per unit effort in the recreational and commercial fishery sectors. Cost-benefit analysis indicates that less than 1% of stocked barramundi need to be recaptured to cover the costs of the stocking program.

Barramundi, *Lates calcarifer* (Bloch), is a large, euryhaline, catadromous centropomid found throughout most of the Indo-west Pacific including the coastal rivers of tropical Australia (Greenwood, 1976). In northeastern Australia, barramundi spawn in coastal waters and estuaries from October to February, just before or during the wet season (Dunstan, 1959; Russell and Garrett, 1985). Larvae recruit into estuarine nursery swamps, where they remain for several months before they move out into the freshwater reaches of coastal rivers and creeks (Russell and Garrett, 1983, 1985). Although some barramundi have been recorded as undertaking extensive movements between river systems, most barramundi remain in their original river system and move only short distances (Russell and Garrett, 1988). This limited exchange of individuals between river systems is one factor that has contributed to the development of genetically distinct groups of barramundi in northern Australia. Six recognized genetic strains of barramundi occur in Queensland, and another 10 in the Northern Territory and Western Australia (Keenan, 1994).

In northern Australia, the barramundi is a popular and highly sought after food and sports fish. It is an important component of both recreational and commercial fishery sectors in Queensland (Russell, 1987; Rutledge et al., 1990) and supports a developing aquaculture industry (Barlow et al., 1996). In recent years fishermen have expressed concern over perceived declines in barramundi populations. Little information on the health of barramundi stocks is available, but statistics from the east Queensland commercial fishery suggest there has been a historical decline in stock size (Russell, 1987), and recent data from the Gulf of Carpentaria suggest that daily commercial catch rates have fallen by 30% since 1981 (R. Garrett, pers. comm.). The reasons for the decline in the fishery are debated, but habitat degradation and overexploitation appear to be major factors (Russell, 1987). Fisheries managers have attempted to respond to this situation and since 1981 have progressively introduced a range of management initiatives directed at effort reduction in the commercial and recreational fisheries (Russell, 1988). Major components of the present management strategy include a closed season from November to January inclusive, a minimum legal size of 580 mm and maximum legal size of 1200 mm, a recreational-angling bag limit of five fish, and additional commercial-sector restrictions (including gear-size restrictions and area closures).

Barramundi have been released into freshwater impoundments in Queensland since the mid-1980s to improve recreational fishing opportunities (Pearson, 1987). Because barramundi require salt water to reproduce, impoundments support only "put and take" fisheries for barramundi. Originally, most stocked barramundi were produced by government hatcheries, but the development in the early 1990s of efficient and cost-effective technology for producing barramundi fingerlings (Rutledge and Rimmer, 1991) has resulted in the widespread availability of cheap (ca. AUD$0.25 each) fingerlings from commercial hatcheries. In Queensland, there is wide support for stock enhancement programs, particularly among recreational fishers. Numerous community-based stocking groups have been formed to promote stocking of barramundi and other native fish species in impoundments and coastal streams, and these stocking groups can obtain fingerlings from government or commercial hatcheries. In 1990, the Russell-Mulgrave became the first open river system to be stocked with hatchery-reared barramundi, and since then, fish have been released into many coastal streams in eastern Queensland and in the Gulf of Carpentaria. Stocking barramundi in Queensland's coastal rivers has been a contentious issue. It has been suggested that the pressures that have apparently adversely affected wild barramundi stocks will also reduce survival of stocked fish and that stocking programs will not be cost-effective. Queensland government fisheries agencies have adopted many aspects of the "responsible approach" (Blankenship and Leber, 1995) as a basis for policy development for stock- enhancement programs. To support a "responsible approach" to stock enhancement of barramundi, assessment of the contribution of stocked fish to population recovery and evaluation of the cost-effectiveness of stocking are essential. The present paper outlines the preliminary results of a study designed to assess the use of stock enhancement as a method for increasing barramundi populations in coastal rivers. Our three main objectives are: (1) to develop appropriate stocking strategies for barramundi in coastal rivers, (2) to assess the contribution that stocked fish make to both recreational and commercial sectors of the barramundi fishery, and (3) to document the costs and benefits of this stocking program.

