Barlow, Christopher G. (1998) ***Aspects of the biology of juvenile barramundi Lates calcarifer (Bloch) relevant to production for recreational fisheries and farming, with a note on the proposal to introduce Nile perch Lates niloticus (L.) to Australia.*** **PhD thesis, James Cook University.**

Aspects of the biology of juvenile barramundi *Lates calcarifer* (Bloch) relevant to production for recreational fisheries and farming, with a note on the proposal to introduce Nile perch *Lates niloticus* (L.) to Australia

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in January 1998

for the degree of Doctor of Philosophy in

the Department of Zoology at AQUACULTURE

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Christopher G. Barlow 15 January 1998

ABSTRACT

The research covered in this thesis concentrated primarily on improving production protocols for juvenile barramundi *Lates calcarifer* through studies on diet and feeding habits, pond rearing techniques, effects of photoperiod on growth, and weaning strategies. Juvenile barramundi are produced in northern Australia for two reasons; to supply seed for the aquaculture industry, and to supply fingerlings for recreational fisheries enhancement programs. Within this context, two related studies were undertaken: firstly, an analysis of the proposal to introduce Nile perch to Australia, which preceded the barramundi production studies; and secondly, an evaluation of the use of circulus patterns on scales for discriminating wild and hatchery-produced barramundi.

A review of the historical and present distribution of barramundi (a catadromous species) in Queensland indicated that barriers (barrages, weirs and dams) built in river systems, coupled with the inability to negotiate even minor stream barriers, have restricted access of this fish to much of its original, natural habitat. Further, while the construction of dams has created vast new aquatic habitats (potentially at least 100 000 ha in Queensland), these have also been inaccessible to barramundi *via* its normal life-cycle movements. To fill the 'niche' made available by the decreasing distribution of barramundi, it was proposed that a congener of barramundi, the Nile perch *Lates niloticus*, be introduced to establish sport fisheries in tropical impoundments. The principal rationale for this introduction was that,

unlike barramundi, the Nile perch reproduces in fresh waters and, hence, once established would be capable of sustaining breeding populations.

Contrarily, however, three lines of evidence suggested that the introduction of the Nile perch would have negatively impacted upon Australian aquatic fauna. The lower temperature tolerance of the species and analysis of water temperatures in rivers in eastern Australia indicated that its range would have extended to temperate regions, thus endangering established fisheries for native species in those areas. The introduction of the Nile perch, an opportunistic predator, to Lakes Victoria and Kyoga in eastern Africa caused a drastic decrease in species diversity and fish biomass. *L. niloticus* is not restricted to lacustrine habitats, and known features of its biology indicate that it could have colonised and adversely affected the fauna in a broad range of freshwater habitats in Australia. The risks associated with the proposed introduction were considered to outweigh the potential benefits, and hence it was abandoned. As an alternative, attention was given to hatchery production of barramundi as a means of supplying fingerlings for stocking fresh waters for enhancement of recreational fisheries in northern Australia.

Hatchery-reared barramundi fry were studied to determine feeding behaviour, diel feeding patterns, stomach evacuation rates, daily food consumption and growth rates. At 16–18 mm total length (TL), the feeding behaviour of the fry changed abruptly from a roving zooplanktivore to that of a lurking predator. A distinct change in pigmentation accompanied the change in feeding behaviour. Fry reared in hatchery ponds were obligate zooplanktivores between 10 and about 17 mm. Between about

17 and 50 mm the diet changed progressively from zooplankton to insect larvae to small vertebrates. The fry were visual feeders, taking food throughout the day, and showed a peak in feeding activity at dusk. Feeding continued at a reduced level under moonlight conditions, but ceased in total darkness. Stomach evacuation rates for 16 mm fry under continuous feeding and non-feeding conditions were 47 and 210 minutes, respectively; for 37 mm fry the rates were 73 and 108 minutes, respectively. The daily rations for these two size groups were 19–86% and 38–56%, respectively. Specific growth rates were 13–16% body weight/day for fry reared in ponds.

Laboratory-based experiments were conducted to determine the vulnerability of different sized barramundi fry to predation by nymphs of the dragonfly *Pantala flavescens*. Mortality of 10 mm mean TL fry was significantly greater in the presence of dragonfly nymphs, whereas 20 mm mean TL fry exhibited comparatively minor levels of mortalities. The results accorded with feeding behaviour patterns of the different sized fry and the development of an escape response in barramundi fry at 16–18 mm TL. An examination of the growth rates of *P. flavescens* in newly-filled ponds, the development of the pond fauna on which the barramundi fry feed, and the growth rates of fry, indicated a rearing strategy to optimise survival of barramundi fry reared in freshwater ponds.

An experiment was conducted to determine the effect of extended periods of light on the growth, survival, feeding pattern and daily food consumption of barramundi fry reared in a freshwater hatchery. There was no significant difference in growth or survival of fry, initially 11–12 mm TL, in either 12, 18 or 24 hours light. Fish exposed to 12L/12D photoperiod fed continuously during daylight, and ceased feeding in darkness. Under continuous daylight conditions, fish fed throughout the normal daytime period, but ceased feeding at a time corresponding to the normal onset of darkness; feeding started again near midnight. Daily food consumption for 34 mm fish was approximately 40% more in continuous light than in 12L/12D photoperiod. The results clearly showed that there was no advantage to be gained by rearing barramundi fry in extended light regimes.

An experiment was conducted to determine if survival during weaning was affected by the size of the fry at the initiation of weaning. At the outset of the trials, feeding of live zooplankton was discontinued and a commercially available salmon starter crumble was dispensed by automatic feeders every hour for the 12 hours of daylight (photoperiod 12L/12D). Four trials were undertaken using fish initially 12.8, 13.6, 16.7 and 19.6 mm TL. Survival through the 10-day weaning period averaged 39, 58, 97 and 92%, respectively. An asymptotic curve described the relationship between initial size and survival, and indicated that survival of greater than 90% could be expected with fry greater than 16 mm TL at the time of weaning. This is the size at which barramundi fry change their feeding habit from that of a roving zooplanktivore to a lurking predator. Cost-benefit analyses indicated a considerable economic saving in delaying weaning until the fry are 16 mm TL.

A study was conducted to determine if hatchery-reared and wild barramundi could be distinguished by the patterns of circulus spacing on the scales. Proprietary software and digitising equipment was used to obtain measurements of circulus spacing within one millimetre of the focus of the scales. Discriminant analyses separated the groups with up to 83% accuracy. As the technique utilises innate tags laid down in response to the rearing environment, it has considerable potential for evaluating the efficacy of large-scale enhancement programs. However, because scales from fish larger than 350 mm TL were too thick and heavily pigmented to be reliably read, the applicability of the technique with barramundi is limited to fish smaller than 350 mm TL.

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DECLARATION

I declare that this thesis is my own work and has not been submitted in any form for another degree or diploma at any university or other institution of tertiary education. Information derived from the published or unpublished work of others has been acknowledged in the text and a list of references is given.

Christopher G. Barlow 15 January 1998

ACKNOWLEDGEMENTS

Many colleagues and friends have assisted me in various ways while I have been undertaking this Ph.D. program. I wish to acknowledge and thank them here.

- My colleagues at the Freshwater Fisheries and Aquaculture Centre, Walkamin. In particular, I thank Les Rodgers for his excellent technical assistance, fish husbandry skills and unfailing attention to detail. Others include Alf Hogan, Clive Jones, Paul Clayton, Paul Palmer, Clare Longhurst, David Bull and Trevor Marnock. Kim Hodgon, Sandra Lange and Dianne Crellin provided clerical support.

- My supervisor, Associate Professor Norm Milward for his guidance on the project and thesis preparation, and considerable patience while awaiting submission of the thesis.

- Zena Seliga, the Fisheries Librarian within DPI, has provided a truly excellent service during the course of the project, as she continually does for all Fisheries staff within QDPI.

- Barbara Gregg, Bill Rutledge and others within the Texas Parks and Wildlife Department, who provided facilities and assistance to enable the study reported in Chapter 7 to be undertaken.

- Colleagues at the Northern Fisheries Centre, in particular Mike Rimmer, Rod Garrett and John Russell, for their comments and advice on aspects of the work.

- Joanne De Faveri, David Reed and Allan Lisle helped with statistical analyses. Ian Ruscoe, Phil Hales and Joanne Grady prepared some of the figures.

- Administrative backing for the project was provided by many people within QDPI, but in this regard I particularly wish to thank Jim Gillespie and Bob Pearson, who as managers have provided support and encouragement for the work undertaken at the FFAC, Walkamin.

- Financial support for the work described herein was variously provided by the Fisheries section of QDPI, the Fishing Industry Research and Development Council (Grant 89/67) and the Churchill Fellowship Memorial Trust Fund.

- To the many industry colleagues (barramundi farmers, researchers and anglers) on whom I drew for information and/or assistance, I express my sincere gratitude.

- I particularly thank my family for their patience, encouragement and support in many ways during the course of this study

CHAPTER 1. GENERAL INTRODUCTION

1.1 PRODUCTION OF FINGERLING FISH

1.1.1 *Reasons for production*

Controlled breeding and production of fingerling fish is primarily undertaken for three reasons:

- to provide fish for farming, either for grow-out as food fish or for the ornamental fish trade;
- to provide stocking material for enhancement of recreational and/or commercial fisheries; and
- as part of management programs for endangered species.

The respective importance of these rationales varies with the species and to a lesser extent with the country in which the activity is undertaken. Of the three, producing fish for food is the most important activity on a world-wide basis, and has the longest history. Pillay (1990) and Landau (1992) have reviewed the origins and growth of aquaculture, and cited the earliest known report on the subject, namely 'Yang Yu Ching', variously interpreted as the 'Classic of Fish Culture' or 'Treatise on Fish Culture', written by Fan Lei, a Chinese politician-turned-fish-culturist around 500 BC. Food production from fish farming is now practised in various forms on all inhabited continents, although it is a more common and economically important activity in the

Asian region between India and Japan than elsewhere (Shepherd 1988). The most important families are the Cyprinidae and Cichlidae (primarily 'tilapias') in tropical regions, and the Salmonidae in temperate areas.

Breeding and rearing ornamental fish, particularly goldfish *Cyprinus carpio* and carp *Cyprinus carpio*, is an ancient practice in Japan and China. Nowadays the ornamental (or 'aquarium') fish trade encompasses numerous species, and world-wide trade in fish and accessories is believed to be worth more than US$7000 million per annum (Andrews 1990). Of the estimate of at least 150 million fish traded each year, the great majority are freshwater species, and around 90% of these are bred on farms, primarily in South-East Asia, Japan, Israel and the USA (Andrews 1990).

Producing fish for enhancement of recreational fisheries started in Europe and North America in the mid-19th Century (Landau 1992). Obviously the activity is confined to highly sought-after angling species and to areas where recreational fishing is a major activity. The most valued taxonomic group is the family Salmonidae, various species of which have been translocated from Europe and North America into cool-water recreational fisheries throughout the world. Native angling species are also produced in different areas, for example the Percichthyidae (perches and cods) in Australia, the Centrarchidae (basses and sunfishes) in North America, and the Esocidae (pikes) and Percidae (perches) in both North America and Europe. An offshoot of recreational fisheries is the production of forage and bait species (Brown and Gratzek 1980), although this is negligible compared with the production of sport fish.

Enhancement of commercial fisheries for anadromous species has been undertaken in Europe, Japan and North America since the mid-1800s and continues to the present day (Moring 1986). The most important of these fishes are the salmonids, and others include striped bass *Morone saxatilis*, clupeid fishes *Alosa* spp., and various sturgeons *Acipenser* spp. Enhancement of commercial fisheries for marine species also started in the 1800s, but these early efforts were constrained by the inability of fish culturists to rear the larvae beyond the yolk-sac stage (Richards and Edwards 1986). Techniques for successful production of marine species were developed in the late 1960s–early 1970s, and since then an increasing number of marine fishes has been reared for aquaculture and restocking purposes (Sorgeloos *et al.* 1994). Enhancement of commercial marine fisheries is now a common practice in the Scandinavian countries (principally with cod *Gadus morhua*), the Mediterranean (with European sea bass *Dicentrarchus labrax*, gilthead sea bream *Sparus aurata*, mullets *Mugil* spp., and flatfishes *Solea* spp. and *Scophthalmus* spp.), Japan (with red sea bream or snapper *Pagrus (Chrysophrys) auratus*, flatfish *Limander* spp. and *Paralichthys* spp., puffers *Fugu* spp. and breams *Acanthopagrus* spp.), and the USA (primarily with red drum *Sciaenops ocellatus*) (McCarty *et al.* 1986, Richards and Edwards 1986, Danielssen *et al.* 1994). It is likely that enhancement of commercial fisheries will be increasingly used as a fisheries management tool; the real challenge is in determining the efficacy of such programs (Blankenship and Leber 1995).

Management programs entailing controlled breeding of endangered species is a very recent activity. The aims of breeding programs with endangered species vary depending on the degree of alteration of the native habitat. In some instances, amelioration of those factors which caused the original decline may be possible, in which case captive breeding is to provide fish for restocking in native habitats or preserves (for example, desert fishes in north America (Pister 1990)). At the other extreme, the changes may be irreversible; in such cases, breeding is simply to preserve the gene pool (for example, cichlid species from Lake Victoria in east Africa (Bruton 1990)).

1.1.2 *Production of fingerling fish in Australia*

In Australia, fingerling fish are produced for fisheries enhancement, farming, and conservation purposes.

Traditionally, production for enhancement of recreational fisheries has been the major activity. This started in the early 1860s when eyed ova of brown trout *Salmo trutta* were brought to Tasmania (Cadwallader and Backhouse 1983). Other salmonids, cyprinids and percids were later brought to Australia by fish acclimatisation societies, the European members of which wanted familiar species for recreational fishing purposes (Clements 1988). These and other introductions, their success in establishing fisheries and some of their concomitant ecological consequences have been reviewed by Weatherly and Lake (1967), Tilzey (1980), McKay (1984, 1989), Fletcher (1986), Arthington (1989, 1991) and Pollard (1990).

Production of salmonids (principally brown trout and rainbow trout *Oncorhynchus mykiss*) for recreational fisheries enhancement is still a major activity at Government hatcheries in NSW, Victoria, Tasmania and Western Australia. Many millions of fish are stocked annually into mountainous streams and large impoundments (see review of stocking large reservoirs in Australia by Cadwallader (1983)). Stocking sizes vary from eyed ova, which are placed in artificial redds (nests) in streams, to yearling fish weighing approximately 500 g.

Experiments on the production of Australian native fishes began in the early 1900s. H.C. Dannevig conducted experiments in 1905 on artificial production of Murray cod *Maccullochella peelii* (Dakin and Kesteven 1938). T.L. Bancroft was rearing lungfish *Neoceratodus forsteri* prior to 1914, and in the 1930s set up what was possibly the first hatchery for production of an Australian fish (Bancroft 1914, 1933). However, it was not until the 1960s that programs were initiated with the specific aim of producing native species for fisheries enhancement. The first of these programs was at the Inland Fisheries Research Station at Narrandera, New South Wales, which was developed primarily to investigate breeding of native fishes in the Murray–Darling River system. Part of the impetus for these investigations was the decline in native fish stocks in rivers and the failure of many high-quality sport fishes to establish large populations in the numerous impoundments which were being established for water storage. Breeding of the principal sport fishes was quickly achieved (Lake 1967a, 1967b), but fry production was problematical, and it was not until the late 1970s that large-scale production of fry, and subsequently stocking of impoundments, became routine

(Rowland *et al.* 1983). Following the early work at Narrandera, breeding programs for native fishes were established in Queensland and Victoria. At least 11 native species and 5 salmonids have now been produced in Australia for recreational fishing purposes (Table 1.1), although not all are currently being propagated.

Enhancement of commercial fisheries via hatchery releases has not been undertaken on a commercial basis in Australia up to the present time, although preliminary investigations into the supplementary stocking of prawn fisheries operating in relatively confined estuarine waters are being made (P. Rothlisberg, CSIRO, Cleveland, pers. comm. 1996).

Ornamental fish production in Australia at a commercial level is primarily confined to goldfish. The few native species which are commercially traded (principally rainbowfishes, family Melanotaeniidae) breed naturally in small ponds.

Aquacultural production of fish in Australia for food production began in the early 1960s with the development of rainbow trout farms in Victoria (Clements 1988), followed by New South Wales and later Tasmania. In the early 1980s Atlantic salmon *Salmo salar* were taken from the mainland to Tasmania, where production of fry was commenced in a freshwater hatchery to supply smolts for a large marine-based farming industry. Farming native species for food production started with barramundi *Lates calcarifer* in Queensland in the mid-1980s (Pearson 1987). Silver perch *Bidyanus*

Table 1.1 Native and introduced fish species produced in Australia for recreational fisheries enhancement: tabulation of scientific and common names, States in which stocked, and key references — with comments — on production techniques.

Scientific name (Family)	Common name	State in which stocked	Key references * Comments
Macquaria ambigua (Percichthyidae)	Golden perch	Vic., NSW, Qld	Rowland (1983a) * Spawning in captivity requires hormonal induction; larvae and fry reared in fertilised freshwater ponds. Rowland (1986) * Description of facilities and techniques for spawning and extensive larval rearing.
Macquaria novemaculeata (Percichthyidae)	Australian bass	NSW, Qld	Battaglene *et al.* (1989) * Review of hormone-induced spawning, larval rearing and stocking in the period 1979–86. Battaglene and Talbot (1990) * High salinity, low light and low aeration required for high percentage swim bladder inflation in intensive larval rearing.
Maccullochella peelii peelii (Percichthyidae)	Murray cod	Vic., NSW, Qld	Rowland (1983b); Cadwallader and Gooley (1985) * Spawns naturally in ponds; artificial substrates used to facilitate egg retrieval; larvae and fry reared in freshwater ponds. Rowland (1988) * Documentation of hormonal induction of spawning. Gooley *et al.* (1995) * Maturation and spawning of a population in a small, confined lake.

Scientific name (Family)	Common name	State in which stocked	Key references * Comments
Bidyanus bidyanus (Teraponidae)	Silver perch	Vic., NSW, Qld	Rowland (1984) * Spawning in captivity (in temperate areas) requires hormonal induction; larvae and fry reared in fertilised freshwater ponds. MacKinnon (1986) * Spawns naturally in ponds following rain in tropical areas.
Hephaestus fuliginosus (Teraponidae)	Sooty grunter	Qld	MacKinnon (1986) * Production methods entail hormone induction and extensive larval rearing in freshwater ponds.
Tandanus tandanus (Plotosidae)	Eel-tailed catfish	Vic., NSW, Qld	Merrick and Midgley (1981) * Description of spawning behaviours. MacKinnon (1986) * Breeds naturally in ponds; currently not being produced for stocking.
Oxyeleotris lineolatus (Gobiidae)	Sleepy cod	Qld	Merrick and Midgley (1982) * Description of artificial spawning substrate. MacKinnon (1986) * Production currently relies on collection of eggs, which are attached as a mat onto substrates; fry produced in fertilized ponds.
Scleropages jardini (Osteoglossidae)	Saratoga	Qld	MacKinnon (1986) * Breeds naturally in small ponds; parental female incubates eggs in her mouth.

Scientific name (Family)	Common name	State in which stocked	Key references * Comments
Scleropages leichardti (Osteoglossidae)	Saratoga		Merrick and Green (1982) * Breeds naturally in small ponds; female incubates eggs in her mouth.
Lates calcarifer (Centropomidae)	Barramundi	Qld	Copland and Grey (1987) * Review papers on culture techniques throughout Indo-Pacific region; larvae reared intensively in hatcheries. Rutledge and Rimmer (1991) * First report of extensive rearing using fertilised brackish water ponds.
Salmo trutta (Salmonidae)	Brown trout	NSW, Vic., Tas.	Cadwallader and Backhouse (1983) * Adults mature in captivity; gametes obtained by hand-stripping; fertilised eggs incubated in troughs; larvae reared intensively on artificial dry foods.
Oncorhynchus mykiss (Salmonidae)	Rainbow trout	NSW, Vic., Tas., WA	Cadwallader and Backhouse (1983) * As for *S. trutta*.
Oncorhynchus tshawytscha (Salmonidae)	Chinook salmon	Vic.	Cadwallader and Backhouse (1983) * As for *S. trutta*; released to land-locked lakes in Victoria.
Salvelinus fontinalis (Salmonidae)	Brook trout	NSW, Tas.	
Salmo salar (Salmonidae)	Atlantic salmon	NSW, Tas.	

bidyanus farming is now developing in New South Wales and Queensland (Rowland 1994). These two species are the only ones being produced commercially, although there is limited experimental work being conducted on marine snapper *Pagrus auratus* (Bell *et al.* 1991), striped trumpeter *Latris lineata* (Hutchinson 1993) and freshwater Murray cod *Maccullochella peelii* (Gooley and Anderson 1992).

Artificial propagation programs have been developed as part of management strategies for five threatened freshwater species in Australia, these being trout cod *Maccullochella macquariensis*, eastern freshwater cod *Maccullochella ikei*, Mary River cod *Maccullochella peelii mariensis*, Macquarie perch *Macquaria australasica,* and Lake Eacham rainbowfish *Melanotaenia eachamensis* (Ingram *et al.* 1990). Hatchery production of these species provides fry for restocking, safeguards stocks, and provides opportunities for research into the biology of threatened fishes (Pollard *et al.* 1990). Key references to production techniques and management strategies are listed in Table 1.2.

From the foregoing discussion it is apparent that the type of species and end use of progeny from fish breeding programs varies enormously. However, many steps in the production process are inherently similar and independent of the ultimate aim of the breeding program. This can be seen in Figure 1.1, in which the various steps involved in fish production are diagrammatically shown.

Table 1.2 Fish species produced in Australia for conservation purposes: tabulation of scientific and common names, and key references to production techniques and management strategies.

Scientific name (Family)	Common name	Key references * Comments
Maccullochella macquariensis (Percichthyidae)	Trout cod	Ingram and Rimmer (1992) * Fish mature in ponds, but hormonal induction necessary for spawning; egg incubation and larval rearing as for *M. peelii.* Douglas *et al.* (1995) * Hybridisation between trout cod and Murray cod in natural populations in the Murray River.
Macullochella ikei (Percichthyidae)	Eastern freshwater cod	Rowland (1993) * Bred for restocking native habitat.
Maccullochella peelii mariensis (Percichthyidae)	Mary River cod	

Scientific name (Family)	Common name	Key references * Comments
Macquaria australasica (Percichthyidae)	Macquarie perch	Ingram *et al.* (1994) * Breeding protocols have been investigated at NSW and Victorian Government hatcheries; induced spawning of captive fish generally unsuccessful.
Melanotaenia eachamensis (Melanotaeniidae)	Lake Eacham rainbowfish	Barlow *et al.* (1987); Ingram *et al.* (1990); Moritz *et al.* (1995). * Disappearance from Lake Eacham, Queensland, associated with translocation of other Australian native fishes into the lake; stocks being maintained in ponds at Walkamin Research Station; re-introduction to Lake Eacham has not been successful. Taxonomic status of this species and congenerics under review.

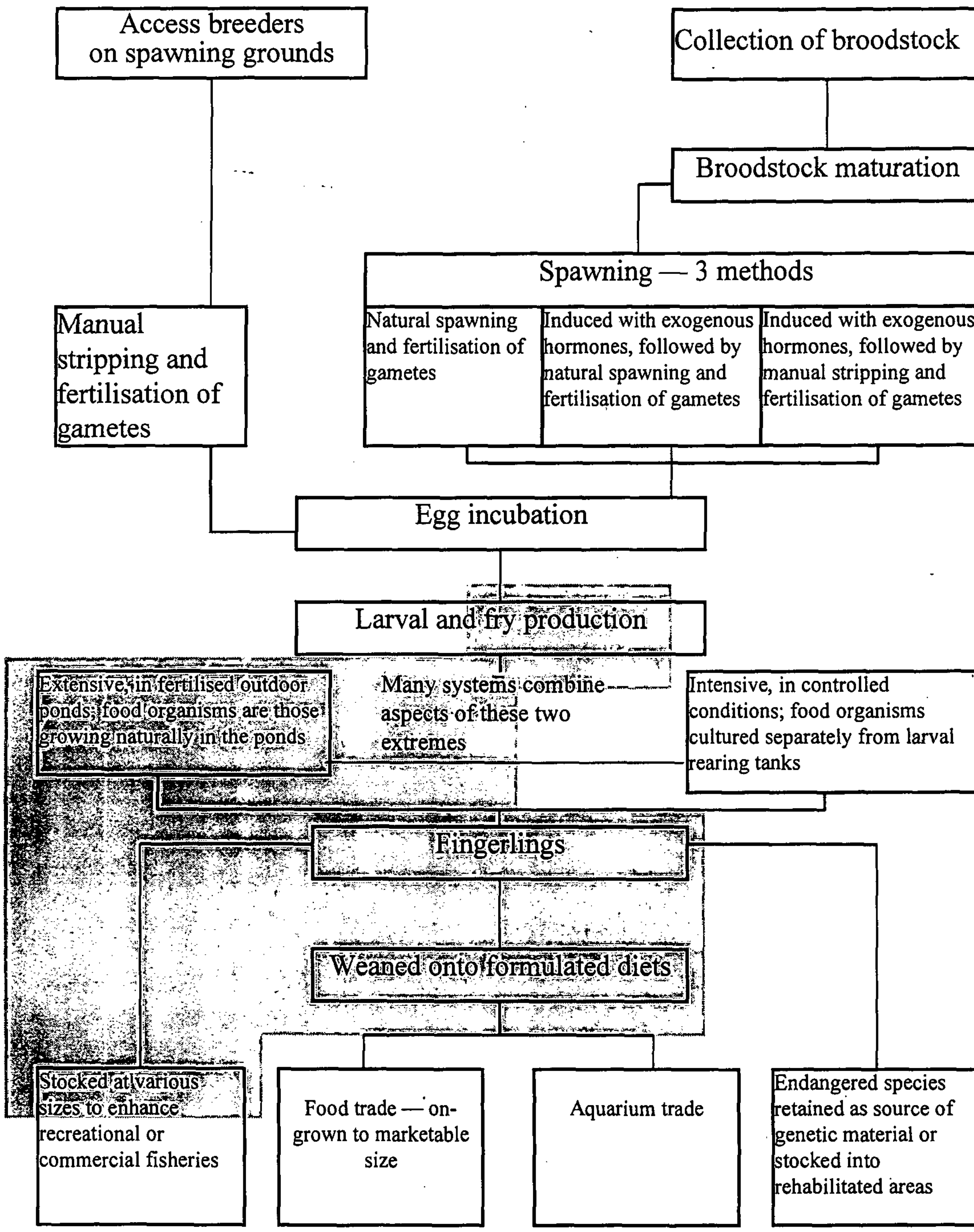

Figure 1.1 Schematic representation of the various procedural steps involved in fish production programs. The shaded section highlights the area of research covered within the present study.

1.2 PRODUCTION OF BARRAMUNDI

1.2.1 *History of barramundi aquaculture*

There are early reports of farming of barramundi using wild-caught fingerlings in India (Menon 1948), and pond and cage rearing of wild progeny were traditionally practised in other south-east Asian countries. However, aquaculture of the species was limited by the difficulty and unreliability of obtaining fry from natural waters. In an attempt to solve this problem, the Thai Government commenced research in the early 1970s on artificial propagation of barramundi at the Songkhla Marine Fisheries Station. Hatchery production of fingerlings was achieved for the first time in 1973 using eggs stripped from wild spawners (Wongsomnuk and Manevonk 1973). By 1975, the station had successfully produced the first batch of fry from eggs obtained from induced breeding of captive broodstock (Sirikul 1982). The supply of hatchery-produced fry facilitated large-scale farming in Thailand, which, coupled with international training programs offered by the Thais, provided the impetus for other countries in the region to investigate hatchery production of barramundi. Within a decade, hatchery production was achieved in the Philippines (Harvey *et al.* 1985), Taiwan (Lin *et al.* 1985), Singapore (Lim *et al.* 1986) and Malaysia (Ali 1987). Barramundi now forms the basis of well-developed farming operations in these countries.