The present paper reports on the results of the first four years of this study.

Materials and Methods

Study Site. — The river system chosen for this study was the Johnstone River, which rises on the Atherton Tableland and flows into the Coral Sea near the township of Innisfail (17°32' S, 146°02' E), about 90 km south of Cairns in far northern Queensland (Fig. 1). The river bifurcates about 5 km from its mouth into the North and South Johnstone Rivers. The Johnstone River catchment has an area of approximately 1630 km^2 and an average annual rainfall between 1.7 and 4.0 m. Average annual runoff is 2.7 million megaliters. The rainfall pattern is distinctly seasonal; most rain falls in

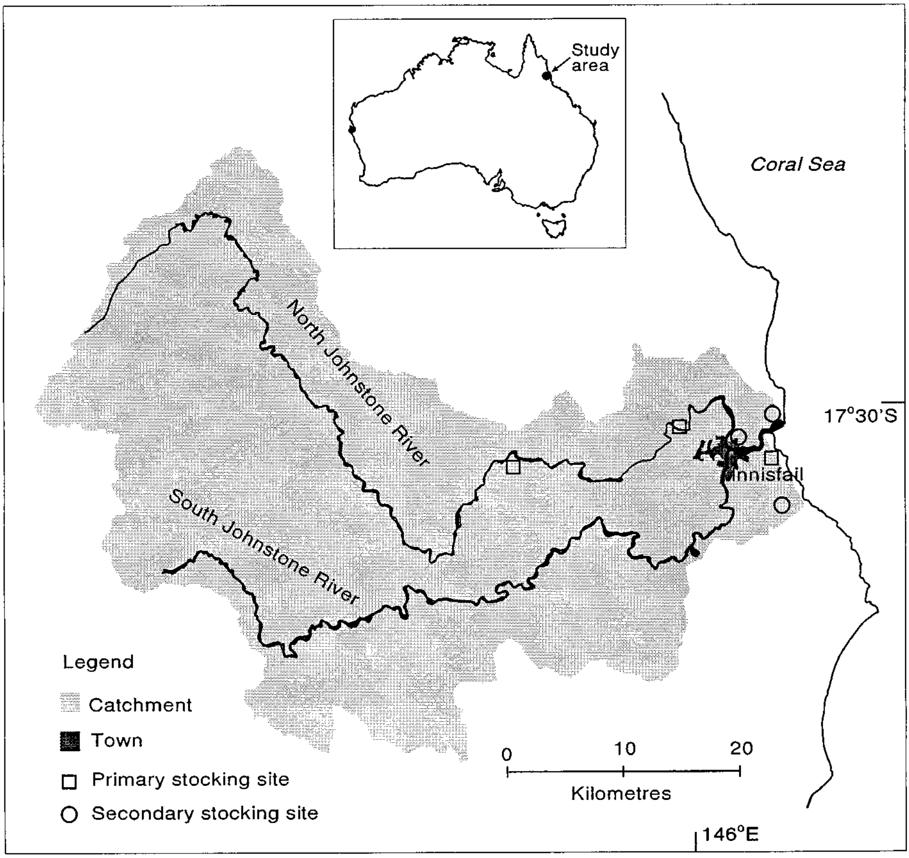

Figure 1. Map showing location of study site, the Johnstone River catchment, and locations of primary and secondary stocking sites.