In Australia, detailed work on barramundi culture commenced in 1983, in two separate projects. The first was a project on development of barramundi hatchery and farming techniques, funded by the Fishing Industry Research Trust Account (FIRTA Project 83/38). This project was conducted in the Cairns–Innisfail region in north Queensland, and led to the formation in 1985 of the publicly listed aquaculture company 'Sea Hatcheries'.

The second was a program conducted by the Queensland Department of Primary Industries (QDPI) at its Cairns and Walkamin laboratories. The initial aims of the work were to investigate controlled breeding and production of fingerlings for stocking freshwater impoundments in north Queensland. The program was given high priority within QDPI because, if successful, the use of barramundi for enhancing recreational fisheries would provide an alternative to the exotic Nile perch, which was concurrently being investigated with a view to importation and stocking in northern Australian waters.

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

Outside Queensland, the Northern Territory Department of Primary Industry and Fisheries started a program on barramundi aquaculture in 1987. In 1993, six grow-out farms were licensed in the Northern Territory. In South Australia, West Beach Aquaculture Pty Ltd has established a hatchery operation, which provides fingerlings, expertise and facilities to a network of grow-out farms (in 1998, these were located in New South Wales and South Australia). There is also one farm in South Australia producing barramundi in geothermal water; it uses fingerlings from farms in north Queensland.

1.2.2 *Types of farming systems used in Australia*

Broodstock maintenance

Early work on culture techniques for barramundi relied heavily on obtaining fertilised eggs by stripping running-ripe male and female barramundi caught on spawning grounds. This approach is expensive, unreliable and can potentially be in conflict with commercial fisheries' interests. It has now largely been replaced by the development of controlled breeding techniques for captive broodstock. Fertilised eggs are obtained from captive broodstock in two ways (Palmer *et al.* 1993). The most reliable and commonly used method is hormone-induced tank spawning, in which the fish spawn naturally following the injection of reproductive hormones (Garrett and Connell 1991). The other is hormonal induction of broodstock followed by manual stripping of semen and ova soon after ovulation. The semen and ova are manually mixed to enable fertilisation. This method is not preferred because of the labour requirement, the difficulties in predicting the time of ovulation, and the fact that fertilisation rates are generally not as good as with natural spawning.

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

<u>Larval–fingerling rearing</u>

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

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

In South-East Asia, barramundi larvae are reared intensively and it was these larval rearing techniques which were introduced to Australia, where they are still used in a few hatcheries. The QDPI barramundi rearing project originally used the intensive technique for early larval production, but modified it to incorporate a freshwater pond rearing phase for larvae older than 15–20 days. In the early 1990s the intensive system was dropped in favour of extensive rearing in brackishwater ponds for all larval and early juvenile stages. The majority of barramundi fry now produced in northern Australia is produced using extensive larval rearing procedures. More recently, barramundi farmers have begun using the 'green water' culture technique, which entails the phytoplankton, zooplankton and larval fish being grown together in large (5–20 tonne) tanks.

Grow-out systems

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

The most common grow-out system currently utilised in Australia is pond culture, in either brackish or fresh water. Fish are usually maintained in cages, although recently cage culture of fish less than 120–150 mm total length and free-ranging for larger fish have been sometimes combined. Pond rearing of free-ranging fish does not require the labour associated with cage culture, and produces fish with a better appearance and colour (silver rather than dark grey to black). The major disadvantages of these methods are difficulties in stock management and harvesting.

The third method of farming barramundi is intensive production in an indoors, controlled environment building, using underground water (i.e. pathogen free) and a high level of recirculation through biological filters. This facility and technology have been developed and patented by a South Australian company (West Beach Aquaculture Pty Ltd), which has established plants in South Australia, New South Wales and Queensland. The facility is generic, in that it is suitable for any species which can be intensively farmed. Because of the controlled environment, it allows for year-round production virtually anywhere that underground water is available, regardless of the temperature requirements of the species. By the mid 1990s, many small recirculation units had been established in southern Queensland for production of barramundi.

1.2.3 *Barramundi production*

Aquacultural production of barramundi in South-East Asia is presently more than 10 000 tonnes per annum (Table 1.3) (FAO 1994a).

Table 1.3 Aquacultural production (tonnes) of *Lates calcarifer* in 1986–92 in countries reporting to FAO (FAO 1994a). Data for the Philippines in 1991 and 1992 are from Ferdouse (1995); she also lists 'other Asia' as Taiwan.

COUNTRY	1986	1987	1988	1989	1990	1991	1992
Australia	2	1	22	18	33	94	145
Brunei Darus	...	1	1	0	0	0	8
Hong Kong	105	34	23	170	167	224	187
Indonesia	798	1 384	1 356	2 645	2 267	1 539	1 670
Malaysia	819	1 067	1 267	3 999	1 608	1 954	2 784
Other Asia	...	...	...	2 708	4 673	4 674	6 063
Philippines	...	...	...	...	779	698	636
Singapore	203	219	235	201	307	239	393
Thailand	823	1 183	1 034	1 290	1 005	1 650	1 600
TOTAL	**2 750**	**3 889**	**3 938**	**11 031**	**10 839**	**11 072**	**13 486**

In Australia, production of barramundi from aquaculture commenced in 1986, with 2 tonnes of fish coming from Sea Hatcheries' farm in that year. Since then, farms have been developed in the Northern Territory, South Australia and New South Wales. There is also one pilot-scale operation in Lake Argyle, Western Australia. Production has increased significantly since then, with approximately 460 tonnes (live weight) being sold from farms Australia-wide in 1995–96 (Table 1.4). The value of the barramundi aquaculture industry now equals that of the capture fishery (Table 1.4).

Table 1.4 Production and value of barramundi from aquaculture and capture fisheries in Australia in the financial years 1989–90 to 1996–97. Production figures are tonnes live weight (t).

		1989–90		1990–91		1991–92		1992–93		1993–94		1994–95		1995–96		1996–97	
FISHERY	**STATE**	**t**	**$'000s**	**t**	**$'000s**	**t**	**$'000s**	**t**	**$'000s**	**t**	**$'000s**	**t**	**$'000s**	**t**	**$'000s**	**t**	**$'000**
AQUACULTURE	Qld[a]	37	429	103	1100	152	1538	232	2313	248	2419	200	2192	328	3332	350	3439
	NT[b]	0	0	0	0	5	51	10	100	50	500	100	1000	20	200	10	100
	SA/NSW[c]	0	0	2	22	5	55	10	110	40	420	55	633	116	1469	150	1762
	TOTAL	37	429	105	1122	162	1644	252	2523	338	3339	355	3825	464	5001	510	5301
CAPTURE FISHERY	Qld[d]	733	5864	783	3913	471	2035	582	3055	478	2870	520	2705	667	2567	601	2103
	NT[d]	550	2052	459	1819	457	1689	451	2073	472	2111	482	2263	552	2956	577	2839
	Wa[e]	56	346[f]	61	282[f]	46	212[f]	46	228[f]	43	225[f]	40	197[f]	39	280	46	319
	TOTAL	1339	8262	1303	6014	974	3936	1079	5356	993	5206	1042	5165	1258	5803	1224	5261

Information sources:

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

b. Personal communication from Dr. C. Shelley, N.T. Department of Primary Industries and Fisheries. The data are estimates.

c. Personal communication from Dr. J. Trendall, West Beach Aquaculture Pty Ltd; and L. Gray, SA Fisheries.

d. Australian Fisheries Statistics 1992, 1995 and 1998. ABARE, Canberra. (The value of Queensland production reported in *Aust. Fish. Stat. 1995* and 1998 were twice the actual value, due to confusion between the value of fillet and the reporting of tonnes live weight).

e. Personal communication from Ms H. Brayford, W.A. Fisheries Department

f. Estimated from value of QLD and NT product.

1.3 AIMS OF THE STUDY

The overall goal of this study was to investigate the biology of juvenile barramundi to determine effective means of producing the species for recreational fisheries enhancement and farming purposes. Several aims were identified, which in effect comprise Chapters 2–7 of the thesis.

Ch. 2 The aim of this section was i) *to review the sport fishery for barramundi and the effect of catadromy and stream modification on the species' distribution;* and ii) *to analyse the proposal to introduce the exotic Nile perch* Lates niloticus *for establishment of sport fisheries in northern Australia.* In the context of developing sport fisheries in impoundments through the stocking of barramundi, it is helpful to appreciate why the alternative proposal of introducing Nile perch was not, in an ecological sense, soundly based.

Ch. 3 At the commencement of this project, there was no information available on pond-rearing of juvenile barramundi. Consequently, the feeding habits of juvenile barramundi reared in a hatchery and pond complex were studied, with the aim of *developing guidelines on husbandry techniques to maximise survival and growth of juvenile barramundi reared in fresh water.*

Ch. 4 Predation (particularly by dragonfly nymphs) is a serious problem in the rearing of fish larvae and fry in freshwater ponds. Experiments were undertaken i) *to* *determine if barramundi fry are susceptible to predation by dragonfly nymphs;* ii) *to compare predator avoidance responses of barramundi fry and similar sized sooty grunter,* Hephaestus fuliginosus (a freshwater breeding species); and iii) *to determine procedures to minimise predation by dragonfly nymphs on juvenile barramundi in ponds.*

Ch. 5 Barramundi are visual feeders and as such it was hypothesised that extended periods of light may influence feeding and growth patterns. Consequently an experiment was conducted *to determine growth, survival and feeding periodicity of juvenile barramundi reared in extended light regimes.*

Ch. 6 Weaning juvenile fish from live (or natural) food onto dry, manufactured diets is a critical phase in an aquacultural production process. Size is an important biological factor influencing a fish's amenability to weaning. Literature reports indicate that barramundi fry are generally weaned at about 10 mm TL (effectively at the time of metamorphosis), but with considerable associated mortality. Thus an experiment was performed *to determine the optimum size for weaning barramundi onto formulated feed.*

Ch. 7 The ability to recognise hatchery fish after stocking into open systems is a fundamental requirement for determining the efficacy of enhancement programs. Fingerling fish, because of their small size, are particularly hard to tag, and traditional methods are subject to error (tag loss and mortality) and are labour intensive. Studies overseas have shown that growth patterns laid down on scales can be a function of the rearing environment. A study was undertaken, using facilities provided by the Marine Fish Hatchery at Corpus Christi, Texas, USA, with the aim of *determining if patterns of circulus spacing on barramundi scales could be used to distinguish hatchery-reared and wild fish.*

CHAPTER 2. THE BIOLOGY AND EXPLOITATION OF BARRAMUNDI AND THE PROPOSAL TO INTRODUCE NILE PERCH *Lates niloticus* TO AUSTRALIA

2.1 A BRIEF REVIEW OF THE BIOLOGY AND EXPLOITATION OF BARRAMUNDI AND THE EFFECT OF STREAM MODIFICATION ON ITS LOCAL DISTRIBUTION.

2.1.1 *Taxonomy*

The barramundi was originally described by Bloch (1790) using specimens collected from the Indo-Pacific region. The exact location of collection of the type specimen is not known. Bloch (1790) listed it as Japan, but Cuvier and Valenciennes (1828) considered that Bloch was mistaken and that it was Java. They based this on the facts that the specimen was collected by Dutch traders (whose centre of operations was the Indonesian Archipelago), and that Bloch had mistakenly listed Japan as the locality for several other Javanese species.

Bloch (1790) named the species *Holocentrus calcarifer* (*'calcarifer'* meaning 'thorn carrier', a reference to the spines on the operculum and pre-operculum). The genus *Lates* was erected by Cuvier and Valenciennes in 1828 to encompass barramundi and several related African species. (According to Cuvier and Valenciennes (1828), 'Lates' was the name used by 'des anciens' for the Nile perch, *Lates niloticus*, and it was still in use in parts of Egypt up to the 17th Century). Congeners of barramundi are seven African species (Greenwood 1976) and the akame *Lates japonicus* from southern Japan (Katayama and Taki 1984). *Lates* has at various times been placed in several families in the Order Perciformes (see listing by Grey 1987), and is now in the family Centropomidae. Thus, the current taxonomic status of the barramundi is as follows.

Phylum Chordata

Subphylum Vertebrata

Class Osteichthyes

Subclass Actinopterygii

Order Perciformes

Suborder Percoidei

Family Centropomidae

Genus *Lates*

Species *calcarifer* (Bloch, 1790)

Lates calcarifer is known by a variety of common names throughout its range. In Australia the accepted common name is barramundi (derived from an aboriginal word 'burramundi', meaning large scales), but in the past it has also been called palmer, cock-up and giant perch (Grant 1985). Throughout South-East Asia the accepted common name in English is sea bass (or Asian sea bass). As expected for a fish with such a wide distribution, there are numerous local names for the species, such as 'bhekti' in

India (James and Marichamy 1987), 'ka-ka-dit' in Burma (Htin 1987) and 'pla kapong kao' in Thailand (Ruangpanit 1987).

The taxonomic description of *Lates calcarifer* from FAO (1974) is given below. It should be noted that the colour description is incomplete as it applies only to subadults and adults. Juveniles up to approximately 100 mm TL exhibit various patterns of black/dark-grey/silver (see section 3.3.1. of this thesis; also Russell (1987)).

Description. Body elongate, compressed, with a deep caudal peduncle. Head pointed, with concave dorsal profile becoming convex in front of dorsal fin. Mouth large, slightly oblique, upper jaw reaching to behind eye; teeth villiform, no canines present. Lower edge of pre-operculum with a strong spine; operculum with a small spine and with a serrated flap above origin of lateral line. Dorsal fin with 7–9 spines and 10–11 soft rays; a very deep notch almost dividing spiny from soft part of fin; pectoral fin short and rounded, several short, strong serrations above its base; dorsal and anal fins both have scaly sheaths; anal fin rounded. Scales large, ctenoid (rough to touch).

Colour. Two phases, either olive-brown above with silver sides and belly (usually juveniles) or green-blue above and silver below. No spots or bars present on fins or body.

2.1.2 *Distribution*

Lates calcarifer is widely distributed in rivers and coastal areas throughout the tropical and subtropical Indo-West Pacific region (Fig. 2.1). Its western limit is the Persian Gulf. To the north it ranges to Xiamen (24° 30'N) in southern China. Its eastern and southern limits are the eastern tip of Papua New Guinea and the east coast of Australia south to the Noosa River (26° 30'S) (Dunstan 1962, Greenwood 1976).

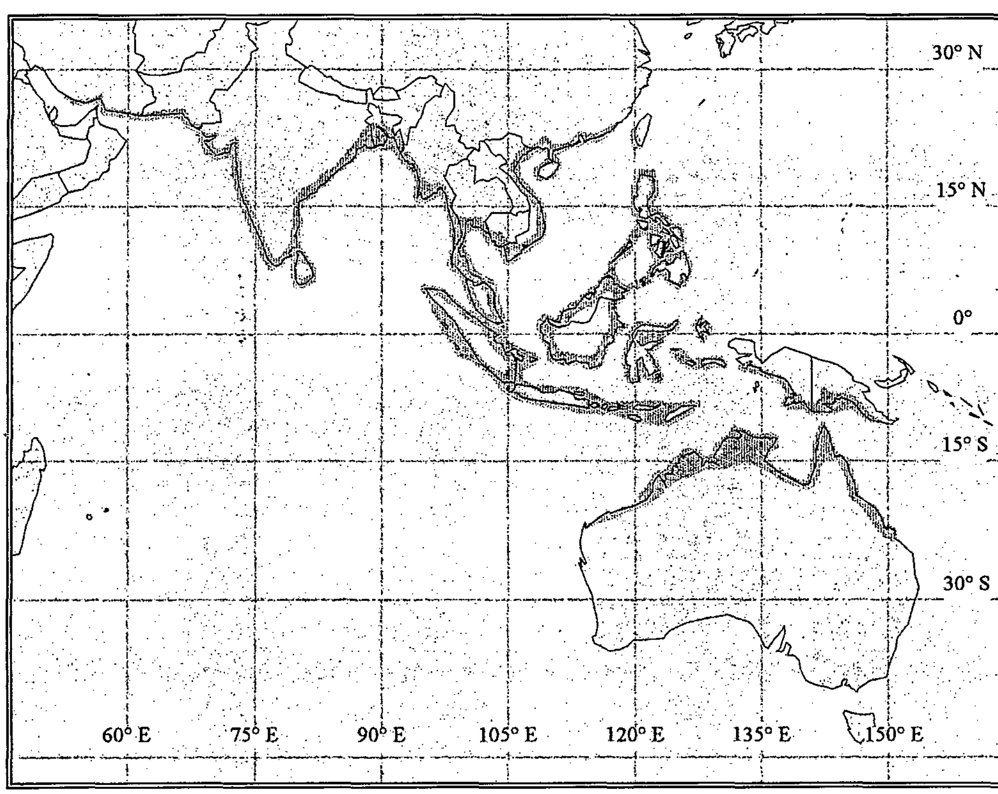

Figure 2.1 Distribution of *Lates calcarifer*.

In Australia, the barramundi is found in all the coastal waters and river systems north of the Noosa River on the east coast and the Ashburton River (22° 30'S) on the west coast (Morrissy 1985). It has also been recorded from the Abrolhos Islands (28° 40'S) off the coast of Western Australia (Whitley 1959), but this record results from misidentification of the similar-looking sand bass, *Psammoperca waigiensis* (Morrissy 1987). It is rarely collected at any distance from the coast, and is generally found only in waters subject to freshwater influence (Grey 1987).

In Papua New Guinea and Irian Jaya *Lates calcarifer* is found only on the southern side of the island. Moore (1980) proposed that its distribution in PNG is linked to the occurrence of river systems with associated large deltaic swamps combined with large tidal variations. On the southern (Papuan) side of the island the abundance of *L. calcarifer* is greatest around the Fly River, form where it decreases in numbers to both the east and west. Its absence from the northern (New Guinea) side of the island is intriguing, as the Sepik River provides habitat very similar to the Fly River. Reynolds (1978) referred to three possible reasons for *L. calcarifer* not being found there. The first, postulated by Dunstan (1961), was the small tidal rise in this area (0.6 m as compared with 2.5 m at the mouth of the Fly River). The second, suggested by Rapson (1968), was that the south equatorial current sweeping the north coast would remove eggs and larvae from the breeding area. The third, pointed out by Reynolds (1978), was that there is very little continental shelf at the mouth of the Sepik, with a sharp drop off within 800 m of the shore. He concluded that further information was required before any firm explanation could be given for the absence of barramundi from New Guinea.

The limits to the distribution of barramundi have been reported by Grey (1987). He considered that the lack of large rivers and fresh water to the west and the lack of continental land masses (and thus rivers) to the east would limit further distribution past these extremes. Latitudinal distribution is most likely controlled by temperature (note that southern China and southern Queensland are at similar latitude (24–26° N and S, respectively)). At the southern extreme of the barramundi's range in Queensland it is effectively dormant through winter at which time riverine water temperatures drop to 15–16°C. Captive broodstock held at these temperatures exhibit stress-related mortalities. Breeding during summer does not start until January in southern Queensland, when water temperatures reach 27–28°C. The seasonal temperature cycle is such that 0+ fish would have a very short growing season prior to the cessation of growth due to low temperatures (less than about 20°C) (J. Burke, Bribie Island Aquaculture Research Centre, pers. comm. 1996).

2.1.3 *Reproduction and associated movements*

Lates calcarifer in Australia and Papua New Guinea is a protandrous hermaphrodite. Individuals start life as a male, and after spawning one or more times, become female (Moore 1979, 1982; Davis 1982). Thus, the occurrence of females becomes more common with increasing size. Sex inversion takes place rapidly (probably in less than two months) immediately after spawning (Moore 1979). The size and age at which this occurs varies markedly between populations. For instance, stocks of *L. calcarifer* in Papua New Guinea and areas of the Northern Territory and southern Gulf of Carpentaria have a 1:1 sex ratio at about 80–100 cm total length (6–7 years old) (Moore 1979; Davis 1982, 1984). However, there have been precocious populations identified from northern Cape York Peninsula which mature much earlier (functional males at 1–2 years versus 3–5 years in 'normal' populations), and in which a 1:1 sex ratio occurs at about 45 cm total length (3 years old) (Davis 1984).

Primary females (that is, fish which mature initially as females and do not undergo sex reversal) are sometimes found, but their proportion in populations studied to date is very low (apparently less than about 1%) (Moore 1979, Davis 1985).

Researchers in the Philippines (Parazo *et al.* 1990) and Malaysia (Ali 1987) consider that stocks of *L. calcarifer* in those countries change sex, but there are no records of sex inversion in other areas of the fish's distribution. Detecting sex change in wild populations is very difficult because of the rapidity with which barramundi undergo sex inversion and the difficulty in detecting transitional fish macroscopically (Moore 1979). Nevertheless, the protandrous nature of the barramundi in Australian populations is very evident from the disparity in size between males and females. It is noteworthy that researchers in the Songkhla Lakes region in Thailand, where wild and captive populations of *L. calcarifer* have been studied in great detail since the early 1970s, do not consider it to be hermaphroditic (S. Maneewong, Songkhla Marine Fisheries Station, Thailand, pers. comm. 1983). Thus, while it appears that most *L. calcarifer* populations are protandrous hermaphrodites, some populations may not undergo sex reversal.

Barramundi is generally classed as catadromous; that is, a species which spends most of its life in freshwater and migrates to the sea to breed (Myers 1949, cited in

McDowall 1987). However, movement and migration associated with spawning is a particularly complex process in barramundi, and shows considerable regional variation.

In Australia, colonisation of upstream freshwater reaches of rivers is by 0+ fish, which leave estuarine nurseries when only a few months old (Dunstan 1959, Davis 1985, 1987, Russell and Garrett 1985, Griffin 1987). The fish mature in freshwaters, then travel downstream at first maturity to spawn in estuarine or coastal waters adjacent to the rivers from which the fish emigrated (Shaklee and Salini 1985). It seems that most adult fish then remain in estuarine waters or lower river reaches, with recolonisation of the upper riverine reaches again being by 0+ juveniles (Davis 1987, Griffin 1987), although there is a small percentage of fish which apparently spend their entire lives in estuarine or coastal waters.

In contrast, in Papua New Guinea maturing barramundi move out of inland rivers and swamps and then undergo extensive coastal migrations to specific spawning sites. The coastal migration is apparently a consequence of inadequate salinities for spawning and larval recruitment at the mouths of many river systems. After spawning, most adults leave the coastal waters and migrate back to the inland swamps and rivers from which they originated, although there are some adult fish which remain in coastal waters. Juvenile fish remain in coastal nursery swamps until about six months old, when the drying swamps force them to leave and distribute along coastal and estuarine regions. They later colonise the inland waters as 1+ or 2+ fish (Moore 1982, Moore and Reynolds 1982).

Spawning takes place in areas of high salinity (27–36 ppt) close to nursery grounds (Garrett 1987). Generally the spawning sites are in sheltered waters near river mouths, although barramundi will breed in the upper reaches of large estuarine systems if the salinities are suitable (Garrett *et al.* 1987). The spawning season in Australia is linked to seasonal temperature cycles, and only takes place when water temperatures exceed 27°C (Garrett 1987). This coincides with the summer monsoons in Australia, when there is maximum availability of nursery swamp habitat.

In equatorial regions the spawning season for barramundi is considerably extended; for instance in Thailand it breeds all year round (Ruangpanit 1987) and in India it breeds for 8 months of the year (James and Marichamy 1987).

Movement of young barramundi into freshwaters is an integral part of their life history. Juvenile fish have been recorded up to 800 km upstream in the Fly River in Papua New Guinea (Moore 1980), and up to 130 km upstream in India (James and Marichamy 1987). In Australia it is regularly found more than 100 km upstream from the mouths of rivers traversing flat country.

Natural or artificial structures across streams present barriers to fish migration. The capacity of percoid fishes to negotiate the barriers depends largely on the swimming ability of the particular species. Hogan and Graham (1994) documented flood gates on streams preventing barramundi moving upstream in the Herbert River in Queensland.

Kowarsky and Ross (1981) and Russell (1991) have studied two tidal barrages in central Queensland that effectively stopped upstream migration of barramundi (even though both were equipped with fish ladders). Research on swimming ability has shown that under experimental conditions burst swimming speeds of barramundi are considerably less than those exhibited by Australian bass *M. novemaculeata* (Mallen-Cooper 1989), another catadromous species from eastern Australia with similar body shape and ecology to barramundi. Field observations tend to confirm this finding, as Australian bass is found at higher altitudes and over steeper stream inclinations than is barramundi. Similarly, in tropical eastern Australia the catadromous jungle perch *Kuhlia rupestris* ascends streams to considerably greater altitudes than barramundi. The comparatively poor swimming ability of barramundi was further confirmed by Clague (1991), who showed that under laboratory conditions small barramundi (30–70 mm total length) exhibited slower burst and sustained swimming speeds than did similar-sized sooty grunter *Hephaestus fuliginosus*.

Obviously, the barramundi is not a strong swimmer, and even minor barriers across streams will prevent the species from moving further upstream.

From this brief review it is apparent that the reproductive biology of *L. calcarifer* varies geographically. This flexibility has enabled it to colonise a range of habitats within an extremely wide natural distribution. Despite this flexibility, there are several key factors which control the occurrence of barramundi within its natural range. These are:

1. the presence of major freshwater influence (barramundi is not found on small islands without major river systems);
2. high salinity for spawning;
3. nursery swamps for recruitment; and
4. unimpeded passage for upstream colonisation of river systems.

2.1.4 *Capture fishery*

Barramundi is a highly esteemed fish and consequently is exploited by commercial fishermen throughout its range. FAO (1994b) lists that the capture fishery for the species worldwide was 34 479 tonnes in 1992, but the actual catch was presumably considerably more, as no data were provided for Taiwan, China, Vietnam, Kampuchea, Thailand, Singapore, Burma, India and Sri Lanka (Table 2.1). Its relative importance in regional fisheries in unclear. The only pertinent reports are those of Sodikin (1987) who considered barramundi an important marine species in Indonesia, accounting for about 1% by weight of the commercial marine catch; Kasim and Jones (1987) who reported that in certain estuarine fisheries in India it comprises 4–6% of the catch.

The statistics for the capture fishery in Australia indicate landings of approximately 1000 tonnes annually (Table 1.4). Production is static (or slowly declining) due to stringent controls aimed at preventing over-exploitation and, in the case of the Northern Territory, redistribution of the resource between the commercial and the recreational fisheries (Lea *et al.* 1987, Anon. 1991). The number of fishers involved is difficult to determine as not all licence holders are active, and in many cases barramundi fishing provides only a minor part of their income. Nevertheless, in 1996–97 licence endorsements for barramundi fishing totalled 386 in Queensland (Queensland Fish Management Authority, pers. comm. 1996), 28 in the Northern Territory (Roland Griffin, N.T. Department of Primary Industries and Fisheries, pers. comm. 1996) and 14 in Western Australia (Tim Bray, WA Fisheries, pers. comm. 1996).

Table 2.1 Capture fishery landings (tonnes) of *Lates calcarifer* in 1986–92 in countries reporting to FAO (FAO 1994). It is possible that some of these figures (e.g. Singapore, Hong Kong) include aquaculture product; cf. Table 1.3.

Country	1986	1987	1988	1989	1990	1991	1992
Pakistan	605	500	420	325	312	250	237
Malaysia	944	1 067	1 267	3 999	1 608	1 954	2 010
Singapore	203	219	235	230	345	274	424
Indonesia	17 443	18 872	19 029	26 746	27 503	24 059	30 160
Australia	1 034	1 320	1 385	1 295	1 417	1 372	1 051
Papua New Guinea	442	473	331	526	520	400	410
Hong Kong	105	34	23	170	167	224	187
Total	20 776	22 485	22 690	33 291	31 872	28 533	34 479

2.1.5 *Recreational fishery*

The recreational fishery for barramundi in Australia is considered an important fishery in terms of harvest of fish, participation rate and economic activity. Although this is widely accepted, quantitative data on the extent of the fishery are limited because the collection of reliable information is inherently difficult due to the dispersed effort in the fishery.

Most surveys on recreational fishing for barramundi have been carried out in the Northern Territory. Griffin (1982, 1988) estimated that recreational fishermen accounted for 23% and 31% of the total barramundi catch landed in the eastern part of the Northern Territory in 1979–80 and 1986 respectively. Commercial fishing in the Mary River (the principal fishing site in the area) was totally banned in 1988, as the Government considered that on an economic and social basis the resource was more productive if exploited by the recreational fishery. Participation in the Mary River fishery was estimated at 17 000 and 11 000 angler days in 1991 and 1992 respectively, but this was only about half the participation level in 1986 (Griffin 1993).

There is no direct assessment of the extent of the recreational fishery for barramundi in Queensland. However, Rutledge *et al.* (1990) estimated the recreational harvest to be in the range of 50 000–100 000 fish, and that this was worth \$8–15 million per annum. Their data were in part derived from a tag-recapture study which indicated that in the east coast fishery in Queensland the ratio of commercial to recreational caught fish was 3:1 (Russell 1988). However, Russell (1988) warned that commercial fishermen may have under-reported the return of tagged fish; if this was the case the estimates of Rutledge *et al.* (1990) would have been too high.

The only specific study on recreational fishing for barramundi in Queensland was conducted in the Lakefield National Park in the period 1986–91 (Russell and Hales 1993). They estimated that each year 1500 anglers landed 4.4–9.4 tonnes of barramundi. Direct expenditure (consumables used during the fishing trip) amounted to $49 per trip, and capital investment per fishing party was $32 500.

There are no data available on the recreational fishery for barramundi in Western Australia, or in other areas within the range of barramundi.

2.1.6 *Stream modification and its effect on the distribution of barramundi in Queensland.*

Construction of barriers across streams to impound water for domestic, irrigation, industrial, flood- and salinity-control purposes has been widespread in Queensland, particularly in areas of major population centres or agricultural activity. Russell (1990) reported that all the major rivers in eastern Queensland have dams or weirs on them. The Water Resources section of the Queensland Department of Primary Industries manages 27 dams impounding 72 781 ha and 79 weirs impounding 8327 ha of stored water (Anon 1993). The South-east Queensland Water Board manages 3 dams impounding 17 300 ha. Significantly more stored water is contained in large dams controlled by various other water boards, local councils, mining companies and private land holders. Thus, although there is no complete listing of the dams and weirs in Queensland, it is clear that there are more than 100 000 ha of impounded water (excluding farm dams) at full supply level in the State.

The largest storages are built in the headwaters of river systems, outside the natural range of the barramundi. However, there are numerous weirs and tidal barrages built on the lower reaches of rivers and creeks which have effectively excluded the barramundi (and other diadromous fishes) from much of their former range. The extent of habitat lost to the barramundi is not known, as a complete listing of all barriers is not available. One documented example of the impact of man-made barriers on the distribution of barramundi is the tidal barrage on the Fitzroy River at Rockhampton (Midgley 1987). Historically, barramundi accessed many hundreds of kilometres of streams in the Fitzroy, Don, Dawson, Comet, Nogoa, MacKenzie, Isaac and Connors Rivers (Fig. 2.2). Construction of the 5 m barrage on the Fitzroy River in 1970 effectively precluded barramundi from all the freshwater reaches of the system. The barrage was constructed with a fish ladder, but it is ineffective for upstream movement of barramundi (Kowarsky and Ross 1981; Peter Long, Fisheries Inspector, QDPI, Rockhampton, pers. comm. 1996). Several other weirs were constructed on the system after the barrage, but they are comparatively low-level and are submerged in medium floods, and so would not prevent movement of barramundi during floods.

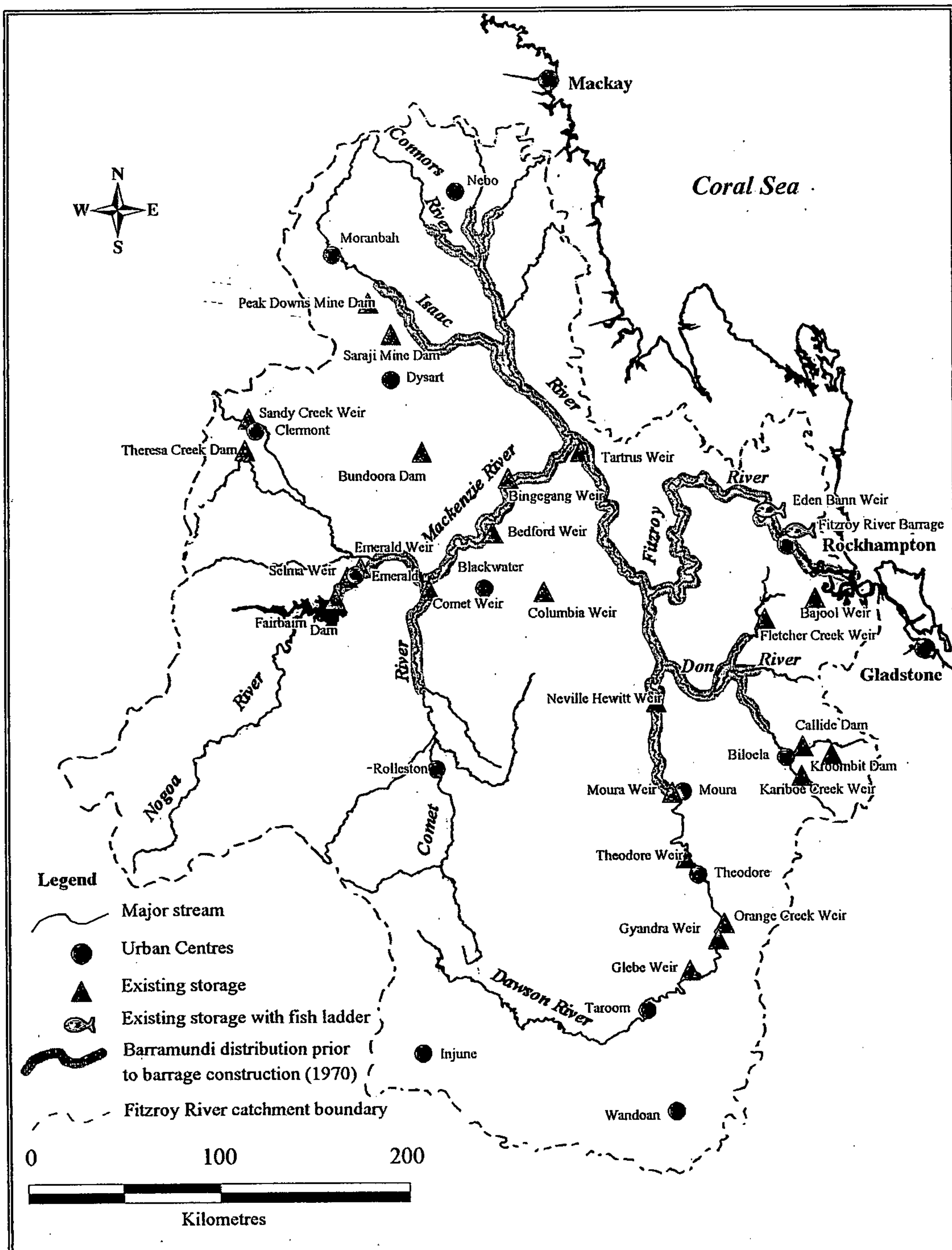

Figure 2.2 Historical distribution of barramundi in the Fitzroy River system in Queensland. The tidal barrage at Rockhampton now effectively prevents upstream colonisation by barramundi.

2.2. EVALUATION OF THE PROPOSAL TO INTRODUCE NILE PERCH TO AUSTRALIA

2.2.1 *The rationale for introducing Nile perch*

There have been vast new aquatic habitats created in Queensland as a consequence of stream impoundment. As a general rule, these impoundments do not naturally contain either a wide variety or a large number of good angling fishes. Obviously, the primary reason for this is the comparatively impoverished Australian freshwater fish fauna, which is to a very large extent comprised of families of marine origin (Allen 1989). The breeding biology of the majority of Australian freshwater species is generally geared to riverine environments. Since rivers and their running waters obviously provide very different habitats from that found in impoundments, our native fishes are not necessarily capable of successfully colonising the latter.

There are two ways of developing the population of angling fishes in these water storages. The first is to develop fisheries based on continual restocking. The impoundments are stocked with a large number of hatchery-reared fingerlings, a proportion of which then grow to a size suitable for catching and eating. When the number of fish available declines to low levels due to fishing or natural mortality, the impoundments are restocked. This is a common practice overseas and also in southern Australia, where the best example is the chinook salmon fishery in Lake Purrumbete in

Victoria (Barnham 1977). Obviously the costs of maintaining hatcheries to supply fingerlings make this system expensive.

The second method is to stock the impoundments with species of fish that will breed in the confined waters, resulting in self-sustaining fisheries. In general, most native species that qualify as sport fishes are unsuitable for this purpose, due to their riverine requirements for breeding. However, there are some storages in which the inflowing rivers provide suitable habitats for a few native sport fishes to breed, and from there to recruit to the impoundments. In addition, there are some less-favoured sport fishes, such as the eel-tailed catfish *Tandanus tandanus*, the saratoga *Scleropages* spp., the archer fish *Toxotes chatareus*, and the sleepy cod *Oxyeleotris lineolatus*, that will breed in most Queensland storages. In this context, the quest to obtain populations of high-quality angling fish able to breed successfully in the majority of impoundments led to arguments for the introduction of a 'suitable' tropical foreign species.

It was on this basis that S. H. Midgley (a private fisheries consultant) proposed in 1968 that the Queensland Government introduce the Nile perch *Lates niloticus* from Africa for stocking impoundments in North Queensland (Midgley 1968, 1969). He considered that the Nile perch was the most appropriate fish for the purpose because of the following purported attributes: it is an excellent angling and eating fish; it breeds in lakes and rivers; its temperature requirements would prevent it colonising waters in southern Australia; and it inhabits the open waters as well as margins of lakes.

Midgley (1981) argued that it was unlikely there would be serious ecological consequences resulting from the introduction of the Nile perch, on the grounds that it was closely related taxonomically, was physically similar, and had similar feeding habits to the barramundi. He considered that the only major biological difference between them was that the barramundi bred in salt water, while the Nile perch bred in fresh water.

Arguments against the proposal stressed the unpredictable consequences of faunal introductions (Williams 1970) and also questioned the basic assumption that an exotic fish was necessary, given the possibility that hatchery-bred barramundi could be used for creating put-and-take fisheries (Reynolds and Moore undated, Williams 1982).

In order to resolve the debate on the Nile perch issue, a pre-release study was conducted to determine the likely impact of the Nile perch on native fauna should it be introduced to Australia. The experimental protocol was divided into three phases, namely determining the lower temperature limiting the fish's distribution, determining its salinity tolerance, and finally investigating its interaction with native fishes (Barlow 1984). Quarantine facilities were built for this purpose. However, before the fish was imported, data on its lower temperature tolerance (Hashem and Hussein 1973) and information from Africa on the impact of the Nile perch in lakes into which it had been introduced (Barel *et al.* 1985), indicated that the Nile perch might not be suitable for Australia. Consequently, the program was halted pending evaluation of the information.

In the remainder of this chapter, I present data on the lower temperature tolerance of the Nile perch and its potential distribution in Australia. I then summarise findings on its effect on the native fish and fisheries of Lake Victoria and Lake Kyoga in eastern Africa, as information from these exotic environments provides valuable background against which the Nile perch proposal can be evaluated. Finally, I discuss other aspects of the biology of the species relevant to its proposed role as a sport fish in Australia.

2.2.2 *Temperature tolerance of L. niloticus, with reference to the species' potential range if introduced into Australia.*

Importance of the potential range of Nile perch if introduced into Australia

The potential range of the Nile perch if introduced into Australia was an important evaluation criterion, as it was essential that the species not extend as far south as the Murray-Darling River system. The Murray-Darling is the biggest river system in Australia, in terms of both flow and catchment area. It originates in Queensland, and extends through New South Wales into Victoria and South Australia. The requirement not to colonise the Murray-Darling system stemmed from the possible impact of the Nile perch — a large piscivore which often eats prey about 25% of its own body length (Gee 1969, Okedi 1971, Bishai 1975, Ogutu-Ohwayo 1984) — on native fishes in the system. Two of the most important recreational and commercial species in this system are the golden perch *Macquaria ambigua* and the silver perch *Bidyanus bidyanus*. Both species migrate upstream to breed, and recruitment downstream is by egg and larval drift (Reynolds 1983). Thus it was conceivable that Nile perch living in the upper reaches of the Darling River (southern Queensland) could prey on adult golden perch and silver perch, and consequently affect their recruitment into New South Wales waters, and perhaps even into South Australia.

Lower temperature tolerance of Nile perch

It was postulated that the southern extension of the Nile perch's potential range in inland Australia would be controlled by a combination of biotic and abiotic factors (Arthington and Mitchell 1986), with the most important probably being temperature. The only experimental work on temperature tolerance of *L. niloticus* was conducted by Midgley (1968), who suggested that the fish should not be subjected to temperatures below 15°C but warned that his uncontrolled experiments could not be regarded as conclusive and that future work could prove a lower thermal minimum.

More ecologically-meaningful information on the lowest temperature tolerated by the Nile perch can be inferred from temperature data for waters in the Nile delta, which is the coldest part of the species' natural range. Hashem and Hussein (1973) reported that some mortalities of *L. niloticus* were usually observed in the Nozha Hydrodome near Alexandria and in other shallow Nile delta lakes '... when the water temperature dropped to less than 10°C, especially when this relatively low temperature prolonged for some days'. The temperature in these lakes occasionally drops to 8°C overnight (M. T. Hashem, pers. comm. 1985). At the Manzalah Fish Farm, where the Nile perch was cultured in ponds with no reported temperature-related mortalities, the average water temperatures recorded at 1100h in December (the coldest month) in 1969 and

1970 were 12.0°C and 11.2°C respectively (Eisawy *et al.* 1974). Considering that the quoted temperatures were averages for the month, and were recorded after the temperature had started to rise in the morning, one can reasonably assume that the overnight minimum would have occasionally been less than 10°C. Thus, the conclusion of Hashem and Hussein (1973) that 10°C may be considered a limiting factor in the geographical distribution of *L. niloticus* into higher latitudes is reasonable.

Water temperatures in the Murray-Darling River system

To relate temperature tolerance information to the potential distribution of the Nile perch in the Murray-Darling system it is necessary to define the temperature regimes of these rivers. Unfortunately, there are insufficient long-term, continuous records of water temperature over the whole river system to enable this to be done directly from water temperatures. However, a study by Crisp and Howson (1982) showed that the relationship between air and water temperatures in streams in northern England was approximately linear when air temperature was above 0°C. If a similar relationship could be shown to exist in the Murray-Darling system, use could be made of the extensive air temperature data available from the Australian Bureau of Meteorology to predict water temperatures over the whole catchment.

Relationship between water and air temperatures in the Murray-Darling River system

Water temperature data were obtained for 12 stations situated in New South Wales, Victoria and South Australia. For convenience I refer to these sites as 'calibration stations'. These stations were all in large rivers sufficiently removed from the snowline to avoid the influence of melting snow on water temperatures.

All water temperature records were taken in the top 50 cm of the water column. Temperatures were usually taken in the morning with mercury-in-glass thermometers, although bimetallic thermometers were also used in Victoria. No allowance was made for diurnal variation in temperatures, as this is usually negligible in large rivers (N. McKay, River Murray Commission, pers. comm. 1985).

The New South Wales (Bourke, Menindee, Buronga, Bathurst, Yass, Condobolin, Balranald and Deniliquin) data are from Llewellyn (1978a,b,c, 1979a,b, 1980a,b,c,d, 1981). The Victorian (Torrumbarry and Swan Hill) temperatures were supplied by the State Rivers and Water Supply Department (unpublished data). The periods during which water temperatures were recorded and the number of records taken at each station are listed in Table 2.2.

Table 2.2 The stations and rivers at which air-water temperature regressions were determined, and the number of water temperature readings (n) taken during the period 1963–83. (Air temperatures for Torrumbarry, Buronga and Cadell were taken at Echuca, Mildura and Waikere, respectively.)

Stations	River	Period monitored	n
Bourke	Darling	1963–80	680
Menindee	Darling	1965–80	593
Torrumbarry	Murray	1977–82	189
Swan Hill	Murray	1977–83	197
Buronga	Murray	1963–71, 1973–80	690
Cadell	Murray	1 June 1981–31 May 1983	500
Murray Bridge	Murray	1 June 1981–30 September 1982,	
		1 November 1982–30 November 1982	
		1 February 1983–31 March 1983	403
Bathurst	Macquarie	1963–66, 1969–80	686
Yass	Yass	1966–71, 1974–80	425
Condobolin	Lachlan	1965–79	550
Balranald	Murrumbidgee	1965–68, 1970–80	512
Deniliquin	Edwards	1963–80	592

Air temperature data corresponding to the periods of water temperature measurement were obtained for the meteorological stations nearest to the calibration stations. The only information readily available was average monthly mean air temperature (mean air temp. = ½ (maximum + minimum)), in future referred to as AMMAT. Water temperature records were available on a daily basis, so these were condensed to form average monthly water temperatures (AMWT). The relationship between AMWT and AMMAT was then determined by simple linear regression for each of the 12 calibration stations. This relationship was found to be statistically adequate and highly significant ($P < 0.01$) in all cases. The results of these analyses are summarised in Table 2.3.

Table 2.3 Values for constants *a* and *b* and their standard errors from linear regressions AMWT = $a + b$AMMAT for 12 stations in the Murray-Darling River system. (*n* is the number of monthly data points.)

Station	*a*	(SE)	*b*	(SE)	R^2	*n*
Bourke	1.48	(0.448)	0.96	(0.021)	0.92	176
Menindee	1.51	(0.664)	0.69	(0.034)	0.73	154
Torrumbarry	0.54	(0.586)	1.06	(0.034)	0.94	62
Swan Hill	0.68	(0.541)	1.02	(0.031)	0.94	75
Buronga	1.12	(0.479)	1.06	(0.027)	0.90	171
Cadell	1.33	(0.821)	0.94	(0.045)	0.92	24
Murray Bridge	1.17	(1.446)	0.98	(0.084)	0.89	19
Bathurst	0.59	(0.445)	1.12	(0.031)	0.89	169
Yass	3.09	(0.414)	0.99	(0.029)	0.91	115
Condobolin	1.31	(0.456)	0.95	(0.025)	0.91	149
Balranald	1.79	(0.668)	0.96	(0.038)	0.83	132
Deniliquin	1.95	(0.556)	0.96	(0.032)	0.84	168

An analysis of parallelism and displacement was then carried out to determine whether a single regression relationship could be used for all stations. Results of this analysis indicated that this was not possible. Thus, although water temperature was strongly related to air temperature, the precise nature of the relationship varied according to location.

Prediction of mid-winter water temperature in the Murray-Darling River system

Plots of long-term averages of air and water temperatures showed the same pattern over all the calibration sites (Fig. 2.3) with both reaching minima during July. Thus, conditions during this month would be most likely to determine the limits to the distribution of Nile perch in the Murray-Darling system.

In order to estimate the positions of midwinter water isotherms, long-term mean air temperatures for July were calculated using Bureau of Meteorology data from 142 sites distributed throughout the catchment. These air temperatures were then used to predict the average July water temperature for each site. Since it was not possible to obtain a single regression equation for the entire catchment it was decided that, for any given site, the equation obtained for the nearest calibration station would be used to predict water temperature. These predicted water temperatures, along with the latitude and longitude of each site, were processed using the program 'CONTOUR' (Briggs 1981) to produce a map of the region showing midwinter water isotherms (Fig. 2.4).

The values used to plot the midwinter water isotherms are long-term means, around which the average July water temperature in any year would fluctuate. Consequently, a further map was constructed showing the approximate percentage probabilities of the occurrence of average July water temperatures greater than 10°C (Fig. 2.5). This was done using a pooled estimate of the variance in air temperatures of 0.94 and the estimates of variance in water temperatures at each of the calibration stations.

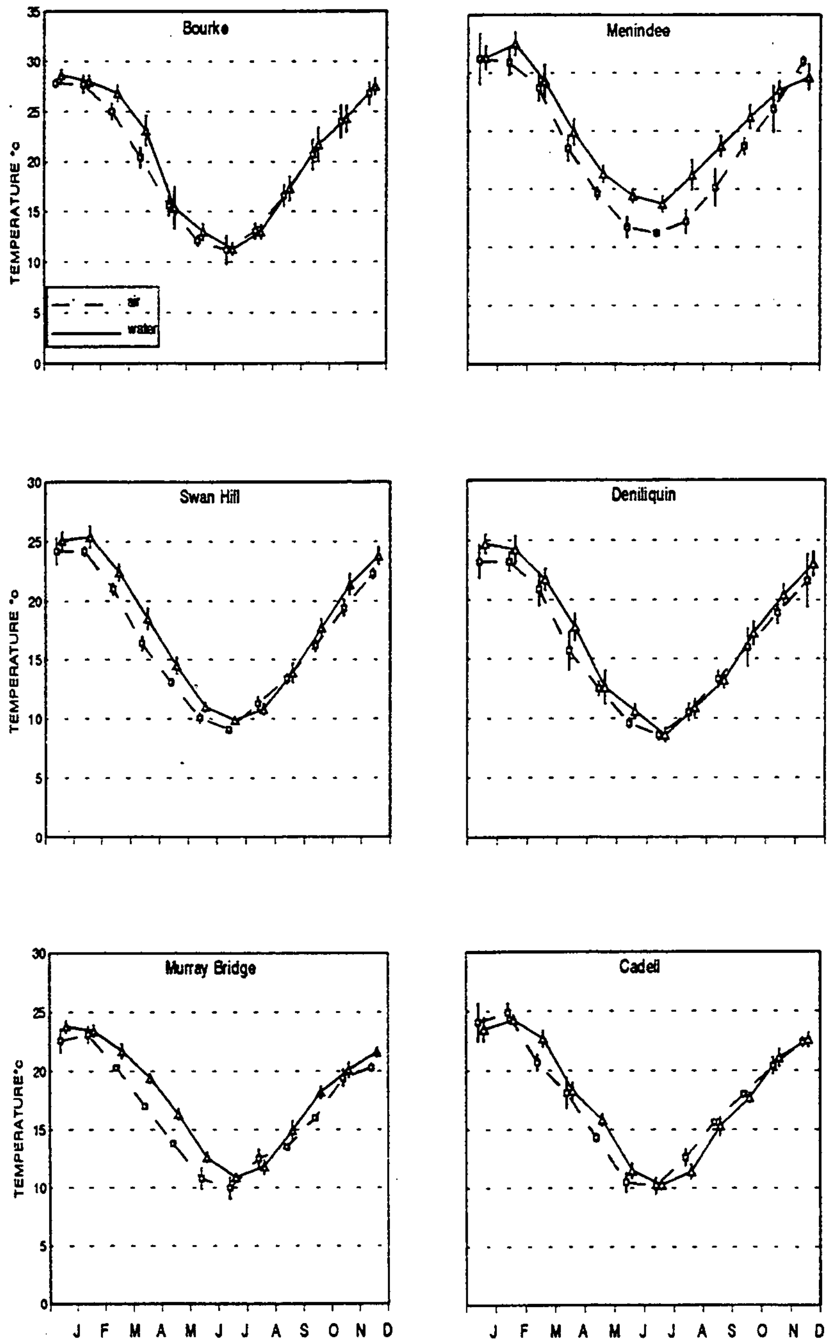

Figure 2.3 Average monthly water temperature (——) and average monthly mean air temperature (- - -) for 12 sites (refer Table 2.2) in the Murray-Darling River system. Data points are averages ± one standard deviation.

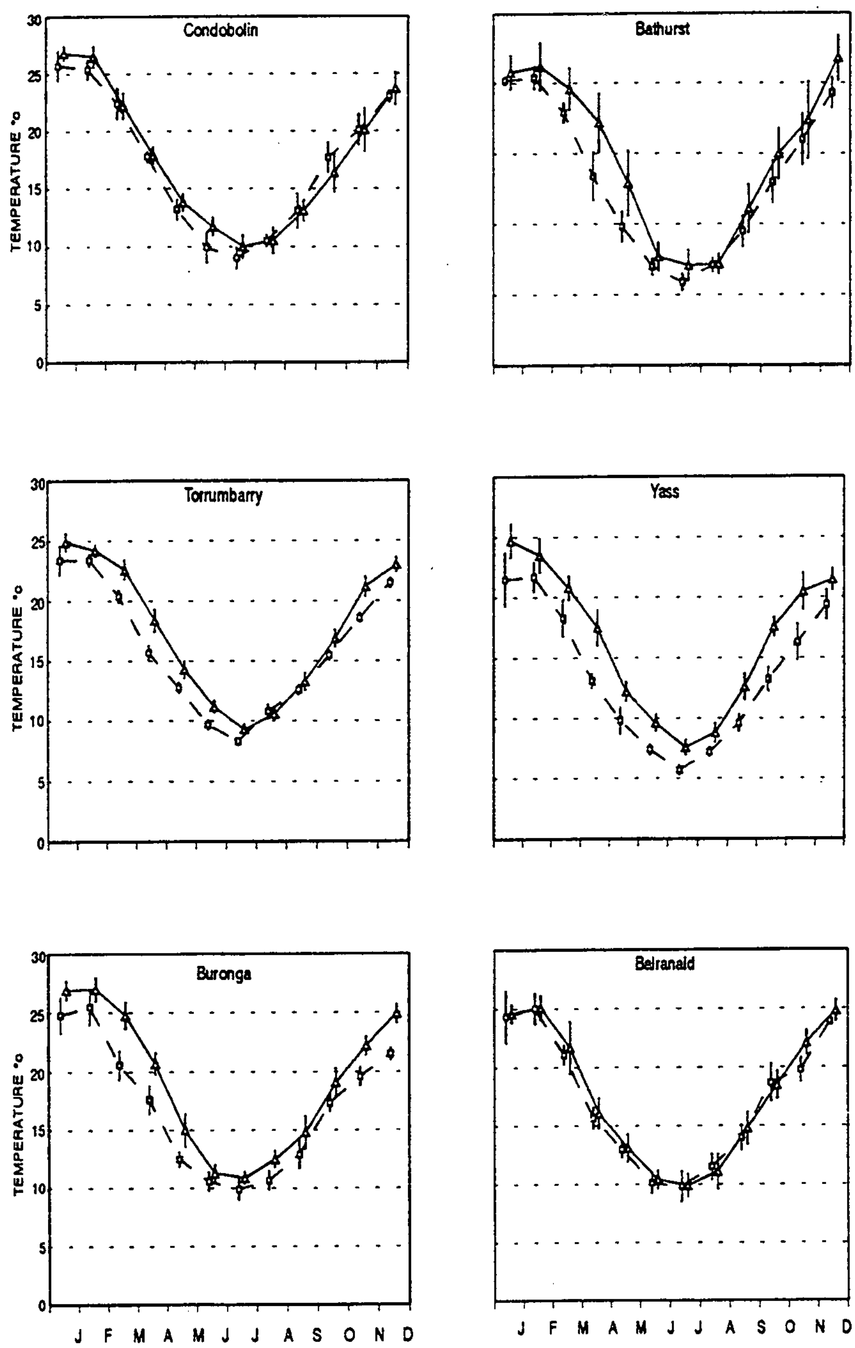

Figure 2.3 (Continued from previous page)

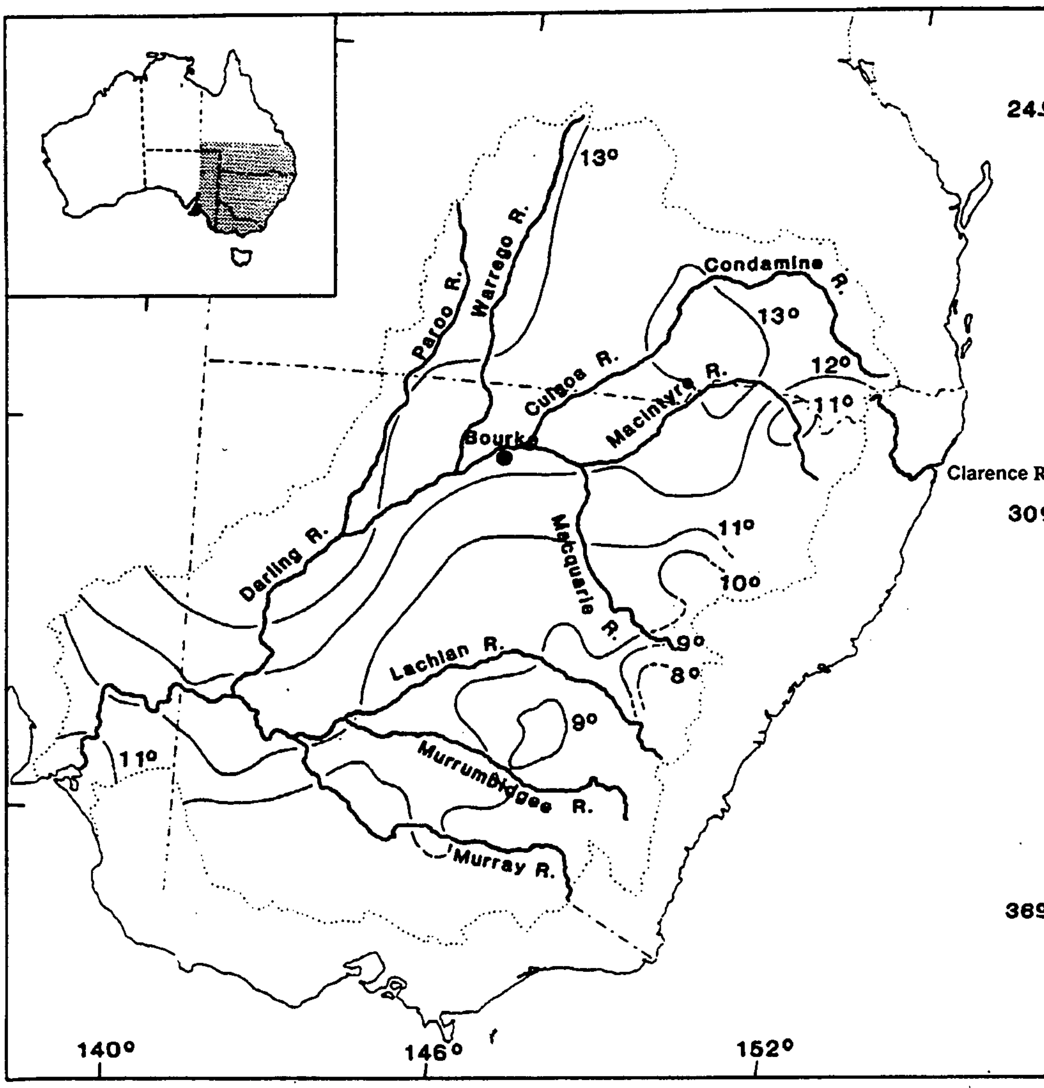

Figure 2.4 Predicted water isotherms during July (mid-winter) in rivers of the Murray-Darling River system.