the "wet season" from January to April. The river's coastal plain is narrow (less than 30 km wide), and an escarpment prevents the upstream movement of fish from coastal areas to the upper tableland. Most of the catchment is forest or agricultural land. On the tableland, dairying is the predominant land use, whereas sugar and banana farming are the main agricultural activities on the coastal plain. About 43% of the catchment, mainly on the steeply sloping, rainforest-covered coastal range, is World Heritage listed (Russell and Hales, 1993a). Agricultural activities have affected wetland habitat within the catchment, causing an overall reduction in coastal wetlands of about 60% over the past 50 yrs (Russell and Hales, 1993a). The river supports a multispecies recreational fishery and a commercial gill-net fishery (the latter is restricted to the lower estuary). About five part-time commercial fishermen operate in the catchment. The river had not been stocked with barramundi before the commencement of this study. Barramundi fingerlings used for these stockings were spawned from brood stock held at the Northern Fisheries Centre (NFC) in Cairns (Garrett and Connell, 1991) and reared to between 25 and 35 mm total length (TL) by extensive larval rearing techniques (Rutledge and Rimmer, 1991). After harvesting from the ponds, fish were held at the NFC hatchery before their release and were on-grown as necessary. The need to tag all stocked fish required that the barramundi fingerlings be weaned to pellet diets for feeding during their time at NFC, so some domestication may have occurred.

The original experimental design required that equal numbers of two size classes of fish, categorized as small (30–40 mm TL) and large (50–60 mm TL), be released in three different habitat types

Table 1. Numbers of fish released at locations in the Johnstone River catchment. Primary release sites are marked with asterisks (*), and n.s. indicates sites that were not stocked in that year.

Location	1992–93	1993–94	1994–95	1995–96	Total
North Johnstone road bridge (upper tidal)*	2,072	6,111	6,667	2,899	17,749
North Johnstone–Nerada (freshwater)*	2,107	6,224	6,345	2,828	17,504
Ninds Creek (estuary)*	2,096	6,308	6,424	3,073	17,901
Bulguru Swamp (freshwater swamp)	n.s.	2,064	3,466	3,383	8,913
Coconuts (river mouth)	n.s.	n.s.	n.s.	3,321	3,321
Town Reach (estuary)	n.s.	n.s.	n.s.	3,382	3,382
Combined	6,275	20,707	22,902	18,886	68,770

(lower estuarine, upper tidal, and freshwater) in the Johnstone River. These three sites were designated primary stocking sites (Fig. 1). This design was undertaken annually for three years beginning in 1992–93 (Table 1) but was subsequently modified in an effort to obtain more information on the suitability of other secondary stocking locations (Fig. 1). The first of these changes, starting in 1993–94, involved the stocking of a freshwater swamp system with large fish, and later, in 1995–96, an extra two estuarine sites were stocked with large size class fish (Table 1). Tagged barramundi fingerlings were released in batches of at least 1000 in an attempt to overcome local predation at the stocking sites. Where both small and large fish were released (i.e., primary stocking sites from 1992–93 to 1994–95), approximately equal numbers of each size class were released at each site. In the four years of the study to date, a total of 68,770 tagged barramundi have been released into the Johnstone River (Table 1).

So that we could discriminate the hatchery-reared fish from naturally recruited fish, all stocked barramundi were marked with coded wire tags, implanted in the cheek muscle, before release. Russell and Hales (1992) successfully implanted coded wire tags into the cheeks of barramundi as small as 30 mm TL and obtained high survival and retention rates. They found that tagging had no significant effect on long-term survival or growth. In the present study, experienced operators have routinely achieved tagging rates of 500 barramundi fingerlings per hour. All tagged barramundi were retained for at least 48 h after tagging and then checked to ensure that the tags were in place before release. Any fish that had shed tags were not released. Tag retention was usually >96%, and tagging mortality was <1%.

Monitoring was undertaken with a boat-mounted, Smith-Root® (7.5 GPP) electrofisher and a small 2-mm-mesh beam trawl, which was used to sample fish in the lower estuary. Electrofishing was carried out on 28 occasions for a total of 46.7 h of effort. Once the stocked fish had reached legal size (580 mm TL), anglers and commercial fishers were asked to retain the heads or frames of all captured barramundi and return them to a central repository. As an incentive, a small reward was offered to all anglers who returned tagged fish. Regular inspections were also made of the commercial catches from the Johnstone River. All captured barramundi were checked for the presence of tags with a Northwest Marine Technology® (NMT) “wand” detector. All fish found to contain tags were retained, and the tags were extracted and read in the laboratory.