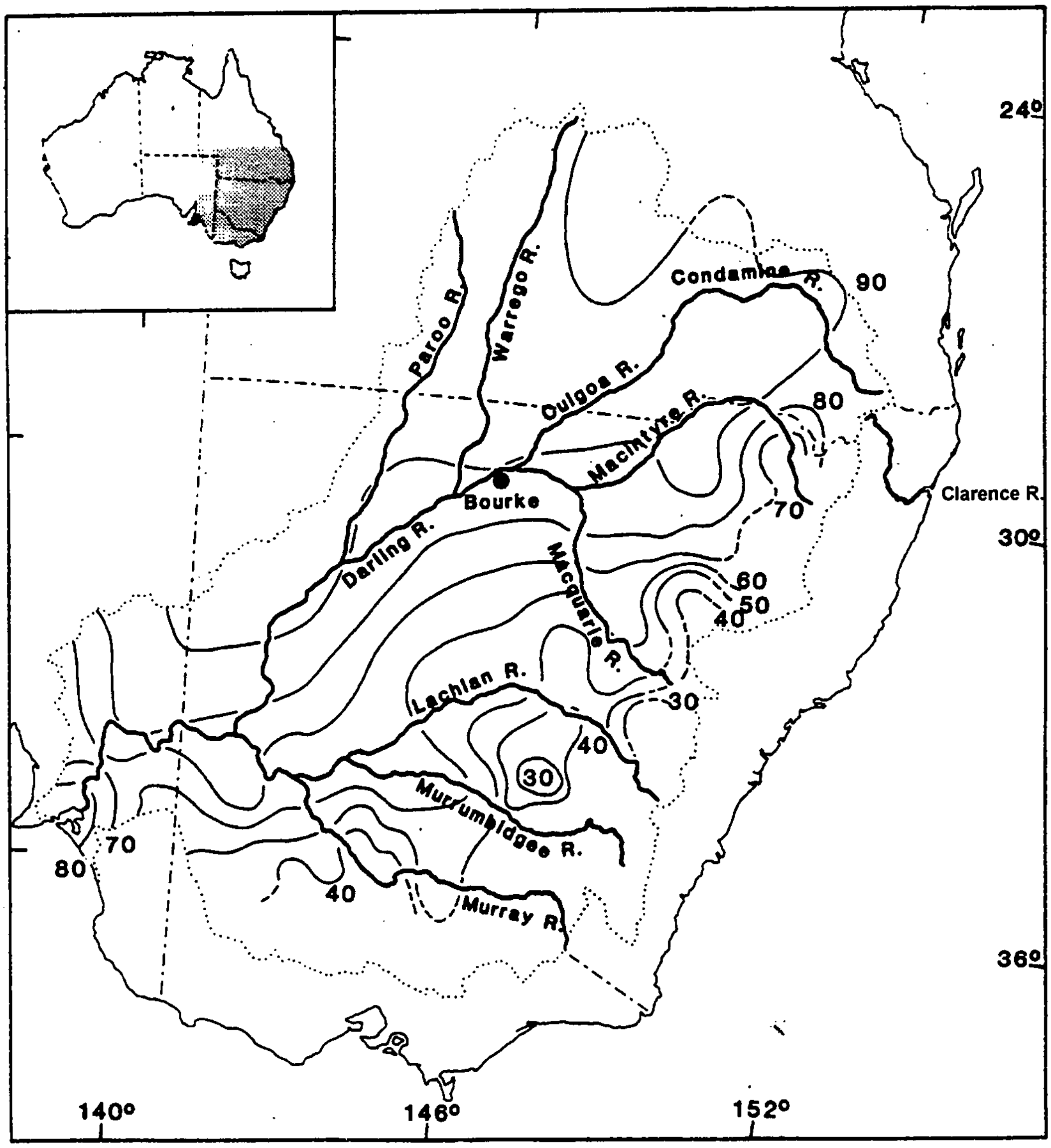

Figure 2.5 Contours showing the percentage probability of the average July (mid-winter) temperature exceeding 10°C in rivers in the Murray-Darling River system.

Predicted range of Nile perch in eastern Australia

Definitive statements cannot be made regarding the potential range of the Nile perch because many factors may influence its establishment and spread in Australia (Arthington and Mitchell 1986). Nevertheless, generalisations based on the data presented herein and the temperature information from northern Egypt can be considered. Taking 10°C as the limiting temperature for the Nile perch, and cognizant that the species can tolerate lower temperatures for at least short periods of time (Hashem and Hussein 1973), it seems clear that this species could form permanent populations in the headwaters of the Darling River system, where more than 9 out of every 10 years can be expected to have average July temperatures greater than 10°C (Fig. 2.5). In fact, the 80 percentile line (Fig. 2.5) takes in all of the Darling River and its northern inflowing rivers. Spawning in the headwaters of the system would result in recruitment downstream, which would be facilitated by the pelagic nature of the Nile perch's eggs. Consequently, during a succession of warmer years it is quite probable that the Nile perch could survive throughout the Darling River.

L. niloticus ceases feeding at temperatures lower than 15°C (Hashem and Hussein 1973). In the Nozha Hydrodome, in which a permanent population of *L. niloticus* exists, temperatures lower than 15°C are experienced for 2–3 months each year (Hashem and Hussein 1973). This thermal regime is similar to that at Bourke, where the water temperature is lower than 15°C for approximately 3 months (Fig. 2.3). Therefore, decreased feeding during the colder months would probably not be as influential as the minimum temperature of 10°C in controlling the southern extension of the Nile perch in inland Queensland and New South Wales.

Analysis of water temperatures in the coastal rivers of northern New South Wales was not undertaken. Nevertheless, the water temperature in the Clarence River in winter is higher than 12°C (Fig. 2.6), indicating that temperature would not restrict Nile perch from colonising the river.

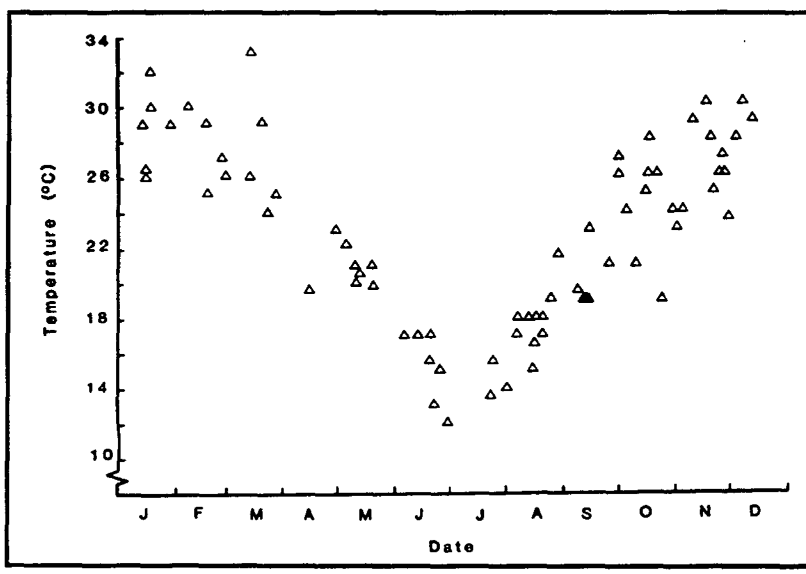

Figure 2.6 Water temperatures recorded in the Clarence River at Lillydale between 1971 and 1985. (Data supplied by NSW Water Resources Commission).

In conclusion, the temperature data presented here indicate that the Nile perch, if introduced into Australia, would be capable of forming permanent populations in the headwaters of the Darling River and in the coastal rivers of northern New South Wales, if all other environmental requirements were met. Consequently, if the Nile perch were released in Australia the native fishes in these rivers could be adversely affected.

2.2.3 *Impact of L. niloticus*[1] *in Lake Victoria, Lake Kyoga and Lake Nabugabo*

Range of *L. niloticus* in Africa

In western Africa the Nile perch is found in all the large river basins between the Senegal and Zaire Rivers, and in the internal drainage of Lake Chad. In the Nile River its natural distribution extends from Alexandria (32°N) to Lake Albert (2°N) on the White Nile and to the headwaters of the Blue Nile in Ethiopia. It is also found in the closed drainages of Lakes Tana, Chamo and Abaya in Ethiopia and Lake Turkana in Kenya (Hopson 1972, Vanderpuye and Ocansey 1972, Greenwood 1976, Moreau 1982).

The range of the Nile perch was extended during the 1950s and early 1960s by translocations within Uganda to Lake Victoria, Lake Kyoga, Lake Nabugabo, Lake Kijanebolola, Lake Saka, Kabaka's Private Lake and Lake Awajo (Gee 1964[2]). The species subsequently thrived in Lake Victoria, Lake Kyoga and Lake Nabugabo

[1]Harrison (1991) concluded that the characters currently used in taxonomy of *Lates* are inappropriate. He found that the Lake Victoria *Lates* showed significant morphological differences from all possible parental stocks. Nevertheless, the stock is considered herein to be *Lates niloticus*, in accordance with all other reports on *Lates* in Lake Victoria.

[2]Gee (1964) also lists the stocking of Lake Kwania and Lake Bisina (formerly Salisbury) with Nile perch. These (and numerous other small lakes) are discrete during dry years, but during years of high water level (e.g. 1965–71) they form a confluent sheet of water comprising the Kyoga Lakes complex (Vanden Bossche and Bernacsek 1990).

(Ogutu-Ohwayo 1993). Considerable information has been published on Nile perch in Lake Victoria and to a lesser extent Lake Kyoga, but not on Lake Nabugabo other than mentions by Ogutu-Ohwayo (1993, 1995). There are no literature reports documenting the Nile perch's fate in Kabaka's Private Lake, Lake Awajo, Lake Saka and Lake Kiganebolola; it is possible it failed to establish in these lakes.

Stocking of Lake Victoria and Lake Kyoga

The introduction of the Nile perch to Lake Victoria was originally suggested by keen anglers (see Worthington 1973), but later proponents argued that the highly esteemed Nile perch would eat the abundant haplochromine fishes (Cichlidae), of which more than 300 species were present in the lake (Oijen *et al.* 1981, Witte *et al.* 1992a,b), and which were said to be under-exploited (Anderson 1961). Opponents of the idea argued that it was indefensible on scientific grounds (introduction of a predator would reduce the efficiency of production by 80%) and that since the diet of the Nile perch was unpredictable the introduction would jeopardise the existing commercial fisheries (Fryer 1960).

Lake Kyoga was stocked on eight occasions between 1954 and 1960 by the Uganda Game and Fisheries Department, purportedly to obtain information on the effects of the Nile perch on the haplochromine-dominated fauna, which was similar to that in Lake Victoria (Anderson 1961). The stocking of Lake Nabugabo in 1959 and 1960, and again in 1963, was similarly justified (Anderson 1961, Gee 1964). Unfortunately, before these trials were evaluated the first Nile perch was caught in Lake Victoria in

May 1960 (Gee 1964). There is no official record of the original release of Nile perch into Lake Victoria, but it probably took place in 1959 with fish brought from Lake Albert (A. Achieng, Lake Basin Development Authority, pers. comm. 1985). Further stockings were carried out in 1962 by the Uganda Fisheries Department with fish from Lake Albert, and in 1963 by the Kenya Fisheries Department with fish from Lake Turkana (Gee 1964, Achieng 1990).

Despite the documented justification for stocking the Nile perch in Lake Victoria and Lake Kyoga, there is evidence that the real reason was to create sport fisheries. Firstly, the proposed rationale does not equate with the fact that the haplochromines were eaten by many of the numerous tribes bordering the lakes (but not by Europeans who preferred the larger fishes) (Bwathondi 1984; G. Fryer, Windemere Research Station, U.K., pers. comm. 1985). Indeed, the haplochromines traditionally (that is, pre-Nile perch irruption) constituted 30–40% of the weight of all fish landed in the Kenyan and Tanzanian waters of Lake Victoria (Ssentongo and Welcomme 1984; see also Table 2.4). Secondly, avid sport fishermen within the Uganda Game and Fisheries Department advocated its dispersal (Achieng 1990), and Gee (1964) noted that Lake Saka was stocked before any analyses of the stockings in Lake Kyoga or Lake Nabugabo were undertaken. Finally, the interest in transport procedures (Hamblyn 1961), angling techniques (Hamblyn 1962), and the widescale translocation of the Nile perch (Gee 1964) indicate that the development of sport fisheries based on this species was a concern of the colonial administrators at the time.

Nile perch in Lake Victoria

The wave of colonisation of Lake Victoria by the Nile perch spread from the north to the south. Small numbers of fish were caught in the Kenyan and Ugandan regions from the early 1960s onwards (Gee 1965), but the species did not form a major portion of the commercial catch until the mid-1970s. Thereafter, the contribution of the Nile perch to the commercial catch increased dramatically, and by 1983 it constituted almost 70% of the catch (Table 2.4). By 1988, it formed over 90% of the fish biomass in the northern part of the lake, as determined by experimental fishing using a variety of gears (gillnets, large and small seines, trawls) (Ogutu-Ohwayo 1990a). In the south of the lake (Tanzania) the Nile perch was caught as early as 1972 but catches in experimental trawls did not increase substantially until 1983 (Goudswaard and Witte 1984).

Along with the massive increase in the catch of the Nile perch there was a marked drop in the catch of virtually all other species (Acere 1984, Goudswaard and Witte 1984, Okemwa 1984, Hughes 1986, Achieng 1990, Ogutu-Ohwayo 1990b, Ligtvoet and Witte 1991). The original multi-species fishery (see Table 2.4) changed to one dominated by Nile perch, the sardine-like *Rastrineobola argentea* and *Oreochromis niloticus* (another species introduced from the Nile River). The catch composition is partly due to target fishing for Nile perch, but stock assessment studies have indicated that the catch statistics are indicative of the relative composition of the fish stock (Ogutu-Ohwayo 1990a, Witte *et al.* 1992a). Fishing practices have contributed to these changes, but there is no doubt that the major influence has been predation by Nile perch (Hughes 1986, Ogari and Dadzie 1988, Ogutu-Ohwayo 1990a,b, Witte *et al.* 1992a).

The impact of the Nile perch on the haplochromine (Cichlidae) stock has been catastrophic. The endemic fauna comprised more than 300 species, and virtually all were restricted to Lake Victoria and Lake Kyoga (which receives its water from Lake Victoria). Prior to the stocking of Nile perch, the haplochromines constituted about 80% of the demersal fish biomass, estimated at 200 kg/ha in the sublittoral areas of the lake (Kunhongania and Cordone 1974, Witte *et al.* 1992b). The haplochromines were the preferred prey of the Nile perch (Hamblyn 1962, Gee 1964, 1965, 1969), and their numbers were rapidly depleted. Research in one area in Tanzania has shown that of the 123+ species present prior to 1980, about 80 had disappeared by 1990 (Witte *et al.* 1992). Extrapolation of these data indicates that approximately 200 of the 300+ endemic haplochromine species have disappeared, or are threatened with extinction (Witte *et al.* 1992a,b).

The establishment of Nile perch (and the tilapia *Oreochromis niloticus*) resulted in a marked increase in the commercial fishery landings from Lake Victoria. Prior to 1975, the commercial fishery in the Kenyan region was about 16 000 tonnes per annum; with the introduction of Nile perch, the yield rose to 135 000 tonnes by 1989 (Table 2.4). Similar trends were recorded in the Ugandan and Tanzanian sections of the lake (Ogutu-Ohwayo 1990b), and the total annual yield from the lake was estimated to have increased three- to fourfold (Ligtvoet and Witte 1991).

It is possible that the high yields and associated economic activity (Achieng 1990) will not be sustained. Indeed, recent data indicate that the yield from the Tanzanian section of the lake is declining (Table 2.5), and this is accompanied by a reduction in the average size of Nile perch being caught (P.C. Goudswaard, Institute of Evolutionary and Ecological Sciences, Leiden University, the Netherlands, pers. comm. 1996). Ecological theory suggests that the introduction of a top predator (in this case a piscivore) will result in the loss of approximately 80% of the biomass from the system (Fryer 1960). However, the food web in the lake is changing, and as the present situation is unstable (Hughes 1986, Ligtvoet and Witte 1991, Goldschmidt *et al.* 1993), the future cannot be predicted. Ogutu-Ohwayo (1990b), using data from Lake Kyoga, suggested that the population of *L. niloticus* is likely to decrease to a level commensurate with oscillations in the abundance of its prey, and that the major primary converter *O. niloticus* (which is eaten by Nile perch, but apparently is not overly susceptible) may increase and dominate the fishery.

Table 2.4 Percentage contributions of different fish species to the total weight (tonnes) of fish landed from Kenyan waters of Lake Victoria from 1970 to 1991*.

Genus	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
Lates	0.2	0.3	0.2	0.9	0.5	0.13	0.5	1.1	4.5	14.0	16.0	59.8	54.4	67.7	57.5	56.5	63.5	69.1	59.3	54.3	56.7	57.3
Haplochromis	32.7	32.0	29.0	33.2	35.0	27.9	34.0	32.4	27.8	21.6	13.5	2.1	4.2	0.8	0	0	0.6	0.3	0.3	1.5	1.1	0.5
Rastrineobola	3.2	5.1	7.8	10.5	21.8	27.4	30.3	34.7	36.5	30.5	35.1	20.4	17.1	21.3	27.1	29.2	30.5	24.5	36.5	38.5	39.6	39.2
Tilapiine	27.5	21.1	14.8	10.1	5.6	3.9	5.4	7.4	10.9	9.0	18.6	10.2	7.3	5.5	10.4	10.7	2.7	2.8	2.4	2.3	2.2	2.4
Clarias	9.7	12.5	17.0	15.7	12.9	15.6	13.0	9.1	7.2	10.0	4.5	2.6	3.4	2.7	1.1	0.6	0.7	0.3	0.6	1.4	0.2	0.2
Bagrus	6.7	7.1	5.4	8.6	6.4	8.4	5.5	6.0	5.9	5.8	2.4	1.1	4.2	3.1	0.1	0.1	0.1	0	0	0.1	0.1	0
Protopterus	11.0	12.8	12.7	13.0	8.6	1.1	5.0	4.0	2.6	1.5	1.4	0.5	0.4	0.3	0.1	0.2	0.2	0.1	0.1	0.1	0.1	0
Schilbe	0.4	0.4	0.4	0.9	0.2	0.3	0.3	0.7	0.5	1.0	0.4	0.1	0.1	0	0	0	0	0	0	–	–	–
Alestes	0.1	0.1	0.01	0.02	0.01	0.08	–	–	–	–	–	0	–	0	0	0	0	0	0	–	–	–
Barbus	1.3	1.6	1.7	1.1	0.7	1.7	1.0	1.0	0.8	1.4	1.6	0.8	1.1	0.1	0.1	0.1	0.1	0.1	0.1	–	–	–
Labeo	1.8	1.5	2.0	0.8	0.3	0.7	0.7	0.3	0.6	1.5	1.8	0.3	1.5	0.1	0.1	–	0	0	0	–	–	–
Mormyrus	0.5	0.5	0.5	1.1	0.8	0.3	0.5	0.5	0.6	1.2	1.2	0.5	4.4	0.3	0.1	0	0.1	0.1	0	–	–	–
Synodontis	1.1	0.7	1.3	1.3	1.1	0.8	1.0	1.6	0.6	1.6	1.4	1.3	0.4	0.1	0.1	–	0	0	0	–	–	–
Small mixed	5.0	5.2	7.9	3.8	1.9	3.8	–	–	–	–	–	–	–	–	3.3	2.6	1.0	0.1	0.7	–	–	–
Tonnes	16400	14918	15989	16797	17175	16581	18680	19332	23856	30592	26914	45667	60958	77327	71854	89589	103000	113000	123000	225000	185000	175000

*Source: Fisheries Department of Kenya, *Statistical Bulletin*. Also Ochumba *et al.* 1995.

Table 2.5 Percentage contributions of different fish species to the total weight (tonnes) of fish landed from Tanzanian waters of Lake Victoria between 1988 and 1992*.

Genus	1988	1989	1990	1991	1992
Lates	68.0	78.6	75.4	65.8	56.7
Haplochromis	0.5	0.3	0.6	0.7	2.2
Rastrineobola	6.0	4.8	12.5	20.1	28.5
Tilapiine	9.7	8.5	7.1	11.2	9.1
Clarias	4.8	2.6	2.6	1.0	1.5
Bagrus	4.5	2.4	0.2	0.1	0.1
Protopterus	1.6	1.2	0.6	0.6	1.0
Schilbe	1.3	0.6	0.6	0.4	0.3
Alestes	0.1	0	0	0	0
Barbus	0.6	0	0	0	0.1
Labeo	0.7	0.3	0.1	0	0
Mormyrus	0.7	0.2	0.1	0.1	0.2
Synodontis	1.4	0.5	0.1	0.1	0.1
Tonnes	218 3	205 4	232 5	146 3	132 1

*Source: P.C. Goudswaard, Institute of Evolutionary and Ecological Sciences, Leiden University, The Netherlands, pers. comm. 1996

Nile perch in Lake Kyoga

The Nile perch spread quickly throughout the lake, with the first fish being caught in 1958 (Anderson 1961). Records show that the species flourished in the 1960s and that the fishery yield increased dramatically after the introduction of Nile perch (Gee 1969). Prior to its introduction the yield was about 4500 tonnes; by 1963 it had increased to 20 000 tonnes and peaked at 167 000 tonnes in 1977 (Ogutu-Ohwayo 1990c). However, in 1986–87 the yield was only 57 000 tonnes (Marriot *et al.* 1988 cited in Ogutu-Ohwayo 1990c), and the fishery is now in decline.

As in Lake Victoria, the introduction of Nile perch to Lake Kyoga has had a devastating impact on the indigenous fishes. Even in the late 1960s, it was suspected that the decreasing abundance of two commercially important species, the catfish *Bagrus dogmac* and the lungfish *Protopterus aethiopicus*, was due to competition from the Nile perch (Stoneman and Rogers 1970). By the early 1980s the haplochromines were virtually absent from the lake and other originally abundant species rare (Ogutu-Ohwayo 1984). Evaluation of the diet of the Nile perch through time has shown that it has changed as preferred species have been depleted (Ogutu-Ohwayo 1990c). Overfishing is also implicated in the change in community composition, but unquestionably the major impact has been predation by Nile perch (Ogutu-Ohwayo 1988, 1990a,b,c, Twongo 1988).

Nile perch in Lake Nabugabo

The native fish fauna of Lake Nabugabo was similar to that in Lakes Victoria and Kyoga. Commercial catch statistics are not available for the lake, but experimental fishing in 1991–92 showed that the Nile perch constituted by weight 79–87% of the catch in seine nets and 68% of the catch in gill nets. The next most abundant species was the Nile tilapia *O. niloticus* which was recorded at 8–15% of the catch (Ogari 1995). The Nile perch has apparently had a similar effect in Lake Nabugabo to that in Lakes Victoria and Kyoga.

2.2.4 *Aspects of the biology of L. niloticus relevant to its proposed role as a sport fish in Australia*

In light of the preceding discussion, it is appropriate to examine other aspects of the biology of the Nile perch to see how they equate with its proposed role as a sport fish in Australia.

The Nile perch grows to approximately 170 cm and 70 kg (based on more than 500 000 specimens taken from Lake Victoria by the Haplochromis Ecology Survey Team: P.C. Goudswaard, Institute of Evolutionary and Ecological Sciences, Leiden University, The Netherlands, pers. comm. 1996). It is primarily a piscivore (Moreau 1982). Large fish commonly eat prey up to 25% of their own body length, and on occasion will eat prey up to 50% of their length (Hopson 1972, Bishai 1975, Ogari 1984, Ogutu-Ohwayo 1990a). Thus the Nile perch if introduced into Australia would have the potential to eat the juvenile and breeding stock of every endemic freshwater fish, with perhaps the exception of the Murray cod *Maccullochella peeli peeli*, the lungfish *Neocertatodus forsteri* and the barramundi *Lates calcarifer*. Moreover, the Nile perch is opportunistic, with the capacity to shift to different types of prey depending on availability (Ogari 1984, Ogutu-Ohwayo 1984, 1990b,c, Okemwa 1984, Hughes 1986, Ogari and Dadzie 1988). Consequently, the foraging activity of the Nile perch is not restricted to any particular trophic level, but directly impacts on fish at all levels in the food chain.

The only documented requirement for breeding of the Nile perch is water temperature rising to about 24°C, and thereafter the breeding season extends for as long as the temperature exceeds that value (Hopson 1972). Thus, in Australia the Nile perch could potentially breed in any body of water in which it could live. In fact, in Africa it has colonised a broad range of habitats from large rivers to lakes and small ponds (Pruginin and Kanyike 1967, Gee 1969, Planquette 1974, Moreau 1982, Bedawi 1985). There is little doubt that the Nile perch would be capable of occupying the same range of habitats in Australia, rather than being restricted to impoundments.

The Nile perch is clearly an r-strategist (that is, an animal that maximises its reproductive potential) with large fish producing up to 16 million eggs per spawning (Kenchington 1939, Okedi 1971, Loubens 1974, Ogutu-Ohwayo 1988). High fecundities predispose invading species to build up large populations rapidly, as has recently happened in Australia with the highly fecund carp *Cyprinus carpio* (Arthington and Mitchell 1986). An r-strategy generally results from selection pressure caused by highly variable environments (MacArthur 1972). In Australian rivers, flow rates (and thus overall riverine environments) are characteristically highly variable, both seasonally and between years (Lake *et al.* 1985).

The Nile perch is also a long-lived fish. Specimens from Lake Chad have been reliably aged at 15 years (Hopson 1972) and there is evidence that in Lake Victoria it may live for up to 20 years (Ligtvoet 1989, cited in Achieng 1990). The longevity of the species endows its populations with resistance to, or the ability to survive, environmental perturbation.