Catch and effort data for the recreational fishery in the Johnstone River were collected from voluntary angler record cards. These cards requested details of the size and number of the species caught, the number of anglers in the party, and the time spent fishing. Anglers were asked to complete the cards after each fishing trip, even if no fish were caught, and to return them to a post-free mailing address or in conveniently located drop boxes. Cards were widely available, and a field liaison officer was made available to promote the use of the cards and to provide support and assistance as required.

Data were stored in a relational database, and size data were analyzed by means of a generalized linear model with a logit link and binomial error distribution. In analyses of the proportions of stocked fish in the population, only size cohorts that were likely to include stocked fish (i.e., <650

Table 2. Total number of fish of the two size classes (small 30–40 mm TL and large 50–60 mm TL) released between 1992–93 and 1994–95 and the number of subsequent recaptures to 1 March 1996.

Location	Small		Large	
	Released	Recaptured	Released	Recaptured
North Johnstone road bridge (upper tidal)	6,969	41	7,881	57
North Johnstone–Nerada (freshwater)	6,785	11	7,891	7
Ninds Creek (estuary)	7,054	2	7,774	7

mm TL) were considered. As stocked fish have just recently started to be captured in the commercial fishery, no assessments of changes in commercial catch and effort have yet been undertaken.

Results

Tag Returns. — To date, 144 tagged barramundi from four year classes have been recaptured. Of these, one fish came from commercial catches, six from the recreational fishery, and the remainder from research sampling. In the research samples, stocked barramundi constituted about 20% of the catch. Because catches made near release sites might be biased by stocked fish remaining resident there, we analyzed only catches made at least 3 km away (Table 1). Consequently, this figure probably underestimates the total proportion of stocked fish in this river system.

Since the opening of the 1996 barramundi season (1 February 1996), 81 fish from the relevant size classes (i.e., < 650 mm TL) have been scanned for the presence of tags: 62 fish from the recreational fishery and a further 19 from commercial catches. Of these, seven were found to be tagged, and these ranged in size from 590 mm to 615 mm TL. Although small, this number can be expected to increase as fish from successive stockings are recruited into the fishery. Tagged fish comprised about 15% of barramundi of relevant size returned by fishers.

Size at Stocking. — Table 2 lists the number of fish of the two size classes (large and small fish) released at the primary stocking sites within the catchment and the number of subsequent recaptures. Large and small fish did not differ significantly ($P > 0.05$) in probability of recapture (small fish, 0.26%; large fish, 0.30%).

Release Locations. — Stocked fish from all three primary release locations shown in Table 2 have been subsequently recaptured. The initial sampling strategy, which involved extensive electrofishing at only one of the release locations (North Johnstone road bridge/upper tidal), has resulted in a high number of recaptures from that site, so it is difficult to come to any conclusions about a preferred stocking location. However, the effects of release site should become clearer as more data become available from recreational and commercial catches.

Some 8913 fish were released into the Bulguru freshwater swamp at the headwaters of Ninds Creek between 1993–94 and 1995–96, but none of these fish has yet been recaptured. As discussed below, this result may be due to periodic declines in water quality, particularly dissolved oxygen levels, at this site. No fish have been recaptured from the other two secondary stocking sites, but this result is probably a function of low sampling effort, as sampling juvenile barramundi in estuarine habitats is difficult.

Table 3. Numbers of barramundi that have moved more than 3 km or stayed resident (<3 km) at stocking location. Movement data for some fish are unavailable.

Location	Resident	Showing movement
North Johnstone River (upper tidal)	45	16
North Johnstone River (freshwater)	2	11
Ninds Creek (estuary)	4	4
All sites	51 (62%)	31 (38%)

MOVEMENTS. — Most (62%) stocked barramundi were recaptured within 3 km of their release sites (Table 3). The remainder had undertaken intrariverine movements of up to 37 km. There was no discernible trend to these movements. Fish released at the freshwater site in the North Johnstone moved downstream to the upper tidal areas (20 km) and into the South Johnstone River (37 km). Fish released in the tidal area of Ninds Creek moved upstream into upper tidal freshwater areas of the North Johnstone and South Johnstone Rivers. No movements to coastal foreshores or into other river systems have yet been recorded.

GROWTH. — Growth of stocked barramundi is rapid during the first 12 mo but then slows considerably during subsequent years (Fig. 2). Seasonal variations in growth rate are apparent; growth is more rapid during summer and slower during the cooler mid-year months (Fig. 2). The first batch of fish released in 1992–93 took about 3 yrs to reach the legal size of 580 mm TL, and subsequent year classes show similar growth patterns (Fig. 2).

RECREATIONAL FISHERY CATCH AND EFFORT. — From December 1993 to August 1996, 1383 angler record cards were received detailing the fishing activities of 2782 anglers over 3415 h. Data were supplied on more than 3300 fish from over 40 freshwater, estuarine, and marine species. The most commonly caught species were the freshwater sooty grunter (*Hephaestus fuliginosus;* n = 1090), barramundi (n = 457), and mangrove jack (*Lutjanus argentimaculatus;* n = 372). Most of the other fish species caught by anglers were marine species.

Monthly catch per unit effort was generally less that 0.25 fish per angler hour and was highly variable both within and between years (Fig. 3). During the year, monthly catch per unit effort was generally less during the cooler winter months and peaked before the start of the closed season in November and immediately after the opening of the fishery in February.

COSTS AND BENEFITS OF STOCKING. — If the 69,000 fish that have been stocked during this study had been purchased from a commercial hatchery (at AUD$0.25 per fish), then the total cost for the program to date would be $17,250. Previous studies (Russell, 1988) have suggested that barramundi will be caught in the recreational and commercial fisheries of northeastern Queensland in a ratio of around 1:3. The values of barramundi to the commercial and recreational sectors are also different. Rutledge et al. (1990) estimated that the direct cost incurred by a recreational fisher in northeastern Queensland in catching a barramundi was approximately $50. To a commercial fisher, the average barramundi (5 kg total weight, with a fillet return of ca. 50% valued at $10 kg^{-1}) is worth $25. On the basis of these data, only about 550 of all the fish released (<1%) would have to be subsequently caught to cover the purchase price of the fingerlings. Note that this analysis is conservative and does not include provision for indirect economic benefits (Rutledge et al., 1990) or indirect costs.