2.2.5 *Conclusions*

The biological characteristics of the Nile perch, and its success in colonising lakes outside its natural range in Africa, indicate that it would be well suited to widespread colonisation of Australian aquatic environments.. It is quite possible that flourishing sport fisheries would develop, at least temporarily, soon after the release of the fish in lakes. However, the temperature tolerance of the Nile perch is such that it would be capable of forming resident populations in the headwaters of the Murray-Darling system and in coastal rivers in northern New South Wales, thus endangering valuable fish stocks in those regions. Furthermore, the Nile perch's dietary habits and its impact on the fishes of Lake Victoria and Lake Kyoga suggest that its introduction into Australia would almost certainly be detrimental to native aquatic fauna, not only in man-made lakes but also in rivers and other water bodies.

On the basis of the analyses and information presented herein, fisheries agencies abandoned the concept of introducing the Nile perch to Australia. In its stead, emphasis was placed on investigations into the breeding of the barramundi to provide juveniles for stocking freshwaters for enhancement of recreational fisheries in northern Australia.

CHAPTER 3. FEEDING HABITS OF HATCHERY-REARED BARRAMUNDI FRY

3.1 INTRODUCTION

The feeding habits of barramundi in the wild have been documented by Menon (1948), Dunstan (1959), Patnaik and Jena (1976), Tait (1981), Davis (1985) and Russell and Garrett (1985). At the time this study was undertaken, however, few papers had been published on the rearing of barramundi fry in nursery ponds: MacKinnon (1987b) had mentioned growth rates and survival in freshwater ponds, and De (1971) and Ghosh and Pandit (1979) had discussed the food of barramundi fry reared in brackish water ponds.

The scant information available was identified as a possible limiting factor in the production of fingerlings and, consequently, the feeding habits of barramundi reared in a freshwater hatchery between metamorphosis and stocking as advanced fry were investigated. (Metamorphosis is defined herein as the time at which scales first form, which in barramundi is at 11 mm TL). This entailed observations on feeding behaviour in aquaria, analysis of stomach contents of pond-reared fish, investigation of diel feeding patterns and stomach evacuation rates (and hence daily food consumption), and description of morphometric relationships and growth rates. Such information was considered to be essential for developing guidelines on husbandry techniques, for maximising survival and growth and, in turn, large scale production of high quality barramundi fry.

3.2 MATERIALS AND METHODS

Larvae were reared at the Northern Fisheries Centre, Cairns, Queensland. At 16–20 days after hatching and 8–10 mm total length (TL), the larvae were acclimated to fresh water (Russell *et al.* 1987) and transferred to the Freshwater Fisheries and Aquaculture Centre at Walkamin, Queensland. The fry were then either stocked directly into 0.1 ha earthen nursery ponds which had been fertilised to promote the algal-zooplankton food chain, or on-grown in the laboratory to 20 mm TL before stocking into ponds.

3.2.1 *Feeding behaviour*

Observations on feeding behaviour were conducted for two weeks in two glass aquaria 900*350*300 mm, each stocked with 50 fish. Both aquaria had a fine-sand substrate and external filtration. Cover was provided in one aquarium in the form of 30 strips, each 30*400 mm, of black plastic mesh (1 mm^2) suspended vertically from polystyrene floats. Several lengths of opaque plastic tubing of various diameters were also placed on the substrate. There was no cover in the other aquarium. The fish were fed with mixed live zooplankton obtained from freshwater ponds, and the temperature maintained at 28°C. Night-time observations were made using dim red light. During the study, the fish grew from 9 mm TL to 15–25 mm TL. Pigmentation patterns were recorded and correlated with feeding behaviour. Complementary observations on the behaviour of similar-sized fish in ponds were also made. This was done by observing the areas in the ponds occupied by the fish, as well as their feeding activity. Observations were made during the day, and at night-time with the aid of spot-lights.

3.2.2 *Diet*

Dietary analyses were conducted on 163 fish, ranging in TL from 10.0 mm to 56.2 mm, taken from three stocked ponds at regular intervals through the 15–30 day rearing period. Samples were collected at 0900 hours by seine netting from these ponds. Immediately after collection the fish were killed by plunging them into an ice-water slurry (which prevented regurgitation) and the stomach contents removed. Food items in each stomach were identified to the lowest possible taxon and counted. The zooplankton, insects, and vertebrates were individually grouped, and the percentage volumes of these three groupings in each stomach were visually estimated. Estimates were made independently by the author and a second person, and then averaged. Diet was analysed as frequency of occurrence (number of fish containing a given food type as a percentage of the total number of fish examined) and percentage composition by number (number of food items of a given food type as a percentage of the total number of food items) for individual taxa, and as percentage composition by volume for the zooplankton, insect, and vertebrate groups.

3.2.3 *Diel feeding*

Diel feeding patterns were determined by sampling 8 fish from a pond-reared population every 3 hours for 24 hours. This was done with small fish (average 15.8 mm TL, standard deviation 2.5 mm) and repeated with larger fish (37.2 ± 3.7 mm TL). Specimens were processed immediately after collection. Dry weights of all fish and of the stomach contents of the larger fish were recorded after drying at 60°C for 24 hours. The weights of the stomach contents of the small fish were determined by counting the zooplankters (copepods and *Moina* sp.) in each sample and interpolating from the weight of a known number of the particular taxon (average weight of copepods 4.19 mg (n = 215), *Moina* sp. 3.44 mg (n = 465)). The stomach fullness index was calculated from the formula

$$\text{Stomach fullness index} = \frac{\text{dry weight of stomach contents}}{\text{dry weight of fish}} * 100$$

Values for stomach fullness index at different times were compared by analysis of variance (ln transformed data) and Duncan's multiple range test.

3.2.4 *Stomach evacuation rate*

Stomach evacuation rates of feeding and starved fish were determined for two groups, corresponding to the small and large fish used in the diel feeding study. Approximately 100 fish were held in an aquarium and fed to excess with wild zooplankton (copepods, cladocerans and rotifers) for 24 hours. All fish were then transferred to another aquarium and given a short meal (20 minutes duration) of *Artemia* nauplii. At the end of *Artemia* feeding (t_0), 50 fish were removed to an aquarium without food and the remainder to an aquarium with abundant wild zooplankton. Eight fish from each group were then dissected at regular intervals (starting at a time — 20–150 minutes after t_0 — determined from preliminary trials) and the presence or absence of *Artemia* in the stomachs recorded. The temperature in all aquaria was maintained at 28.0 ± 0.1^0C. This temperature was chosen because it is close to the optimum temperature for growth of barramundi. The median evacuation time was taken as the period between t_0 and the point when 50% of the fish contained no *Artemia* in their stomachs.

3.2.5 *Daily ration*

Several methods have been proposed for estimation of evacuation rates and daily ration of fishes (see, for example, Jobling (1986) and Persson (1986)), but the method of Bajkov (1935), and a variant of it by Eggers (1977), has recently been shown to be particularly robust (Amundsen and Klemetsen 1988, Boisclair and Leggett 1988). Hence, the Bajkov/Eggers method was used, where

$$\text{Daily ration} = \frac{\text{24 hour average stomach fullness index} * 24}{\text{number of hours to evacuate food from stomach}}$$

The daily ration was calculated using evacuation times for both feeding and non-feeding fish. (In this case, 'non-feeding' means complete evacuation of the stomach before consumption of another meal.)

3.2.6 *Morphometric relationships and growth rates*

Regression relationships for TL, standard length (SL), wet weight (WWt) and dry weight (DWt) were determined for fish 10.0–56.2 mm TL. All analyses were performed on untransformed data, and *F*-tests were used to determine significance levels of the correlation coefficients.

Growth rates were calculated for fish stocked into a 0.1 ha earthen pond at an initial TL of 8.7 mm and density of 3.7 fish/m^2; food for these fish was zooplankton produced naturally in the ponds, and the water temperature was 25–33°C. On another occasion, growth rates were determined for a batch of fish reared from 9.9 to 20.3 mm TL indoors in a 1500 L concrete tank at a density of 2 fish/L; food was wild zooplankton harvested from ponds, fed *ad libitum*; the temperature was maintained at 29–31°C, and the total volume of tank water exchanged twice daily. After attaining an average TL of 20.3 mm, these fish were then stocked into a pond at a density of 2 fish/m^2 and reared to an average TL of 43.2 mm; water temperature during the pond-rearing phase was 23–28°C.

3.3 RESULTS

3.3.1 *Feeding behaviour*

Barramundi less than 17–18 mm TL swam actively throughout the water column, especially when searching for food. The fish targeted zooplankton up to 10 mm away. When eating, they lunged forward to within about 3 mm of the prey, apparently ingesting food items by a sucking action associated with expansion of the gill covers. Sated fish often lay on the sand substrate, while others remained comparatively still in the water column, generally with the body angled upward. Fish of this size showed neither territoriality nor affinity for cover. At night, the fish rested on or within 20 mm of the substrate. Behaviour in aquaria with and without shelters was identical. A descriptor termed for this behavioural stage was 'roving zooplanktivore'.

Fish larger than 17–18 mm TL adopted a comparatively sedentary habit, positioning themselves near the mesh strips but not in the tube shelters on the bottom. The fish oriented in a head-down position, usually in the lower one-third of the aquarium. They often fed on zooplankton or insect larvae near or on the substrate, in addition to prey in the water column. These fish would occasionally chase smaller fry if they came within about 60 mm of the larger fish's station. In the aquarium without shelter, the fish were more mobile and did not exhibit any form of territoriality. Consequently, aggressive interactions were common, and resulted in some smaller fish being eaten. A term given to this behavioural stage, applying to fish larger than about 18 mm TL, was 'lurking predator'.

These two modes of feeding were characterised by strikingly different pigmentation patterns. Fish from 9 mm TL to about 16 mm TL were heavily pigmented, with distinct pale bands running transversely from the posterior half of the spiny dorsal fin to the anal region, and between the posterior limits of the soft dorsal and anal fins (Figure 3.1a). There was also a very prominent pale stripe on the uppermost part of the head, extending from the snout to the dorsal fin. These roving zooplanktivores could be readily seen in daytime in the surface waters of stocked ponds, but not at night, even with the use of spot-lights.

Beyond about 16 mm TL, the pigmentation became less dark (Figure 3.1b). At about 18 mm TL (i.e. when the fish adopted the lurking predator strategy), the pigmentation was paler and the patterning irregular, although the transverse pale bands were still evident (Figure 3.1c). These fish were never seen in stocked ponds, presumably because they occupied the deeper waters.

In aquaria, the change from roving zooplanktivore to lurking predator and the associated change in pigmentation was generally completed in less than 2 days.

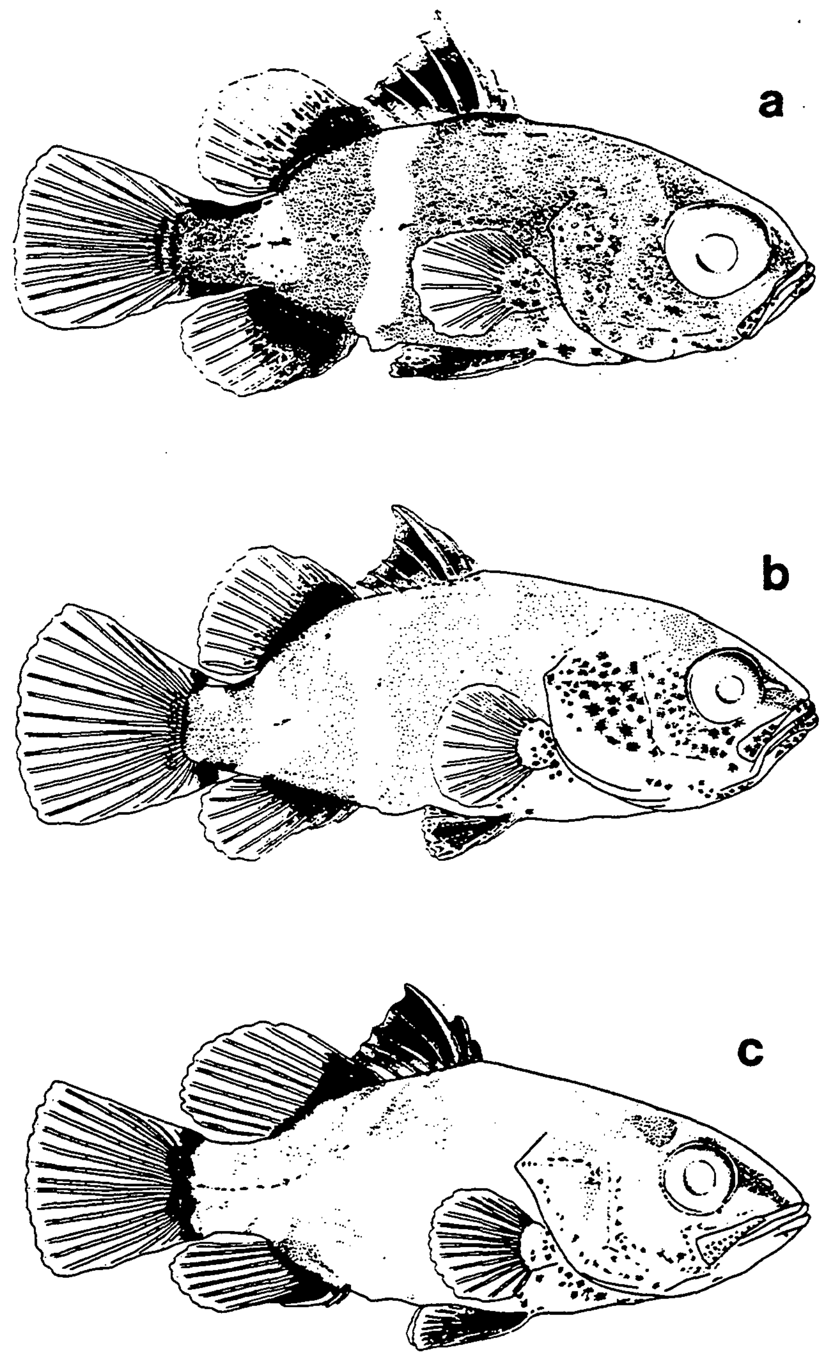

Figure 3.1. Pigmentation patterns of barramundi fry. (a) Barramundi 9–16 mm TL are heavily pigmented with distinct transverse pale bands. (b) At approximately 16–18 mm TL, the pigmentation becomes less prominent. (c) At 18–50 mm TL, the pigmentation is comparatively light and the patterning irregular.

3.3.2 *Diet*

The food items eaten by barramundi fry grouped into 10 mm TL intervals are presented in terms of frequency of occurrence and percentage composition by number (Table 3.1). The most commonly consumed taxa were copepods (≈100–300µ) and the cladoceran *Moina* sp (≈400–800µ). Both became progressively less important with increasing size of fish, although *Moina* sp. continued to be a common element of the diet throughout the study. Larval insects, especially the ephemopteran *Centroptilium* sp. (≈2–6 mm), were important food items for fish larger than 20 mm TL, whereas tadpoles (>8 mm) were prominent in the diet of fish larger than 40 mm TL. Only one fish was found eaten in the course of the study; this was a rainbowfish *Melanotaenia splendida* 17.2 mm TL, consumed by a barramundi of 39.6 mm TL.

The change in diet with increasing size of fish is demonstrated by plotting the percentage volumes of the zooplankton, insect and vertebrate groups against size of fish (Figure 3.2). The diet of fish less than 18 mm TL was entirely zooplankton. As the fish became larger, insects became more important, until in fish 33–48 TL they made up about the same percentage volume as zooplankton. Vertebrates, in this case predominantly frog larvae, were first eaten by fish 38 mm TL, and appeared to replace the zooplankton and insects in fish larger than 48 mm TL.

Table 3.1. Percentage frequency of occurrence (% FO) and percentage composition by number (% CN) of food items in the diet of barramundi *Lates calcarifer* fry reared in freshwater ponds. Data are grouped into 10 mm TL size intervals. (n = number of fish in each size class.)

Food item	Size class									
	10–19 mm $n = 20$		20–29 mm $n = 47$		30–39 mm $n = 47$		40–49 mm $n = 45$		50–59 mm $n = 4$	
	% FO	% CN	% FO	% CN	% FO	% CN	% FO	% CN	% FO	% CN
Rotifera										
Brachionus sp.	10.0	0.2	14.9	0.3	29.8	0.4	42.2	1.4	0	0
Asplanchna sp.	5.0	0.1	0	0	0	0	2.2	<0.1	0	0
Crustacea										
Copepods	85.0	18.0	78.7	29.4	53.2	6.1	37.8	1.2	0	0
Ostracods	0	0	0	0	4.3	<0.1	2.2	<0.1	0	0
Moina sp.	100.0	81.7	74.5	66.8	74.5	90.2	77.8	93.3	25.0	98.2
Daphnia sp.	0	0	4.3	0.2	2.1	<0.1	6.7	1.4	0	0
Insecta										
Ephemeroptera	0	0	40.4	1.6	72.3	2.4	64.4	2.2	25.0	0.9
Odonata	0	0	14.9	0.6	8.5	0.1	20.0	0.2	0	0
Notonectidae	0	0	21.3	0.6	10.3	0.1	6.8	0.1	0	0
Trichoptera	0	0	0	0	4.3	0.1	2.2	<0.1	0	0
Chironomidae	0	0	2.1	<0.1	4.3	0.2	13.3	0.1	0	0
Culicidae	0	0	4.3	0.3	6.4	0.2	4.4	0.2	0	0
Vertebrata	0	0	0	0	6.4	<0.1	11.11	0.1	75.0	0.9
Unidentified	0	0	17.0	0.2	19.2	0.1	6.7	0.1	0	0

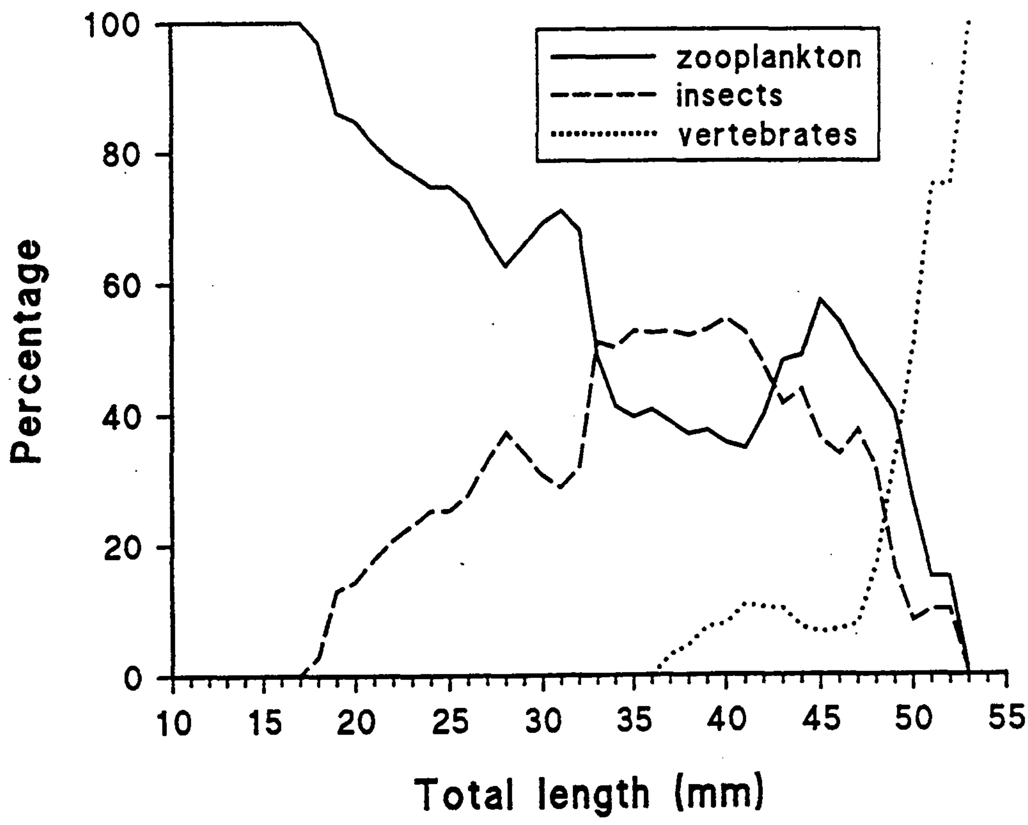

Figure 3.2. Percentage composition by volume of zooplankton, insects and vertebrates consumed by barramundi 10–56 mm TL reared in freshwater ponds. Five-point moving average data points were used to generate the curves.

3.3.3 *Diel feeding*

Small barramundi (15.8 ± 2.5 mm TL) fed continuously during daylight, showing a distinct peak in feeding activity at dusk, but during the night ceased feeding altogether (Figure 3.3a). Food remaining in the stomach at the 2100-hour sampling occasion was well digested, indicating that feeding had ceased soon after sunset. The average stomach fullness index between dawn and mid-afternoon was 3.5 (n = 32), while at dusk it was 7.0 (n = 8). At the time of the trial, there was a new moon which set 39 minutes after sunset.

The larger fry (37.2 ± 3.7 mm TL) showed a similar pattern, although this group did continue feeding at a reduced level in the first half of the night (Figure 3.3b). There were freshly eaten prey items in the fish sampled at 2200 hours, but food remaining at 0100 hours was well digested. At the time, the moon was in its first quarter, and set at 2315 hours. The average stomach fullness index for the times 1000, 1300, 1600 and 2200 hours (at which times the indices were not significantly different) was 3.5 (n = 32), but at dusk it was 6.3 (n = 8). That is, both the small and larger fish ate virtually twice as much at dusk as at other times during the period of feeding.

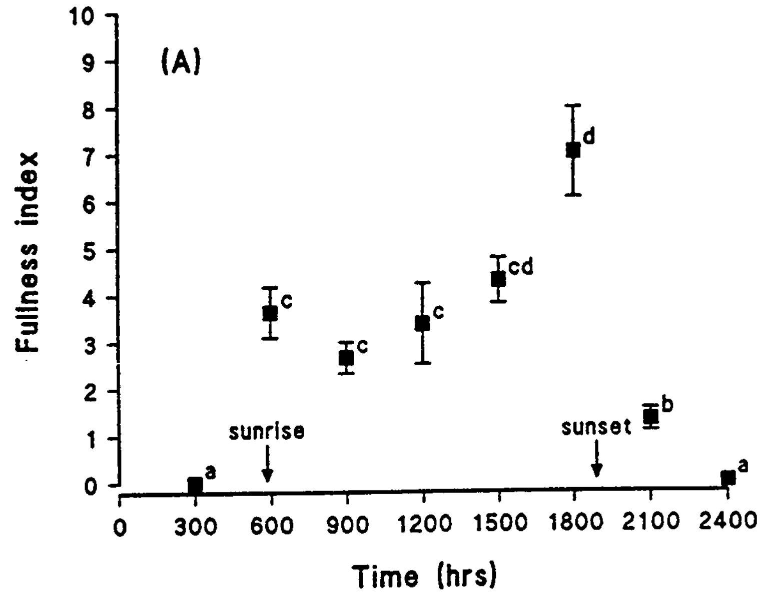

Figure 3.3a. Average stomach fullness indices for pond-reared barramundi fry 15.8 ± 2.5 mm TL. The horizontal bars are means; vertical bars are ± one standard error. Indices marked with the same letter are not significantly different ($P > 0.05$, ANOVA, ln transformed data, Duncan's Multiple Range Test).

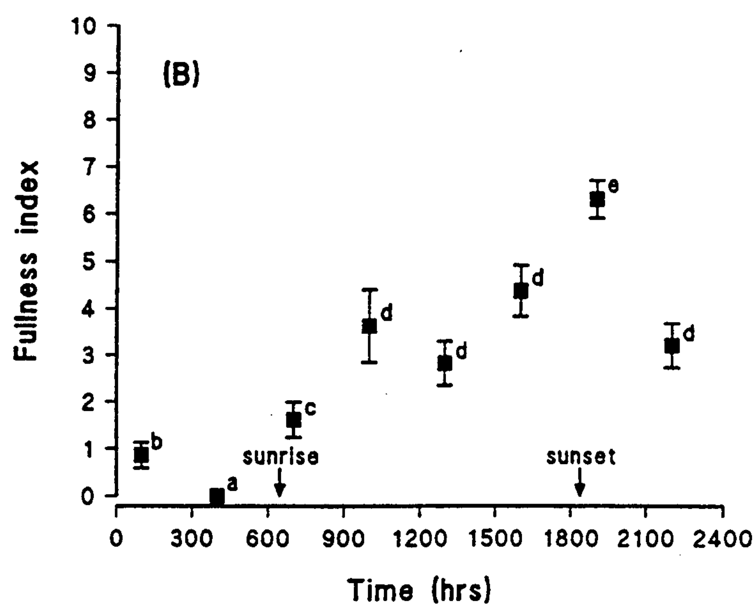

Figure 3.3b. Average stomach fullness indices for pond reared barramundi fry 37.2 ± 3.7 mm TL. The horizontal bars are means; vertical bars are ± one standard error. Indices marked with the same letter are not significantly different ($P > 0.05$, ANOVA, ln transformed data, Duncan's Multiple Range Test).

3.3.4 *Stomach evacuation rate*

Gastric evacuation rates at 28^{0}C for the small and larger fish under conditions of *ad libitum* feeding and no feeding are plotted in Figure 3.4. With the small fish, the median evacuation time for continuously feeding fish was 47 minutes, whereas for non-feeding fish it was 210 minutes. For the larger fish, the median evacuation time for feeding fish was 73 minutes, although under a non-feeding regime it took only 108 minutes for the same degree of evacuation to be achieved.

Within all groups the evacuation time was quite similar for individual fish, as evidenced by the steep slopes of the percentage evacuation versus time plots (Figure 3.4).

3.3.5 *Daily ration*

The 24-hour average stomach fullness index for the small fish was 2.79 (n = 64) and for the larger fish it was 2.86 (n = 64). Using these data and the median evacuation times shown in Figure 3.4, the daily ration for the smaller fish under conditions of *ad libitum* feeding and 'non-feeding' were 85.8% and 19.1% body weight respectively; for the larger fish they were 56.3% and 38.1% body weight respectively.

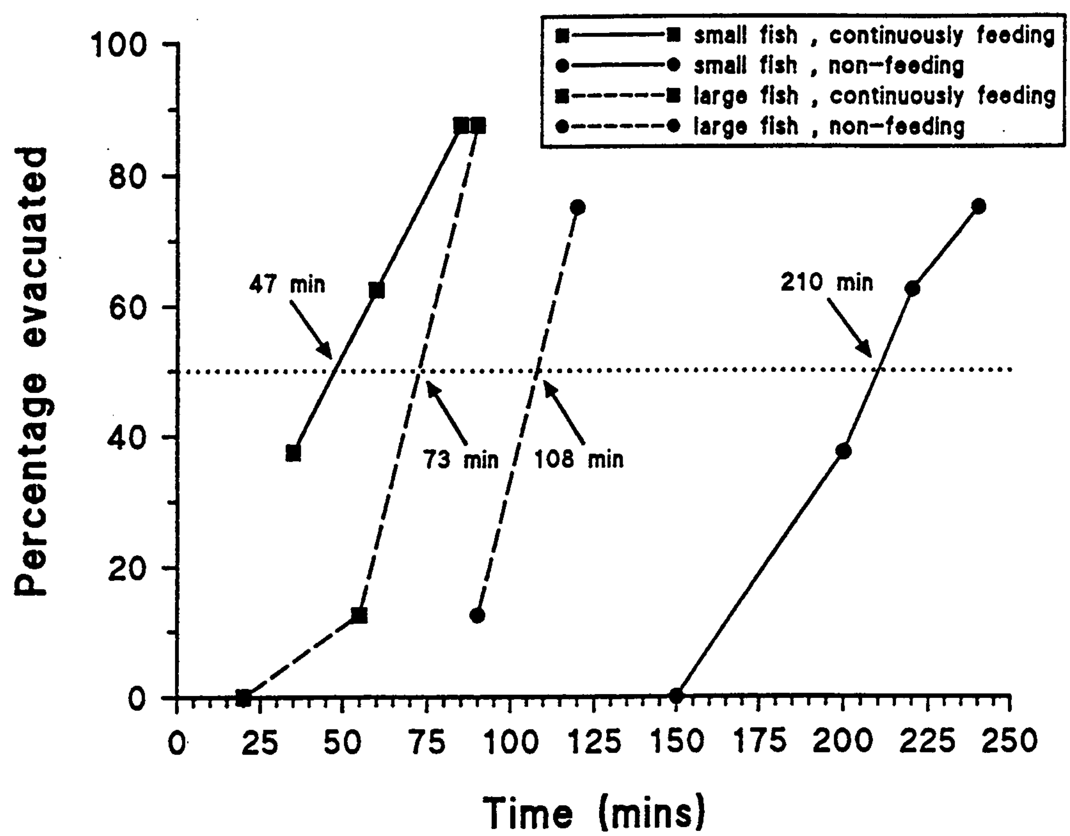

Figure 3.4. Stomach evacuation rates for barramundi fry 15.8 ± 2.5 mm TL (solid line) and 37.2 ± 3.7 mm TL (dashed line), for continuously feeding fish and non-feeding fish. Median evacuation times for each group are indicated.

3.3.6 *Morphometric relationships and growth rates*

The regression equations describing relationships between TL, SL, WWt and DWt are given in Table 3.2. The correlation coefficients for all relationships were highly significant ($P < 0.001$). The relationship between SL and TL was linear (Figure 3.5), whereas power equations described all length–weight and dry weight–wet weight relationships (Figures 3.6, 3.7, 3.8, 3.9, 3.10 and 3.11).

Fish stocked prior to metamorphosis in an earthen pond grew from 8.7 to 44.4 mm TL in 28 days; the daily growth rate based on weight was 16.4%, and density in the pond at harvest was 0.5 fish/m^2 (14% survival). Fish reared intensively in the laboratory grew from 9.9 to 20.3 mm TL in 13 days; the daily growth rate was 15.5%, and survival through this period was 98%. After stocking into a pond at 2/m^2, they grew to 43.2 mm TL in 17 days, achieving a daily growth rate of 12.5% and survival of 99.5%.

Table 3.2. Regression equations, intercepts (a), slopes (b) and r^2 values for length, wet weight and dry weight relationships for barramundi *Lates calcarifer* fry (10.0–56.2 mm TL). (n = number of data pairs; CL = confidence limits; TL = total length (mm); SL = standard length (mm); WWt = wet weight (mg); DWt = dry weight (mg)).

X	Y	n	Equation	a	b(±95%CL)	r^2
TL	SL	129	$Y = a + bX$	-0.359	0.822 (0.006)	0.998
TL	WWt	135	$Y = aX^b$	0.028	2.81 (0.087)	0.984
SL	WWt	61	$Y = aX^b$	0.068	2.73 (0.078)	0.991
TL	DWt	173	$Y = aX^b$	0.004	2.91 (0.031)	0.995
SL	DWt	119	$Y = aX^b$	0.007	2.92 (0.038)	0.995
DWt	WWt	62	$Y = aX^b$	7.302	0.93 (0.018)	0.995
WWt	DWt	62	$Y = aX^b$	0.121	1.07 (0.021)	0.995

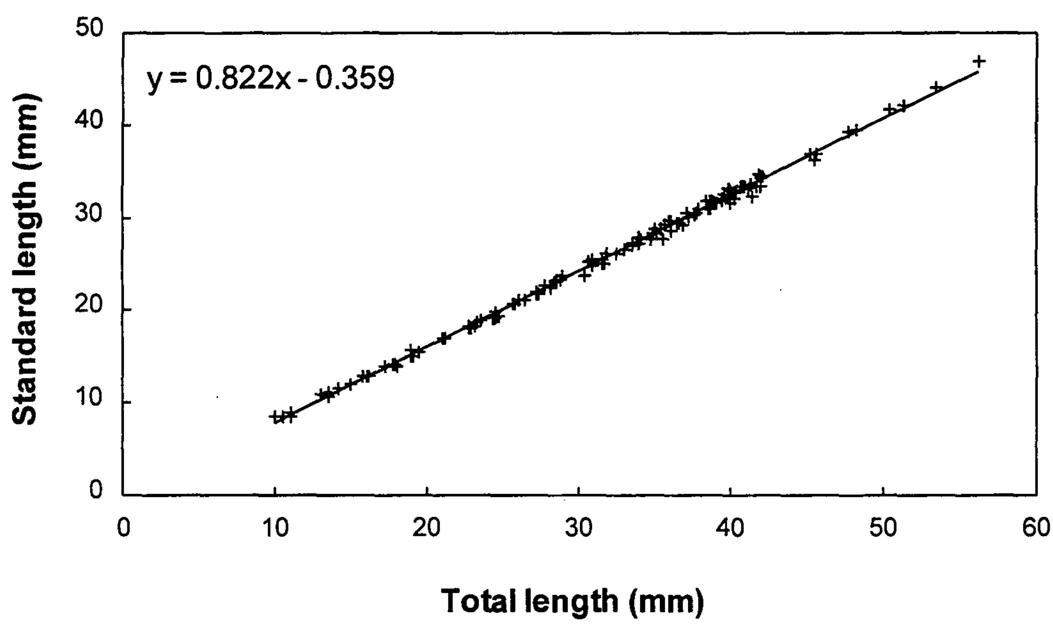

Figure 3.5. Relationship between total length (mm) and standard length (mm) for 129 barramundi in the range 10–56.2 mm total length.

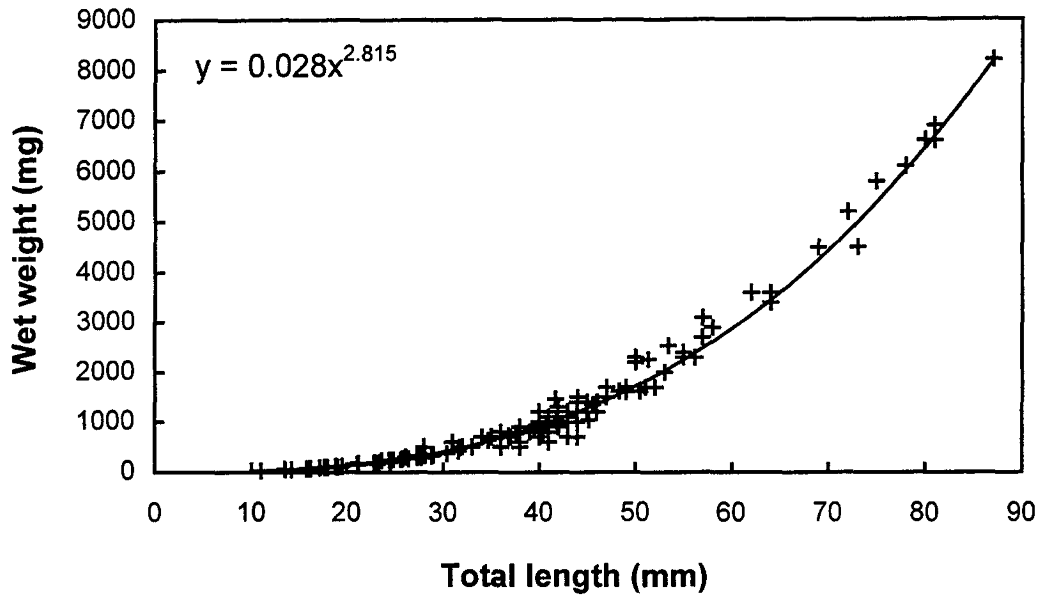

Figure 3.6. Relationship between total length (mm) and wet weight (mg) for 135 barramundi in the range 11–87 mm total length.

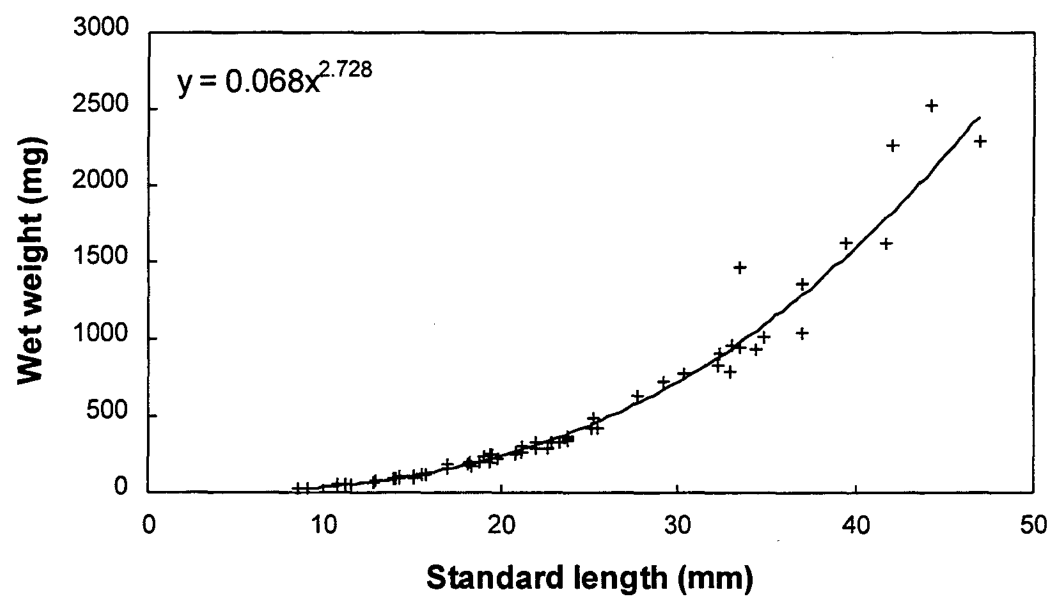

Figure 3.7. Relationship between standard length (mm) and wet weight (mg) for 61 barramundi in the range 8.5–46.9 mm standard length.

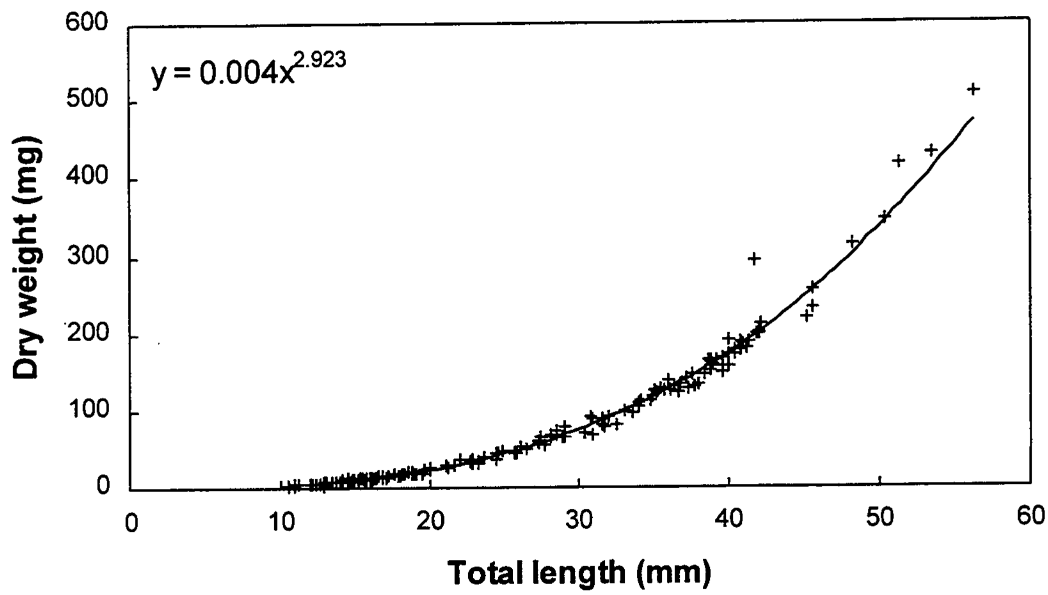

Figure 3.8. Relationship between total length (mm) and dry weight (mg) for 173 barramundi in the range 10–56.2 mm total length.

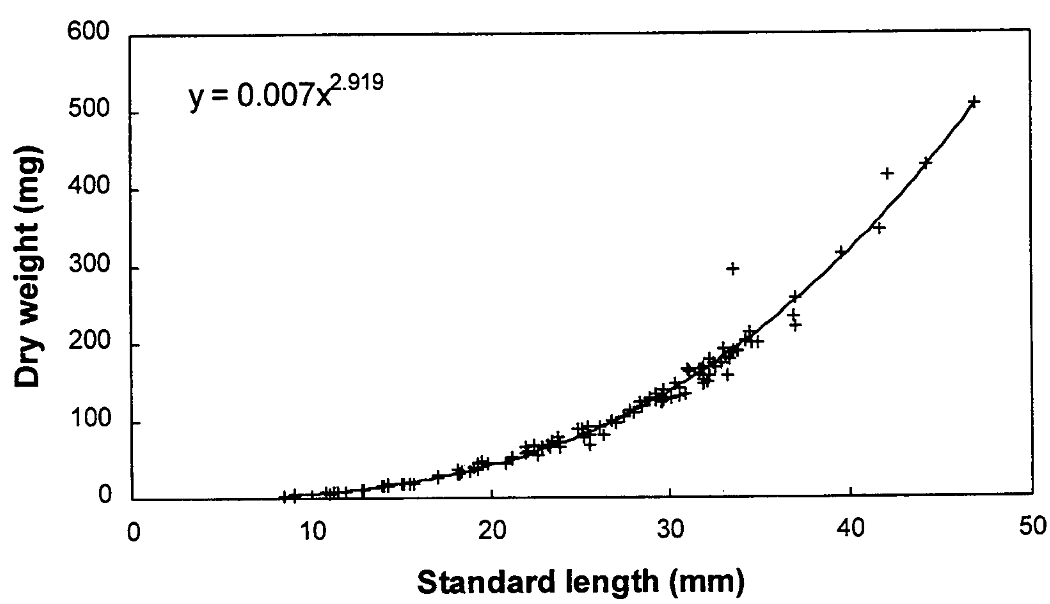

Figure 3.9. Relationship between standard length (mm) and dry weight (mg) for 119 barramundi in the range 8.5–46.9 mm standard length.

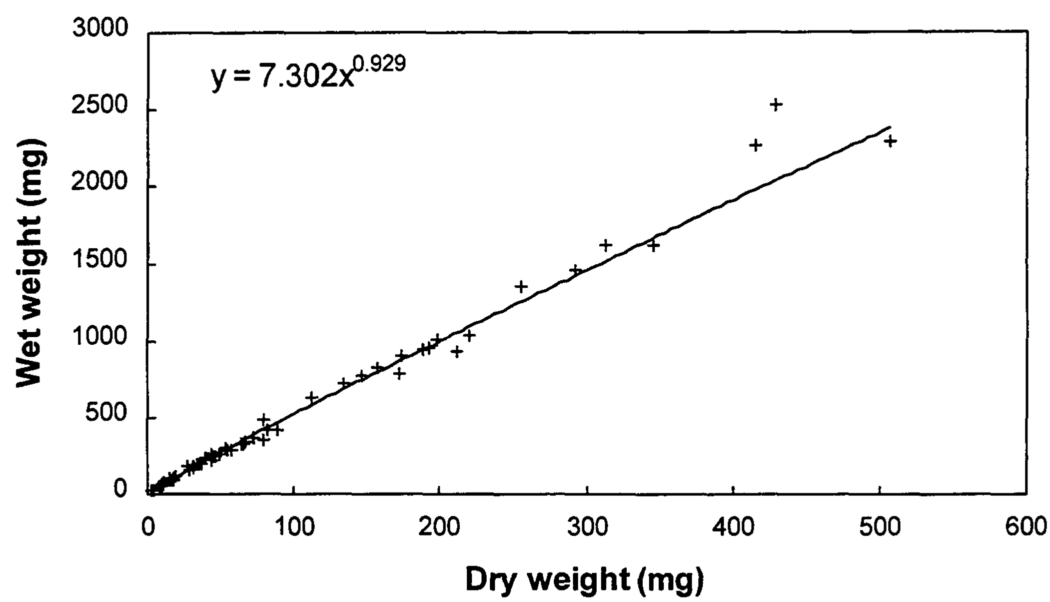

Figure 3.10. Relationship between dry weight (mg) and wet weight (mg) for 62 barramundi in the range 3.4–507 mg dry weight.

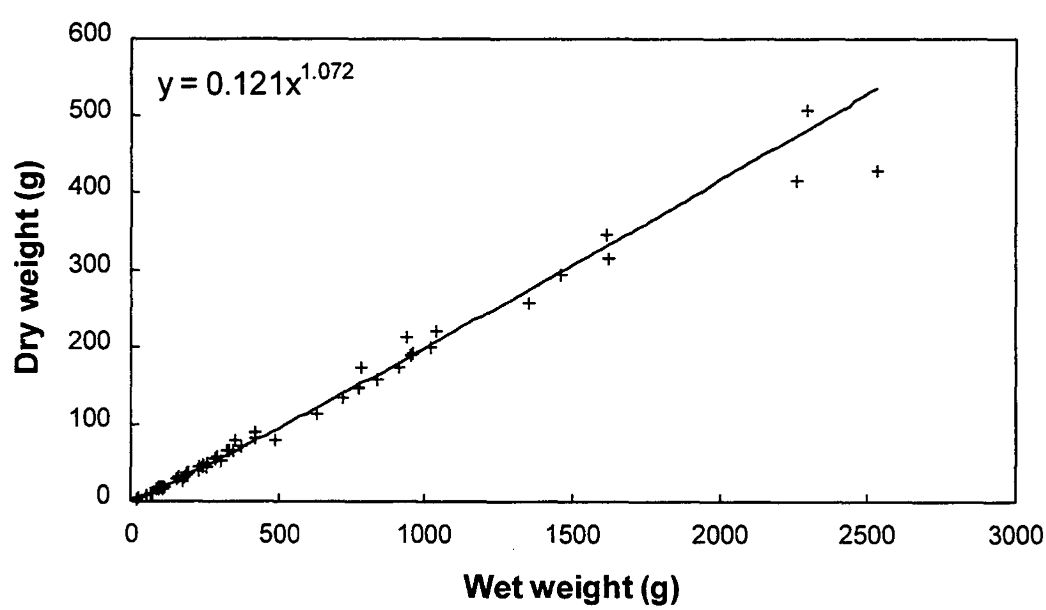

Figure 3.11. Relationship between wet weight (mg) and dry weight (mg) for 62 barramundi in the range 22.9–2530 mg wet weight.

3.4 DISCUSSION

This study has revealed the relationship between ontogenetic changes in pigmentation, feeding behaviour and diet of barramundi in the size range 10–50 mm TL. The changes in pigmentation described here had previously been documented by Moore (1982) and Mukhopadhyay *et al.* (1983), but, as their specimens were wild-caught fish, they did not have the data to relate pigmentation changes to the feeding ecology of the species. Field observation would be required to elucidate the nature of the association between environmental cues and ontogenetic changes, but the pigmentation changes may be associated with camouflage or predator avoidance. Post-larval barramundi inhabit brackish or freshwater swamp systems, typically comprising plant communities of mangroves, *Melaleuca* spp. or *Eleocharis* grasses (Moore 1982, Russell and Garrett 1985). Such systems are characterised by low intensity light, due to filtering by vegetation and occasionally the presence of tannins in the water. The dark pigmentation and distinct pale vertical bands on the 9–16 mm TL barramundi would camouflage fish swimming through the water column in swampy habitats. The irregular but paler pigmentation, which first develops at about 17 mm TL and occurs at the same time as a change in feeding behaviour and diet, may provide camouflage for the fish while utilising the lurking predator feeding habit, particularly when stationed near submerged vegetation. The change to the adult form of pale silvery colour proceeds gradually in fish 50–100 mm TL (Moore 1982), and is presumably associated with movement from swamps to nearshore or riverine systems (Moore 1982, Russell and Garrett 1985).

The ecological significance of the night-time benthic habit of 10–16 mm TL barramundi is difficult to explain without observation of vertical migration patterns of co-existing fauna in natural habitats. An alternating benthic-pelagic habit has been reported in flatfish approaching metamorphosis, and has also been associated with circatidal rhythms as a means of recruiting to and maintaining position in estuaries (Boehlert and Mundy 1988). For barramundi being reared in freshwater ponds, however, this habit could be detrimental because of the presence of predators (for example, dragonfly nymphs) on the substrate.

The shift in diet of barramundi from planktonic crustacea (the sole food category in fish smaller than 18 mm TL) to insect larvae (first eaten at 18 mm TL) paralleled the change from a roving zooplanktivore to a lurking predator feeding habit. The general trend for the diet to change with increasing fish size from planktonic crustacea to a mixture of insect larvae and crustacea, to larger arthropods and vertebrates, is similar to that reported by Patnaik and Jena (1976) and Davis (1985) for wild fish in India and northern Australia respectively, and by De (1971) for fish reared in a brackish water pond in India. It is obvious from these studies that to maximise the growth potential and survival of post-larval barramundi reared in ponds, it is necessary to have abundant zooplankton while the fish are 10 to 40 mm TL, and to have macroscopic animals of increasing size as prey for barramundi about 20 mm TL and larger.

Cannibalism was not recorded in the fish sampled from the ponds for the dietary studies, although it was evident in the feeding behaviour studies conducted in aquaria. De (1971) found cannibalism in barramundi at the upper end of the 40–200 mm TL size class, and Ghosh and Pandit (1979) did not consider the piscivorous habit of *L. calcarifer* to be developed until the fish attained 125 mm. This apparent lack of cannibalism during extensive rearing in ponds is in contrast to intensive rearing in tanks, where it is necessary to constantly grade the population according to size after metamorphosis to prevent cannibalism (Awang 1987, Maneewong 1987, Fermin 1991, Trendall 1991).

Diel feeding patterns have not previously been documented for barramundi fry. This study revealed a distinct pattern of feeding commencing at dawn and remaining constant through the day, but increasing significantly at dusk. Feeding ceased during darkness, although there was some minor feeding activity under moonlit conditions, at least by the larger fish. The enhanced feeding at dusk is presumably an adaptation to store food for the ensuing non-feeding period. Daytime feeding with a peak at dusk has been shown for larvae of American shad *Alosa sapidissima* (Wiggins *et al.* 1985) and largemouth bass *Micropterus salmoides* (Laurence 1971). Daytime feeders can show other patterns, however. For instance, the rabbitfish *Siganus guttatus* feeds continually through the day with no apparent peaks in activity (Hara *et al.* 1986); the rainbow trout *Oncorhynchus mykiss* has been recorded as a daytime feeder with a peak at midday (Angradi and Griffith 1990); juvenile chinook salmon *Oncorhynchus tshawytscha* exhibits maximum feed intake at dawn (Sagar and Glova 1988); and juvenile haddock *Melanogrammus aeglefinus* are daytime feeders, with peaks in feeding activity at dusk and an inferred peak in the morning (Hall 1987).

The evacuation rates of the small and large barramundi fry under feeding and non-feeding conditions appeared to be consistent with their feeding ecology. The small fish (about 16 mm TL) were roving zooplanktivores, whereas the larger fish (about 37 mm TL) had adopted the lurking predator habit. Under conditions of continuous feeding the smaller fish evacuated food more quickly than the larger fish, but under non-feeding conditions the smaller fish took considerably longer to evacuate their stomachs (Figs. 3.3a and 3.3b). It is postulated that the variability in evacuation rates for the small fish is an adaptation to prey availability. For fish consuming zooplankton, which is usually patchily distributed, it would be advantageous to have a comparatively fast evacuation rate when food is abundant and a slow rate when food is scarce. Larval herring *Clupea harengus pallasi* exhibit this strategy of increasing zooplankton intake and evacuation when food concentrations are high. The increased intake is associated with decreased carbon assimilation efficiencies, but experimental studies have shown that the magnitude of increasing ingestion more than compensates for the decreased carbon assimilation, and herring larvae thus gain greater total energy under conditions of high food concentration (Boehlert and Yoklavich 1984).

The strategy of maximising food intake apparently becomes less important as the barramundi grows from an obligate zooplanktivore to a lurking predator. Whereas the smaller fish can be classified as number maximisers, the larger fish, which have a wider range of prey available and greater energy reserves, appear to be energy maximisers, foraging and processing prey to maximise net energy. This pattern supports the conclusion of Griffiths (1975) that many invertebrates and larval vertebrates eat prey as they are encountered while adult vertebrates feed as energy maximisers.

The energy maximiser strategy would also be advantageous for carnivorous fish which can consume large prey. Bromley (1987) has shown that for turbot *Scophthalmus maximus* the rate of gastric digestion is slower for larger meal sizes, but the amount of chyme released to the intestine remains constant, or independent of, meal size. The passage of chyme to the intestine is controlled by the powerful duodenal sphincter, which apparently lets chyme pass freely but retains solids very effectively. It is quite possible that digestive processes for juvenile and adult barramundi are similar, given that, like turbot, they have a powerful duodenal sphincter and the ability to consume large prey.

Both the diel feeding pattern and evacuation rates demonstrated in this study have implications for fish culturists rearing fingerling-sized barramundi. The results indicate that feeding should take place throughout the day with more food being provided at dusk. If feeding live food, it may be more efficient to feed less food more regularly rather than large amounts on fewer occasions. If dry diets are being used, feeding frequency should probably be at least every two hours. However, it is recognised that optimising both the ration size and frequency would depend on a complex interplay between evacuation rates (which are temperature-dependent), digestibility and gross biochemical composition of food, and assimilation efficiency (Boehlert and Yoklavich 1984, Bromley 1987).

The daily growth rates (13–16%) of barramundi fry are high, although not surprisingly so for fry reared at temperatures in excess of 25°C. Arumugam and Geddes (1987) reported that another Australian species, the golden perch *Macquaria ambigua*, reared from first feeding larval stage to fry in fertilised ponds under temperature regimes similar to those in the present study, showed daily growth rates of 15%. Similarly, Houde (1989) has shown a positive correlation between weight-specific daily growth rates and temperature, and that daily growth rates greater than 20% are common for larvae reared at temperatures higher than 25°C. Fermin (1991) and Fermin and Bolivar (1994) recorded daily growth rates of 2.6–18.8% for barramundi larvae reared at 27–30°C on either live or frozen *Moina macrocopa*, *Artemia salina* or minced fish flesh under laboratory conditions.

The daily rations determined in this study (19–86% for 16 mm TL and 38–56% for 37 mm TL fish) are high, which concurs with the rapid growth rates of, and high rearing temperatures employed for, barramundi. The daily ration figures also indicate the amounts of live feeds required for optimal growth of barramundi in intensive nursery culture. Extrapolation to optimum levels of dry diets, however, would require comparison of the energy content of the zooplankton used in this study and the dry diets.

Morphometric relationships for barramundi fry have been recorded by De (1971), but previous documentation of wet and dry weight relationships for barramundi fry has not been located. These relationships, along with information on feeding behaviour, diel feeding patterns and stomach evacuation rates, are valuable indicators for optimising feeding regimes for barramundi fry.

CHAPTER 4. PREDATION BY DRAGONFLY NYMPHS OF THE SPECIES *Pantala flavescens* (ODONATA: LIBELLULIDAE), ON BARRAMUNDI

4.1 INTRODUCTION

Barramundi, *Lates calcarifer,* is being reared in Australia for aquaculture and for stocking to enhance recreational fisheries. Barramundi is a catadromous species, and has a physiological requirement for salt water up to about 8-10 days old (approximately 5-6 mm total length, TL), but thereafter it can be grown in either salt or fresh water. One technique for producing fish for stocking impoundments is to rear them in freshwater ponds from 8–9 mm TL (that is, prior to metamorphosis) to the commonly accepted stocking size of 40–50 mm TL. This technique was employed at the Freshwater Fisheries and Aquaculture Centre, Walkamin, but survival through the pond-rearing phase was always less than 50%, despite low stocking rates (2–16/m^2) and good pond management practices.

One possible explanation for the lower-than-expected survival became evident from studies on the feeding behaviour of small fish, documented in Chapter 3. Barramundi undergo a distinct change in diet and feeding behaviour at about 18 mm TL. While less than 18 mm TL (corresponding to about the first 10 days after stocking into ponds) the fish are obligate zooplanktivores and show no affinity for cover. Fish of this size when hungry swim throughout the water column, but when sated remain still in the water column or even lie on the substrate. Fish larger than 18 mm TL feed on insects and zooplankton, orienting near shelter and adopting a predatory mode of feeding.