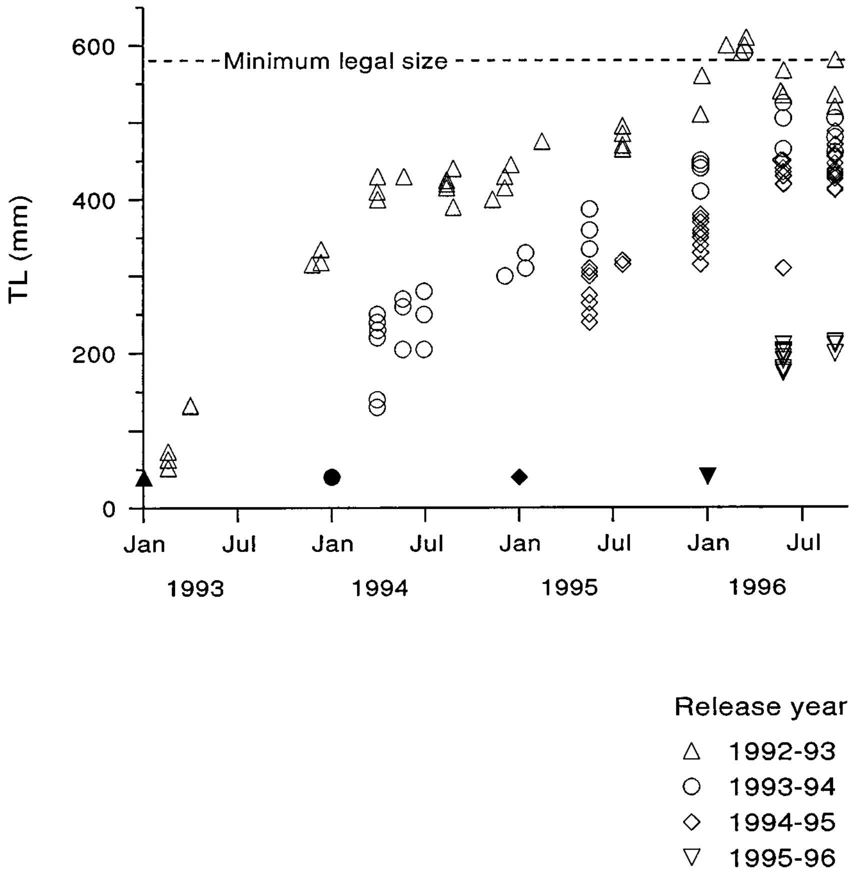

Figure 2. Size of recaptured barramundi released from 1992–93 to 1995–96. Fish released in different years are represented by different markers; filled markers indicate the approximate time of stocking.

Discussion

This study has demonstrated that a range of stocking strategies (release sites and sizes at release) result in survival of barramundi released into coastal waterways in northern Queensland. Fish have been recovered from all four year classes stocked and from all three primary release sites. Estuarine, freshwater, and upper tidal habitats all appear to be suitable locations for stocking, although not enough data are yet available to reveal whether any one habitat type provides better survival than others. A number of factors, including water quality, can make some locations unsuitable for stocking, and these must be evaluated in terms of their suitability as release habitats. For example, there is no indication of survival of any of the fish released into the secondary stocking site in the Bulguru freshwater swamp. Water-quality measurements found low dissolved oxygen levels after the last stocking in February 1996, which were consistent with the distressed behavior exhibited by the fish immediately after release. Low dissolved oxygen in streams after periods of heavy rain can result from influx or resuspension of oxygen-demanding materials as a

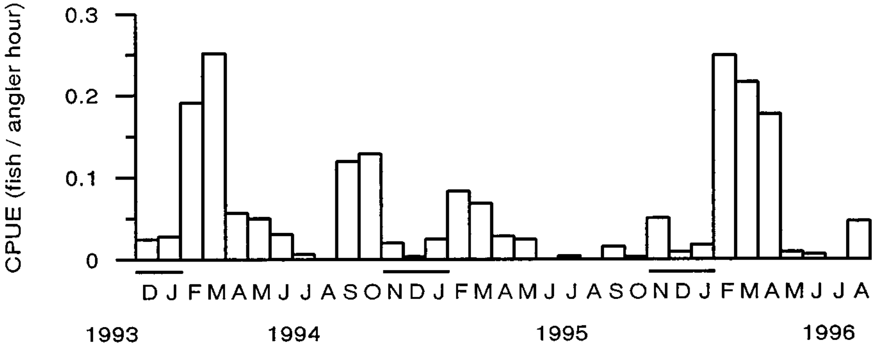

Figure 3. Catch per unit effort (CPUE) for barramundi captured in the recreational fishery in the Johnstone River. Data are from voluntary angler record cards. Horizontal lines below x- axis indicate the closed season for barramundi (November-January inclusive).

result of storm-water input (Graczyk and Sonzogni, 1991). Bishop (1980) recorded natural fish kills in the Northern Territory that resulted from oxygen deprivation due to exposure to anoxic bottom waters disturbed by flood rains. Although coastal swamps and lagoons are natural nursery habitats for juvenile barramundi (Moore, 1982; Russell and Garrett, 1983, 1985), conditions in these areas can be quite volatile, and they may provide adequate habitat for barramundi for only short periods during the year.