It was postulated that the behaviour of fish less than 18 mm TL may make them susceptible to benthic predators, such as the nymphs of dragonflies (Odonata). Odonate nymphs are common in freshwater ponds in the tropics and have often been implicated in mortality of larval fish (e.g. by Huet 1970 and by Piper *et al.* 1982). However, the only quantitative report located is that of McGinty (1980) (referred to in Tave *et al.* 1990) who found that when dragonfly nymphs were uncontrolled they consumed all channel catfish, *Ictalurus punctatus,* fry in nursery ponds. McGinty stocked earthen ponds with 50 000 and 100 000 fry/ha. Prior to stocking, some ponds were treated with methyl parathion to kill dragonfly nymphs, while other ponds were untreated. Survival of fry in the treated ponds ranged from 79–98%, whereas in the untreated ponds dragonfly nymphs consumed all fry within 47 days. Horn *et al.* (1994) conducted laboratory experiments on predation by odonate nymphs (*Enallagma* sp. and *Tramea* sp.) on larval razorback suckers (*Xyrauchen texanus*). The fish larvae (11–15 mm TL) were highly susceptible to both odonate species and, based on observations of nymph densities in natal rearing environments and the ecology of the water bodies (water depth, vegetation, absence of predatory fish), Horn *et al.* (1994) concluded that predation by odonate nymphs may be a severe constraint to recruitment of razorback suckers.

In the present study, laboratory-based experiments were conducted to determine the vulnerability of different-sized barramundi fry to predation by dragonfly nymphs. For comparative purposes, the experiment was also conducted on larvae of the sooty grunter, *Hephaestus fuliginosus*, a tropical freshwater sportfish reared at the Walkamin Research Station for stocking impoundments. The colonisation and development of odonate faunas in two ponds were also monitored. Based on the results of this work, an alternative rearing strategy which precludes predation by odonate nymphs was devised and tested.

4.2 MATERIALS AND METHODS

4.2.1 *Predation on fish by odonate nymphs*

The impact of predation by nymphs of the anisopteran dragonfly, *Pantala flavescens,* on barramundi and sooty grunter larvae was determined in 16 aquaria of dimensions 900*350*300 mm, set up in a 4*4 randomised block design. Temperature was maintained at 28.0 ± 0.5°C. Each aquarium contained 20 fish, together with abundant zooplankton (captured using air-lifts and plankton nets in ponds) and 6 tadpoles (approximately 20 mm total length). The zooplankton was eaten by both the fish and dragonfly nymphs, and was supplied in excess of the feeding requirements of the fish and nymphs. The tadpoles were included because they are a common component of the macrofauna of ponds, and it was thought that their exclusion might artificially increase predation on fish due to the lack of alternative prey for the dragonflies. The treatments were 0 (control), 3, 6 and 12 dragonfly nymphs per aquarium, with the numbers chosen to represent low, medium and high densities of nymphs typically seen in ponds (see Section 4.3.2). The nymphs, zooplankton and tadpoles were introduced to the aquaria at least one hour before adding the fish. This ensured that the nymphs had the opportunity to feed prior to adding the fish. The nymphs had an average TL of 23 mm (standard deviation 2.5 mm, range 17–25 mm, $n = 14$).

Two size-groups of barramundi were tested on separate occasions. The two size-groups exhibited different feeding strategies, being categorised as roving zooplanktivores, applying to fish less than about 18 mm TL, and lurking predators, applying to fish larger than about 18 mm TL. In this experiment, the roving zooplanktivores averaged 9.9 mm TL (s.d. 0.7 mm, range 9.1–11.9 mm, $n = 30$), and the lurking predators 20.2 mm TL (s.d. 1.6 mm, range 17.9–24.3 mm, $n = 30$). The sooty grunter larvae, which do not undergo a similar change in feeding habit, averaged 18.7 mm TL (s.d. 0.7 mm, range 17.2–20.2 mm, $n = 30$). The narrow size ranges of the fish within each group effectively precluded cannibalism. The respective sizes of the fish, dragonfly nymphs and tadpoles prevented predation by the fish on either the dragonfly nymphs or the tadpoles.

The number of mortalities of fish over a 20 hour exposure period (10 h light/10 h dark) was recorded, along with observations on the behaviour of the fish and the dragonfly nymphs. Night-time observations were made using dim red light. Mortality data (arcsin transformation) were analysed using analysis of variance and means were compared using the LSD test. In analysing the tadpole mortality data, Bartlett's test was used to test for homogeneity of variances for the three trials (i.e. small barramundi, large barramundi and sooty grunter) prior to combining the data to examine the influence of dragonfly density on mortality.

4.2.2 *Colonisation of ponds by odonate nymphs*

Colonisation and development of odonate fauna was investigated in two 0.1 ha earthen ponds, situated at the Freshwater Fisheries and Aquaculture Centre, Walkamin. Black plastic, extending 2 m above and below full supply level, was laid around the perimeter of one pond (Pond A). This effectively eliminated ovipositing habitat for odonate species that lay eggs into soil or the tissues of plants near the water (endophytic species, see Williams 1980). Both ponds were filled on 16 February 1988 with channel water originating from Lake Tinaroo. Maximum and minimum temperatures at the bottom of the pond (approximately 1.3 m depth) were recorded every 3 days during the 5 weeks of sampling. Fish were not present in either pond.

Epibenthic fauna was collected with a dredge net (Williams 1980, Barlow *et al.* 1982) made of 425 μm mesh net. The open end was 460*310 mm, and the net tapered for 1 m to a collecting jar 60 mm in diameter. The net was supported 60 mm off the substrate by a frame attached to a ski on each side. A "kick chain" joined the skis 130 mm in front of the mouth of the net.

Six samples were collected twice weekly from each pond for 5 weeks, starting 3 days after filling. The net was positioned randomly in the ponds, and then towed over 15 m of substrate at approximately 1 m/sec. The samples were preserved in 70% alcohol. Odonate nymphs were separated, identified and enumerated in the laboratory.

Development of the population of the most abundant species, *Pantala flavescens*, was monitored by measuring head-widths (HW) of up to 100 individuals on each sampling occasion. HW was converted to total length (TL) using the formula

$$TL = 4.035HW^{0.872}$$

derived from measurements taken from 100 fresh specimens.

4.2.3 *Comparison of husbandry techniques*

Newly metamorphosed barramundi were transferred to freshwater and held at 2 fish/l in two 1500 L indoor tanks, in a flow-through system with water exchanged every 12 hours. The fish were fed on freshwater zooplankton harvested from ponds. After 14 days, when they had attained an average TL of 20 mm, the fish were introduced into 2 ponds which had been filled 7 and 11 days prior to the stocking. Survival to fingerling size (40–50 mm TL) and density at harvest under this rearing system were compared with that under the traditional system, which was to place the fish prior to metamorphosis into nursery ponds, filled 14–16 days previously, and rear them to fingerling size entirely in the ponds.

4.3 RESULTS

4.3.1 *Predation on fish by odonate nymphs*

The impact of predation by different densities of dragonfly nymphs on two size-groups of barramundi and one group of sooty grunter larvae is shown in Table 4.1 and Figure 4.1. Comparing the different groups of fish, the mortality of the large barramundi and sooty grunter was not significantly different, and both groups had significantly less mortality ($P < 0.05$) than did the small barramundi.

For the small barramundi, there was a significant difference in the mortality of fish at each density of nymphs ($P < 0.05$). One fish died in one control aquarium, and there were average mortalities of 46%, 63% and 84% in the 3, 6 and 12 nymphs per aquarium treatments, respectively.

In contrast, predation on the larger barramundi was much less severe. There were no mortalities in the control aquaria, and averages of 4%, 11% and 16% mortality in the 3, 6 and 12 nymphs per aquarium treatments, respectively. The numbers of mortalities at the 0, 3 and 6 nymphs per aquarium treatments were not significantly different, but the number of mortalities at the 12 nymphs per aquarium treatment was significantly different from that at the 0 and 3 nymphs per aquarium treatments ($P < 0.05$).

The impact of dragonfly nymphs on the sooty grunter larvae was similar to that on the larger barramundi. In the controls there were no mortalities, and averages of 11%, 13%

and 30% mortality in the 3, 6, and 12 nymphs per aquarium treatments, respectively. There was no significant difference in the number of mortalities at 0, 3 and 6 nymphs per aquarium, but the number of mortalities at 12 nymphs per aquarium was significantly different from that in the other three treatments ($P < 0.05$).

The response of the two groups of barramundi to the dragonfly nymphs was markedly different. The small barramundi showed no avoidance or escape response even when being attacked. During the day, the fish continually swam into the zone within 50 mm of the substrate, where they were easily captured by nymphs jumping off the substrate. At night, nearly all the fish were near or on the substrate. Behaviour of fish in the control and treatment aquaria was similar. Selective predation on fish near the substrate meant that, at the end of the exposure period, all survivors in the treatment aquaria were in the upper reaches of the water column, whereas in the controls most remained near the substrate.

The larger barramundi generally remained more than 50 mm above the substrate, in controls and treatments, and during light and dark conditions. When a nymph lunged at a barramundi, the fish darted away, easily escaping the predator.

During the daytime, the sooty grunter larvae swam continuously in a loose school in the upper half of the water column in both control and treatment aquaria. At night, in the control aquaria all fish were resting motionless within 1 cm of the sand substrate, dispersed evenly around the aquaria. In contrast, in the treatment aquaria, only 0–3 fish were near the sand, with the remainder in a school near the surface.

Analysis of the mortality data for the tadpoles indicated that within each trial there was no significant effect ($P > 0.05$) of dragonfly density on tadpole mortality (Table 4.1). Inspection of the data indicated that this negative result was a consequence of the low power of the test (Searcy-Bernal 1994). Further analysis employed Bartlett's test for equality of variance between the trials, which indicated that the variances were not unequal ($X^2_{2d.f.} = 3.504$ ($P > 0.1$)). Thereafter, grouping the data from all three trials showed that overall there was a significant effect ($P < 0.05$) of increasing mortality of tadpoles with increasing density of dragonflies (Table 4.2).

Table 4.1. Number of mortalities (mean ± s.d.) of fish (Table A) and tadpoles (Table B) exposed for 20 hours to predation by nymphs of the dragonfly *Pantala flavescens*. At each density of dragonflies there were four replicates, initially stocked with 20 fish and 6 tadpoles. Different superscript letters within the same column indicate significantly different ($P < 0.05$) means.

Table A – Fish mortality

Treatment	Small barramundi	Large barramundi	Sooty grunter
0 dragonflies	0.3 ± 0.5^{a}	0^{a}	0^{a}
3 dragonflies	9.3 ± 1.7^{b}	0.8 ± 0.5^{a}	2.3 ± 1.0^{a}
6 dragonflies	12.5 ± 2.4^{c}	2.3 ± 2.2^{ab}	2.5 ± 1.3^{a}
12 dragonflies	17.3 ± 2.2^{d}	3.3 ± 1.3^{b}	6.0 ± 2.6^{b}

Table B – Tadpole mortality

Treatment	Small barramundi	Large barramundi	Sooty grunter
0 dragonflies	0^{a}	0.3 ± 0.5^{a}	0^{a}
3 dragonflies	1.3 ± 1.3^{a}	0.8 ± 0.5^{a}	0.8 ± 0.5^{a}
6 dragonflies	1.3 ± 1.3^{a}	1.0 ± 0.8^{a}	1.3 ± 1.5^{a}
12 dragonflies	1.8 ± 1.3^{a}	1.3 ± 1.0^{a}	2.5 ± 1.7^{b}

Table 4.2. Number of mortalities (mean ± s.d.) of tadpoles exposed for 20 hours to predation by nymphs of the dragonfly *Pantala flavescens*. The data are combined for the three trials (namely, small barramundi, large barramundi and sooty grunter). At each density of dragonflies there were 12 replicates, each initially stocked with 6 tadpoles. Different superscript letters within the same column indicate significantly different ($P < 0.05$) means.

Treatment	Mortalities
0 dragonflies	0.08 ± 0.29^{a}
3 dragonflies	0.92 ± 0.79^{ab}
6 dragonflies	1.17 ± 1.11^{bc}
12 dragonflies	1.83 ± 1.34^{c}

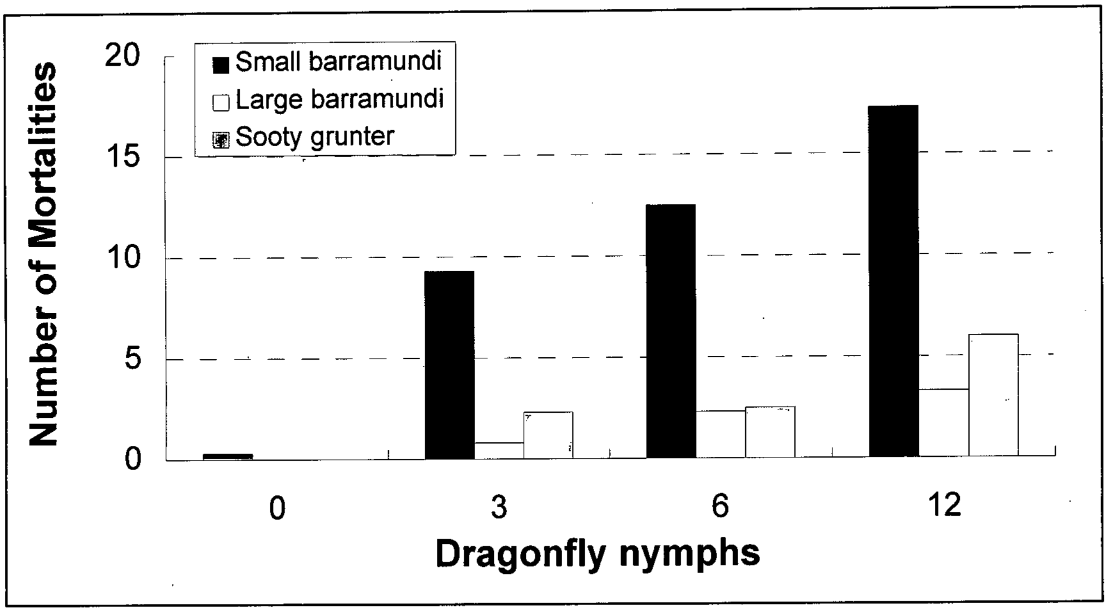

Figure 4.1. Mean number of mortalities of small barramundi (9.9 mm TL), large barramundi (20.2 mm TL) and sooty grunter (18.7 mm TL) exposed for 20 hours to predation by nymphs of the dragonfly *Pantala flavescens*. At each density of dragonflies there were four replicates, initially stocked with 20 fish.

4.3.2 *Colonisation of ponds by odonate nymphs*

Maximum and minimum temperature ranges in both ponds were 27–30°C and 23–27°C, respectively.

The number of dragonfly larvae sampled from the two ponds (A with the black plastic perimeter, B without plastic) in the first 35 days after filling is presented in Table 4.3. By far the most abundant species in both ponds was *Pantala flavescens* (Fig. 4.2), which generally made up more than 90% of the odonate fauna sampled.

The density of *P. flavescens* determined from the data in Table 4.3 is plotted in Figure 4.3a. The density appeared to peak in both ponds at day 14 after stocking, at 6 larvae/m^2 in Pond A and 12/m^2 in Pond B. The nymphs continued to increase in size throughout the 35 days of sampling (Fig. 4.3b).

4.3.3 *Comparison of husbandry techniques*

The barramundi stocked into the two indoor flow-through tanks grew from an average of 9.9 mm to 20.2 mm TL in 16 days. Survival through this period was 94.5% and 97.6% in the two tanks. These fish were then stocked into two 0.1 ha outdoor ponds and on-grown to fingerling size (40–50 mm TL). Mean (±s.e.) survival during the pond phase was 98.2±1.3% (Table 4.4). In comparison, mean (±s.e.) survival of barramundi stocked at an initial average size of 9.9 mm TL into four 0.1 ha ponds and reared to 40–50 mm TL was 31.2±9.1% (Table 4.4). Mean (±s.e.) density at harvest for the larger fish at time of stocking was 2.8±0.75 fish/m^2, while for the smaller fish it was 0.71±0.06 fish/m^2.

Table 4.3. Mean number (± s.d.) of odonate nymphs sampled per 15 m tow with a dredge net 0.46 m wide (determined from 6 tows per sampling occasion) in two 0.1 ha freshwater ponds in north-eastern Queensland during the first 35 days after filling.

Taxon	Pond	Days after filling									
		3	7	10	14	17	21	24	28	31	35
Anisoptera											
Libellulidae											
Pantala flavescens	A	–	0.2 (0.4)	0.14 (0.8)	39 (25)	27 (8)	34 (19)	24 (11)	12 (5)	25 (20)	17 (5)
	B	–	5 (3)	3 (3)	82 (19)	59 (19)	52 (23)	52 (17)	36 (6)	47 (14)	38 (24)
Other	A	–	–	–	–	0.2 (0.4)	–	–	0.4 (0.8)	–	–
	B	–	–	–	–	2 (2)	2 (3)	10 (7)	0.8 (1.0)	–	0.3 (0.8)
Aeshnidae sp. 1	A	–	–	–	–	–	–	–	–	–	–
	B	–	–	–	0.2 (0.4)	–	–	–	–	–	–
Aeshnidae sp. 2	A	–	–	–	–	–	0.5 (0.5)	–	–	–	–
	B	–	–	0.2 (0.4)	2 (2)	2 (3)	8 (10)	5 (10)	2 (2)	1 (1.3)	1 (1)
Zygoptera											
Coenagrionidae	A	–	–	–	–	–	0.2 (0.4)	0.2 (0.4)	–	–	–
	B	0.2 (0.4)	–	1 (1)	3 (5)	5 (7)	1 (1)	0.8 (1.2)	0.8 (1.3)	1 (2)	2 (3)

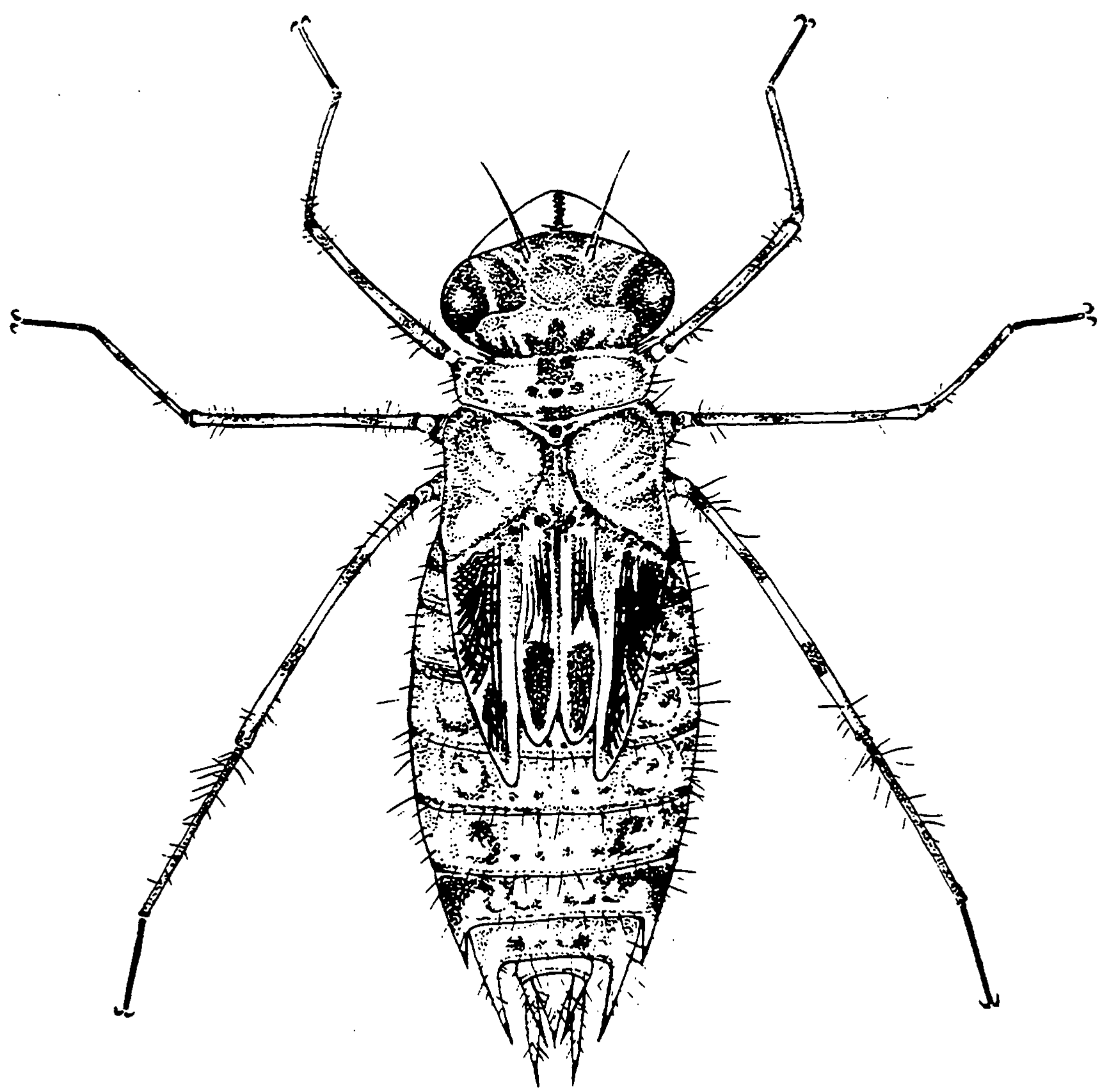

Figure 4.2. Nymph of the anisopteran dragonfly *Pantala flavescens*.

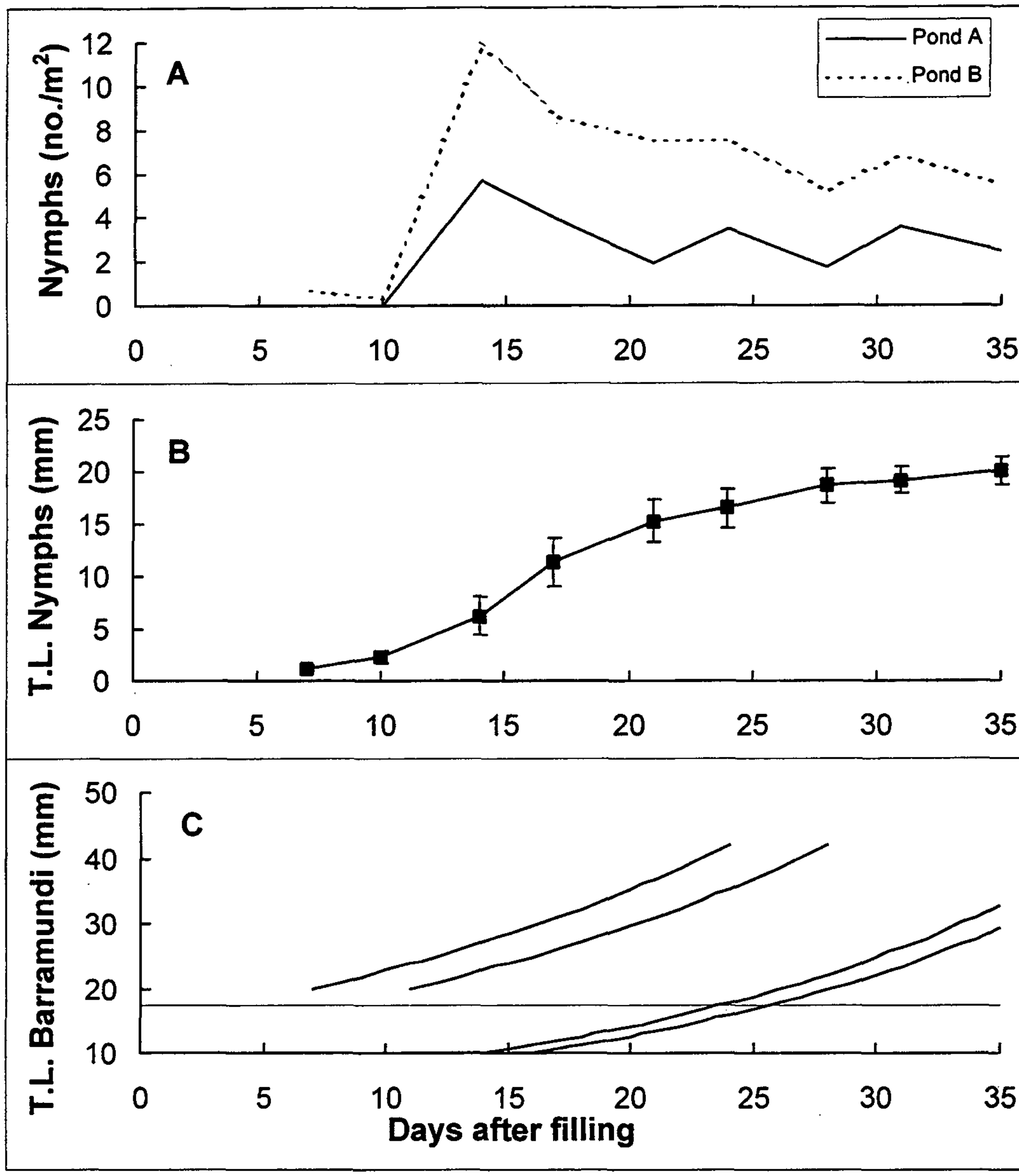

Figure 4.3. A. Density (mean number/m^2 of substrate) of *Pantala flavescens* nymphs in two 0.1 ha freshwater ponds in north-eastern Queensland during the first 35 days after filling, as determined by six 15 m tows with a dredge net 0.46 m wide on each sampling occasion.

B. Total lengths (mm) of *Pantala flavescens* nymphs sampled in freshwater ponds in north-eastern Queensland during the first 35 days after filling. Data points are means and ranges; 28 specimens were measured on day 7, 16 on day 10, and 100 on days 14 to 35.

C. Growth in length of barramundi fry of two size groups (10 mm TL and 20 mm TL at time of stocking) in freshwater ponds in north-eastern Queensland. The dashed line indicates the size (17–18 mm TL) at which barramundi develop an escape response.

Table 4.4 Number of barramundi stocked into six 0.1 ha freshwater ponds, number harvested as 40–50 mm TL fingerlings, density at harvest and percentage survival for fish of two sizes at time of stocking. The smaller fish averaged 9.9 mm TL at stocking and were harvested 27–31 days later; the larger fish averaged 20.2 mm TL at stocking and were harvested 14–17 days later.

	9.9 mm TL at stocking				**20.2 mm TL at stocking**	
Number stocked	4028	3889	1737	1737	3613	2172
Number harvested	577	646	793	835	3500	2162
Density at harvest (No./m^2)	0.57	0.65	0.79	0.84	3.5	2.0
Percentage survival	14.3	16.6	45.7	48.1	96.9	99.5

4.4. DISCUSSION

The different levels of predation by dragonflies on the two size-groups of barramundi in this experiment concur with previously identified aspects of the behaviour of juvenile barramundi (Chapter 3). The lack of an escape response in the small barramundi (10 mm TL) and their night-time habit of resting on the substrate resulted in considerable mortality at all densities of dragonflies, even in a comparatively short exposure period of 20 hours. The impact of predation was less severe on the larger barramundi (20 mm TL), which had a well-developed escape response to an attack by a dragonfly nymph. The development of the escape response is associated with a range of other dietary, behavioural and pigmentation changes which occur in barramundi at 17–18 mm TL (discussed in detail in Chapter 3).

Interestingly, the area occupied within the experimental aquaria did not differ for either group of barramundi in the presence or absence of dragonfly nymphs. This is in stark contrast to the sooty grunter larvae, which at night-time rested on the substrate in control (zero dragonfly) aquaria, but schooled near the surface in aquaria containing dragonflies. The sooty grunter is a freshwater fish and has obviously evolved in habitats containing dragonfly nymphs, whereas the barramundi has a life history in which post-larvae inhabit brackish waters (see Section 3.4), which are generally devoid of dragonfly nymphs. It seems reasonable to assume that sooty grunter larvae have developed a flexible antipredator avoidance behaviour, enabling them to recognise dragonfly nymphs as predators and avoid the benthic areas occupied by the nymphs. I have been unable to locate references to larval and juvenile fish exhibiting avoidance responses to dragonfly nymphs; however, there is a wealth of literature on the converse, namely odonate fauna exhibiting behaviours appropriate for occupying habitats characterised by the presence or absence of insectivorous fish (see review by Johnson 1991).