Other studies have shown that for some species size at release is an important determinant of later survival. For example, Leber (1995) found that size at release of stocked mullet (*Mugil cephalus*) influenced survival and that fish smaller than 70 mm TL rapidly disappeared after release, whereas larger fish survived to contribute to the fishery. The results of our study indicate that the size of barramundi at stocking (30–40 mm or 50–60 mm TL) does not affect their survival, but these results are still preliminary. Further examination of the survival of different size classes of fish, particularly relatively large fish (i.e., 100 mm TL or larger), needs to be undertaken to determine the optimal size at release (in cost-benefit terms).

Recaptures of stocked fish have shown that some barramundi do make substantial intrariverine movements, both upstream and downstream, although most fish were recaptured within 3 km of their release site. The high proportion of fish that remain close to their release site, combined with the absence of any evidence that particular habitat types provide improved survival, suggests that barramundi should be released at various locations throughout a catchment, rather than at a single stocking site. That many fish remain close to their release site suggests that these habitats will support higher densities of juvenile and subadult barramundi than are normally found there. There is no evidence, as yet, of coastal or interriverine movements, although evidence from earlier Australian studies suggests that some limited movements do occur (Davis, 1986; Russell and Garrett, 1988).

Stocked fish in the Johnstone River took approximately 3 yrs to reach the minimum legal size of 580 mm TL, and this result is consistent with the growth rates of natural stocks of barramundi in Papua New Guinea (Reynolds and Moore, 1982) and in the Northern Territory and the Gulf of Carpentaria (Davis and Kirkwood, 1984). Barramundi have also been released into freshwater impoundments in northern Queensland, and in these environments their growth appears to be substantially faster than in rivers. MacKinnon and Cooper (1987) found growth of barramundi in Lake Tinaroo to exceed those estimates for wild stocks in Papua New Guinea and in the Gulf of Carpentaria. Substantially faster growth has also been found for barramundi released into Lake Morris, a small impoundment near Cairns (A. Hogan, pers. comm.). Barramundi in Lake Morris reached the minimum legal size in just over a year (A. Hogan, pers. comm.). The reasons for this extraordinary disparity may be related to lack of competition and predators and an abundance of prey in impoundments.

Catch rates of barramundi in the recreational fishery before the recruitment of stocked fish are low (Fig. 3) but comparable to those in other northern Queensland coastal streams (Russell and Hales, 1993b). The impact that stocked fish will have on these catch rates is yet to be determined, but the high proportions of stocked fish both in research sampling (ca. 20%) and in commercial and recreational catches (ca. 15%) suggest that the contribution will be substantial. These data suggest that the level of catches needed to provide economic benefits for the local community should be easily achievable.

It is now widely accepted that stock enhancement can play an important role in the recovery of fish stocks that have been adversely affected by overfishing or by loss of essential habitats (Holt, 1993; Blankenship and Leber, 1995; Heard et al., 1995; McEachron et al., 1995). Stock enhancement is not an end in itself but is another fisheries-management tool that should be integrated with more traditional, generally restrictive, fisheries-management techniques to facilitate population recovery (see McEachron et al., 1995). In Australia, other state fisheries agencies are also considering, or commencing, stocking programs with barramundi and other marine species. The Northern Territory Department of Primary Industries and Fisheries stocks barramundi in freshwater impoundments but has not yet begun stocking programs in coastal rivers (R. Griffin, pers. comm.). Harvest and environmental pressures on barramundi stocks in the Northern Territory and northern Western Australia are likely to be considerably lower than those in northern Queensland because of the low population density and limited development, so public pressure for stock enhancement in these areas is limited. To date, our study has shown that stocking barramundi is likely to be a cost-effective management technique and has provided useful information on stocking strategies for this species. Additional research is necessary for further examination of optimal release size for stocked barramundi and for determination of the contribution that stocked fish make to recreational and commercial fisheries.

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