Little can be inferred from the comparatively minor dragonfly predation on the tadpoles. It is possible that the fish were preferred prey for the nymphs, or that the tadpoles did not generally exhibit movements that elicited an attack response from the nymphs. Other factors, such as predator–prey size interactions and density of tadpoles (Sherratt and Harvey 1989), could also have contributed to the result.

There were more dragonfly nymphs of all species collected in Pond B than in Pond A (Table 4.3). This was most likely because the substrate in Pond B was covered with a dense growth of grass, providing a complex three-dimensional habitat and associated fauna, whereas Pond A had a bare clay substrate. The effect of the black plastic placed around the edges of Pond A in eliminating ovipositing habitat for endophytic species was unclear. Only five specimens of endophytic species (Aeshnidae and Coenagrionidae) (Williams 1980) were collected in Pond A, but they were also comparatively uncommon in Pond B. Therefore, in the ponds at Walkamin at least, the application of the plastic is essentially irrelevant in controlling dragonfly nymphs, because the numerically dominant species (family Libellulidae) are exophytic (that is, their eggs are dropped freely into the water).

Escapement or avoidance of the dredge net used to collect the samples was not measured. Thus, the density of *P. flavescens* shown in Figure 4.3a is almost certainly an underestimate of the real abundance in the ponds. The apparent decline in density after day 14 could have been due to cannibalism, which has been shown to be a factor influencing population densities in other dragonfly species (van-Buskirk 1989); alternatively, the larger nymphs may have been better able to avoid the sampling device.

Pantala flavescens was by far the most numerous of the odonate species sampled from both ponds. *P. flavescens* is circumtropical, and is the most widely distributed of all the odonate species (Lamb 1925). It is an opportunist and is known to colonise small, temporary ponds (R. Rowe, James Cook University, pers. comm. 1989). In the present study, it appears that only one cohort may have colonised the pond, as early instars were never found in the samples collected during days 21–35 (Fig. 4.3b). Alternatively, nymphs from the initial colonisation may have cannibalised larvae arising from later hatchings, although if this was the case one would reasonably anticipate that a small number of early instars would still have been collected in the later samples.

The nymphs grew to an average size of 7 mm TL within 14 days and 20 mm TL within 35 days of filling the ponds (Fig 4.3b). Lamb (1929) reported the final instar of *P. flavescens* to be 16.7–18.7 mm TL. This suggests that the larval stage in these tropical waters was close to completion after 35 days, which is considerably faster than the 51 days reported for the same species in summertime in Victoria (Hawking and Ingram 1994).

Gonzalez and Leal (1995) reported that *P. flavescens* nymphs as small as 5 mm TL could consume common carp fry, and that nymphs 5–20 mm TL were capable of consuming fry slightly in excess of their own body length. Thus, both the size and density of *P. flavescens* nymphs 14 days after filling the ponds would have been sufficient to impact on barramundi if stocked at an initial size of about 10 mm TL.

The results of the trial on comparison of husbandry techniques clearly demonstrated that survival of barramundi is enhanced if the fry are stocked at 20 mm TL rather than 10 mm TL. However, the conditions of this trial were such that it was not possible to isolate the factor(s) responsible for the better survival of the larger fish. This is demonstrated by the growth curves for the fish and development of the dragonfly population (Fig. 4.3a, b, c). The dragonfly nymphs would have been abundant at the time of stocking the small fish and for the subsequent 8–10 days during which the fish would have grown to 17–18 mm TL. The barramundi would have been vulnerable to predation by the dragonfly nymphs throughout this period, according to the results of the aquarium trials (Fig. 4.1) (see also Gonzalez and Leal 1995). On the other hand, the larger barramundi were stocked earlier in the pond cycle, and they were already beyond the vulnerable stage (determined from the aquarium studies) at the time of stocking. Also, the nymphs were also extremely small (<3 mm TL) and comparatively few at the day 7–11 period (Figs. 4.3a, b). Thus, the influence of size at stocking cannot be isolated from the influence of the different time of stocking. To obtain more definitive information of the effect of dragonfly predation in ponds on the different-sized barramundi it would be necessary to stock the two size groups into ponds filled for the same preparatory period, say 14 days.

Nevertheless, it is still possible to devise pond-rearing strategies for barramundi fry, based on ontogenetic changes in diet and behaviour of the fry and the development of pond fauna (both food and predators). Zooplankton, in particular copepods and cladocerans (Table 3.1), is the sole food for fry smaller than 18 mm TL. Insect larvae are first eaten at 18 mm TL and become increasingly more important food items as the fish grow; at about 30–45 mm TL zooplankton and insect larvae are equally represented volumetrically in the diet (Fig. 3.2). Pond fauna studies at Walkamin (unpublished data) have shown that there is a time lag of 10–14 days after filling a pond before microcrustacea become abundant. The insect larvae, particularly chironomids, are reasonably common 8–10 days after filling. Considering these factors, as well as the growth rate of the fry (1–1.5 mm per day, Chapter 3), the schedule depicted in Table 4.5 is suggested as a guideline for stocking barramundi fry of various sizes into freshwater ponds for on-growing to fingerling size.

Table 4.5 Guideline for stocking barramundi fry into freshwater ponds for on-growing to fingerling size (40–50 mm TL).

TL of fry	Days after pond filled	Rationale
≤ 15 mm	—	Not to be stocked into freshwater ponds. Fry dependent on zooplankton, susceptible to predation by dragonfly nymphs.
16–17 mm	10	Approximately 2 days before escape response developed. Dragonfly nymphs very small (2–3 mm TL).
18–19 mm	8–12	Escape response developed. Fry can eat small insect larvae. Dragonfly nymphs small (2–5 mm TL).
> 20 mm	≥ 8	Diversity of food for fry. Fry not vulnerable to dragonfly nymphs.

Control of air-breathing insects in fish-rearing ponds has been achieved using diesel or oil to create a surface film through which the insects cannot penetrate (Brown and Gratzek 1980). In the case of gill-breathing insects such as dragonfly nymphs, insecticides (organophosphates and pyrethroids) have been used (e.g. Burleigh *et al.* 1993), but such chemicals have not been approved for use in aquaculture in Australia. Moreover, the use of insecticides would be detrimental to the fish, as insecticides are also toxic to microcrustacea, which are the major component of the food base for fish larvae reared in ponds

In summary, the experimental results have clearly shown that barramundi up to 10 mm TL are extremely susceptible to predation by nymphs of the dragonfly *P. flavescens*. By 20 mm TL the barramundi are no longer susceptible, as at that size they have a well-developed escape response. The escape response first becomes apparent at about 18 mm TL, in association with changes in behaviour, diet and pigmentation (Chapter 3). Under the trial conditions, the dragonfly populations in ponds at the Walkamin Research Station peaked at about 14 days after the ponds were filled, and growth of the most abundant species *P. flavescens* was rapid. Barramundi fry 20 mm TL show significantly better post-stocking survival in freshwater rearing ponds than do 10 mm TL fry. On-growing barramundi fry to fingerling size in freshwater ponds requires management strategies to preclude predation by dragonfly nymphs.

CHAPTER 5. EFFECTS OF PHOTOPERIOD ON GROWTH AND FEEDING PERIODICITY OF BARRAMUNDI FRY

5.1 INTRODUCTION

Barramundi have been routinely reared in hatcheries in several South-East Asian countries since the mid-1970s, and consequently there is considerable published information on rearing procedures (Chomdej 1986, Copland and Grey 1987, Parazo *et al.* 1990). However, there is surprisingly little literature on the biology of larvae and juveniles as it relates to survival and growth in hatcheries.

Several authors have shown that fish biology and behaviour are influenced by light. Extending the photoperiod under which teleost larvae are reared affects growth and survival, although the nature and extent of the effect varies between species (see, for example, Marliave 1977, Tandler and Helps 1985, Duray and Kohno 1988). Pearce (1991) reported that artificially extending daylight during larval rearing resulted in increased growth due to greater food consumption, but that it had no effect on survival. In Chapter 3 it was shown that barramundi fry are visual feeders, taking food throughout the day, with a peak in feeding activity at dusk. The fry continue feeding at a reduced level under moonlit conditions, but cease feeding in total darkness.

Based on this information, I hypothesised that artificially increasing the day length during hatchery rearing may increase the growth rate of barramundi fry. Consequently, trials were conducted to determine if photoperiod had any effect on the growth, survival, feeding pattern and daily food consumption of barramundi fry reared in a freshwater hatchery.

5.2 MATERIALS AND METHODS

5.2.1 *The fish*

The fish used in this experiment were bred from eggs stripped from wild fish captured on the spawning grounds in the Hay River, Weipa (12°34'S, 142°53'E). The larvae were reared at the Northern Fisheries Research Centre, Cairns. At about 18 days old, the fish were acclimated to fresh water over a 24 hour period and transferred to the Walkamin Research Station. They were maintained in fresh water for at least 5 days prior to starting the growth and survival experiment, and at least 25 days prior to starting the feeding periodicity experiment. Two trials were conducted within each experiment, using fish from separate spawnings.

5.2.2 *Effect of photoperiod on growth*

The first trial was designed to test the effect on growth of 12 hours light and 12 hours dark (12L/12D) and continuous lighting (24L/0D) in combination with food being available for either 12 or 24 hours. Treatments were as follows:

Treatment 1	:	12L/12D, food available for the 12 daylight hours
Treatment 2	:	12L/12D, food available 24 hours
Treatment 3	:	24L/0D, food available 12 hours
Treatment 4	:	24L/0D, food available 24 hours

The second trial was designed to test the effect on growth of 12L/12D (treatment 1), 18L/6D (treatment 2) and 24L/0D (treatment 3) light regimes, with food constantly available.

All treatments were replicated 5 times, with 20 fish per replicate. Each replicate consisted of an aquarium tank 900*350*300 mm^3, fitted with an independent biological filter and aeration. Artificial shelter, in the form of 12 strips (30*400 mm^2) of black plastic mesh (1 mm^2) was suspended in each aquarium. Temperature was maintained at 29.0 ± 1.0°C.

Lighting was controlled by covering each aquarium with black material and positioning one 15 watt incandescent globe 25 cm above the surface of the water at the centre of the aquarium. Automatic time switches turned lights on and off at either 0700 hours and 1900 hours (Trial 1, treatments 1 and 2; Trial 2, treatment 1) or 0700 hours and

0100 hours (Trial 2, treatment 2) respectively. Light intensity at the water surface varied from 300 lux at the ends of the aquaria to approximately 1100 lux directly under the globes.

Equal aliquots of live zooplankton were added to each aquarium at 0700 hours and 1600 hours. The zooplankton was harvested from a pond using airlifts and a 250 mm net. The amount fed was sufficient for excess food to be available continuously during the feeding period. To preclude zooplankton being extracted from the aquaria by the biological filters, inlet water to the filters was strained through 200 mm filter boxes. In the 12 hour food-availability treatments in Trial 1, the inlets to the biological filters were removed from the filter boxes at 1900 hours, which effectively removed all zooplankton from the aquaria within one hour.

Fish were allocated randomly at the start of each trial, with a subsample retained for weighing and measuring. Total lengths (TL) and wet weights (Wt) at the start of each trial were as follows:

Trial 1	TL (mean ± s.d.)	11.9 ± 1.4 mm, range 10.0–16.1 mm, $n = 46$
	Wt (mean ± s.d.)	23.0 ± 8.7 mg, range 10.0–50.0 mg, $n = 46$
Trial 2	TL (mean ± s.d.)	11.0 ± 1.1 mm, range 9.1–13.0 mm, $n = 50$
	Wt (mean ± s.d.)	21.3 ± 7.1 mg, range 9.0–36.0 mg, $n = 50$

Each trial was run for 13 days, after which all fish were weighed and measured. Two-way analysis of variance (ANOVA) was used to analyse growth data in Trial 1, and one-way ANOVA was used for growth comparisons in Trial 2.

In Trial 1, 10 fish from each treatment were killed by immersion in 0°C water and fixed in 70% alcohol. Longitudinal section mounts stained with haematoxylin and eosin were made and examined to determine if histological abnormalities were induced by continuous lighting.

5.2.3 *Effect of photoperiod on feeding periodicity*

Two trials were conducted with different-sized fish to determine the patterns of food consumption over a 24 hour period for fish exposed to 12L/12D and 24L/0D light regimes. Approximately 80 fish for each treatment were placed into aquaria set up as described above, and acclimated to the experimental conditions for 3 days prior to the trials. The TLs of the fish used in each trial were as follows:

Trial 1 TL (mean ± s.d.) 33.5 ± 3.3 mm, range 24.7–39.9 mm, $n = 64$

Trial 2 TL (mean ± s.d.) 51.7 ± 5.0 mm, range 41.3–62.3 mm, $n = 64$

Excess live zooplankton was fed one hour prior to sampling, which was every three hours for 24 hours. Eight fish per treatment were sampled on each occasion. Immediately after sampling the fish were killed by immersion in 0°C water, and preserved in 70% alcohol. Within one week, the stomach contents were removed, and the dry weights of fish and stomach contents were recorded after drying at 60°C for 24 hours. The stomach fullness indexes for each sampling period were calculated from the formula

$$\text{Stomach fullness index} = \frac{\text{dry weight of stomach contents} * 100}{\text{dry weight of fish}}$$

For the fish in Trial 1, the percentage body weight eaten per day was determined from the formula

$$\text{Daily ration} = \frac{\text{24 hours average stomach fullness index} * 24}{\text{number of hours to evacuate food from stomach}}$$

The number of hours for stomach evacuation for barramundi with a mean total length of 34 mm was taken as 1.5 hours (results reported in Chapter 3). (The percentage body weight eaten per day was not calculated for fish in Trial 2, because the stomach evacuation rate for 52 mm barramundi is not known.)

5.3 RESULTS

5.3.1 *Effect of photoperiod on growth*

Final lengths, weights and survival of barramundi fry in Trials 1 and 2 are listed in Tables 5.1 and 5.2 respectively. In Trial 1, analysis involved the partitioning of treatment effects into photoperiod, food availability and interaction effects. The only effect which was statistically significant was that of food availability. Having food available for 24 hours increased length by 0.7 mm ($P = 0.032$) and increased weight by 19 mg ($P = 0.052$). Note that the latter falls just short of the conventional 5% significance level. The lack of any interaction indicated that this increase was unrelated to photoperiod. This was confirmed in Trial 2, in which there was no significant difference in the length or weight of fish in the three photoperiod treatments.

Mean survival in Trial 1 was in the range 93–97%; in Trial 2 it was 66–76%. There was no significant difference between the survivals in the various treatments within either trial.

Histological examination of specimens from Trial 1 revealed no abnormalities or lesions on any fish.

Table 5.1. Mean lengths (TL, mm), weights (Wt, mg) and percentage survivals (and standard errors) of barramundi fry after being exposed to various photoperiod and food availability treatments for 13 days. Initial size was TL = 11.9 ± 1.4 mm, Wt = 23.0 ± 8.7 mg.

Treatment	**Mean TL ± s.e. (mm)**	**Mean Wt ± s.e. (mg)**	**% Survival Mean ± s.e.**
T1 = 12L/12D, food 12 hours	30.5 ± 3.2	396.5 ± 109.9	93 ± 5.7
T2 = 12L/12D, food 24 hours	31.0 ± 3.1	412.2 ± 113.6	95 ± 0.0
T3 = 24L/0D, food 12 hours	30.7 ± 3.0	400.6 ± 106.4	95 ± 6.1
T4 = 24L/0D, food 24 hours	31.6 ± 2.9	423.7 ± 107.8	97 ± 2.7

Table 5.2. Mean lengths (TL, mm), weights (Wt, mg) and percentage survivals (and standard errors) of barramundi fry after being exposed for 13 days to photoperiod regimes of 12L/12D, 18L/6D and 24L/0D, with food continuously available. Initial size was TL = 11.0 ± 1.1 mm, WT = 21.3 ± 7.1 mg.

Treatment	Mean TL ± s.e. (mm)	Mean Wt ± s.e. (mg)	% Survival Mean ± s.e.
T1 = 12L/12D	30.3 ± 4.5	385.8 ± 175.3	66 ± 11.4
T2 = 18L/6D	29.4 ± 4.1	337.7 ± 142.6	73 ± 10.4
T3 = 24L/0D	30.4 ± 4.2	374.6 ± 166.7	76 ± 2.2

5.3.2 *Effect of photoperiod on feeding periodicity*

The patterns of food consumption over 24 hours were different between the two treatments, with similar patterns being exhibited by both small (Trial 1) and large (Trial 2) fish. Fish subject to a 12L/12D regime commenced feeding upon first exposure to light and continued to feed at a high rate over the next 6 hours of the light period. Following this, on the basis of stomach fullness, feeding slowed and tapered off during the latter part of the light period (ie., after about 1500 hours). The advanced stage of digestion of food in the gut after about 3 hours of darkness indicated that feeding had ceased completely at the switch from light to dark conditions.

Fish exposed to continuous light also showed the same trend of decreased feeding after 1500 hours, and at 2100 hours all had empty stomachs. Thereafter, the fish started feeding again (Fig. 5.1B), in marked contrast to those in the 12L/12D light regime.

The increase in feeding was particularly marked in the smaller fish, which consumed more at the 2400 hour feed than at other times during the 24 hour cycle (Fig. 1B).

The 24 hour average stomach fullness index for the small fish (Trial 1) was 1.65 for the 12L/12D treatment and 2.28 for the 24L/0D treatment. Using these data, the daily ration in the 12L/12D treatment was 26.4%; in the 24L/0D it was 36.5%. That is, the fish exposed to continuous lighting consumed approximately 1.4 times more food than the fish in the 12L/12D regime.

5.4 DISCUSSION

The results of this study clearly show that there is no advantage to be gained by rearing barramundi fry under extended light regimes. While fry in extended daylight did not show any adverse effects (in either survival or morphological development), they grew no faster than those in normal daylength light regimes. This was despite the fact that fry in 24 hours light consumed approximately 40% more food than did those in 12 hours light (with food continuously available in both cases). Presumably, the extra intake under continuous light was expended as non-productive energy associated with increased activity of the fish.

Barramundi fry reared in outdoor ponds have a distinct feeding pattern, with food being consumed throughout the day and with a distinct peak in food intake at dusk. The fry

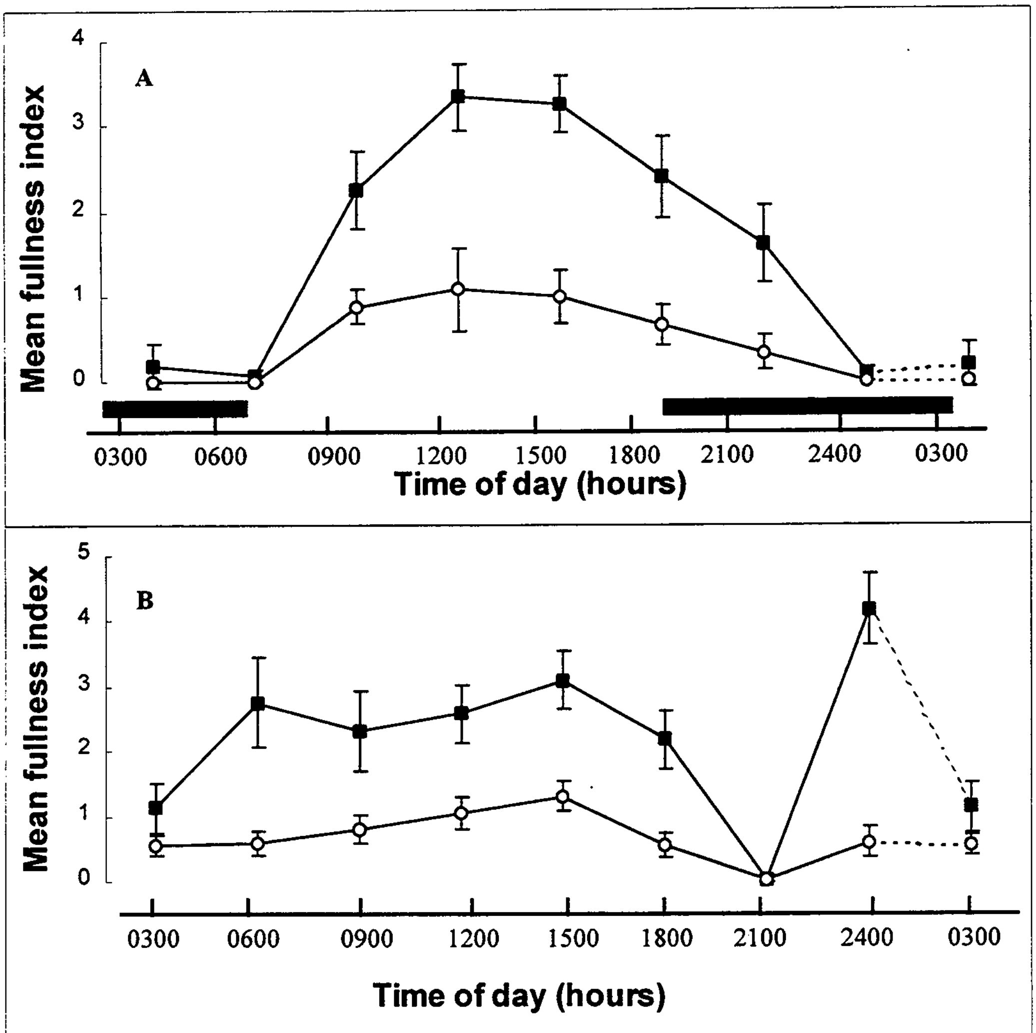

Figure 5.1. Stomach fullness indexes for two size-groups of barramundi fry exposed to 12L/12D (A) and 24L/0D (B) light regimes, with food continuously available. Each datum is the mean ± s.e. (n = 8). The solid bar indicates the period of darkness. ■ = fry TL 33 ± 3.3 mm (mean ± s.d.); o = fry TL 51.7 ± 5.0 mm (mean ± s.d.).

do not feed in total darkness (results presented in Chapter 3). The experimental protocol in the present study did not simulate dawn/dusk conditions; lighting was turned on abruptly at 7.00 am and off at 7.00 pm. Nevertheless, it is instructive to review the results in terms of a diel cycle, particularly with respect to the patterns reported in Chapter 3. Peak feeding in the 12L/12D regime occurred about 6 hours after first light (in the 'early afternoon'), with intake decreasing after that time and ceasing in darkness. A similar 'afternoon' pattern was maintained by fish in continuous light, with all fish having empty stomachs at 2100 hours. Prior to 2400 hours, however, feeding resumed in continuous light (Fig. 5.1B), in contrast to fish in the 12L/12D cycle. The maintenance of a modified feeding pattern in continuous light and in the absence of other external cues indicates that the feeding pattern is only partly controlled by light, and that other, presumably innate or genetic, controls are involved.

The data presented in Figure 1B appear to contain an anomalous result, namely the surprisingly high level of intake (stomach fullness index) exhibited by the smaller fish in continuous light at 2400 hours, that is, immediately after the non-feeding period. The larger fish resumed feeding at the same time, but did not show the same magnitude of increase in feeding. Consequently, in the absence of further experimentation, the datum point for 2400 hours for the smaller fish should be considered indicative of a trend — resumption of feeding — rather than an indicator of a particular level of food consumption.

The lack of growth response to the different light regimes contrasts with the results of earlier work with barramundi larvae (Pearce 1991). He reported that during the rotifer feeding stage (2–10 days old), larval growth was progressively faster under conditions of 8, 16 and 24 hours light each day. The effect was less pronounced during the brine shrimp feeding stage (8–20 days old), when larvae in 8 hours light grew more slowly than in 16 and 24 hours light, but growth rates in 16 and 24 hours light were the same.

Thus, although continuous light may be advantageous for growth of larval barramundi during their first eight days, as shown by Pearce (1991), the experiments conducted in this study show that it becomes less important thereafter and has no effect after metamorphosis (which is at 11 mm TL, or about 20–25 days of age). These findings are similar to those for several other species reported upon, which also tend to show a diminishing effect of continuous light with age (see Table 5.3). It appears that extended periods of light during larval rearing are generally beneficial for growth, but not necessarily survival. After metamorphosis, however, it seems that growth of juvenile fishes is usually the same in both normal and extended light regimes.

Table 5.3. Literature reports on the effect of extended light periods on the growth and survival of larvae and juveniles of several species of fin fishes. (Salmonid fishes are not included, because with these anadromous species the effect of photoperiod interacts with the state of physiological development and time of year.)

Species	Developmental Stage	Treatment	Response	Reference
Siganus guttatus	First-feeding larvae, 0–7 days	Continuous light vs natural light/dark cycle	Growth rate and survival better in continuous light.	Duray and Kohno 1988
Lates calcarifer	Larvae, 2–20 days	12, 18 and 24 hour light periods	Days 2–10 (rotifer feeding) — growth significantly better in 24 hours light, survival not significantly different. Days 8–20 (*Artemia* feeding) — growth significantly better in 16 and 24 hour light, survival not significantly different.	Pearce 1991
Dicentrarchus labrax	Larvae, 0–30 days	12, 18 and 24 hour light periods	Maximum growth at 18 hours light, maximum survival at 12 hours light.	Barahona-Fernandes 1979
Dicentrarchus labrax	Larvae, 1–30 days	9 and 24 hour light periods	Growth significantly better in 24 hour light; survival and swim bladder inflation rate significantly better in 9 hour light	Cerqueira and Chatain 1991
Nautichthys oculofasciatus	Larvae, 0–38 days	13 and 24 hour light periods; simulated natural photoperiod (dawn/dusk plus low intensity light at night).	Survival in 24 hours light and simulated natural photoperiod significantly better than in 13L/11D.	Marliave 1977

Species	Developmental Stage	Treatment	Response	Reference
Sparus aurata	Larvae, 0–70 days	12 and 24 hour light periods	Survival and growth best in continuous light.	Tandler and Helps 1985
Solea solea	Larvae and juveniles to 3 months old	12, 18 and 24 hour light periods	Larvae — survival not significantly different, growth better in 18 and 24 hours light. Juveniles — survival and growth not significantly different.	Fuchs 1978
Mylio macrocephalus	Larvae and juveniles 0–108 days	13, 18 and 24 hour light periods	Larvae — growth best under continuous light. Juveniles — growth not significantly different.	Kiyono and Hirano 1981
Sebastes diploproa	Juveniles, 30–55 mm standard length.	12 and 16 hour light periods.	Growth rates better in 16 hour light.	Boehlert 1981

CHAPTER 6. OPTIMAL SIZE FOR WEANING BARRAMUNDI FRY ONTO ARTIFICIAL DIETS

6.1 INTRODUCTION

The transition from live food to an artificial diet is an important period in the rearing of fish larvae or fry. In general terms, the transition should be accomplished as early as possible, because of the costs involved in live food production, while at the same time avoiding excessive mortalities due to the fish being unable to adapt to the artificial food. In this context, failure to adapt can be due to either a physiological problem (the food is unpalatable or nutritionally unsuitable), a behavioural problem (the fish require live prey to stimulate a feeding response) or a physical problem (the food is rejected because of particle size or texture).

Literature reports have indicated that weaning barramundi onto inert foods (formulated dry diets, or minced fish, prawns or meat) is generally commenced when the fish are about 20 days old, or 10–12 mm total length (TL) (Awang 1987, MacKinnon 1987a, Maneewong 1987, Tucker *et al.* 1988, Walford and Lam 1993). At this length, barramundi have not completed metamorphosis (scales are first apparent when the fish are 11 mm TL). Nonê of these reports have indicated the degree of mortality associated with weaning barramundi at this size.

Studies detailed in Chapter 3 have shown that barramundi undergo an abrupt change in feeding habit at about 16–18 mm TL. At sizes less than 17 mm TL the fish are roving zooplanktivores. When larger than 17 mm TL they change rapidly to a lurking predator mode of feeding, eating small insect larvae in addition to zooplankton. The change in diet is associated with changes in pigmentation and feeding behaviour. I hypothesised that survival of fry through the weaning period would be enhanced if weaning is commenced once the fish have adopted the lurking predator mode of feeding. Consequently, an experiment was conducted to determine the ease of weaning and survival of barramundi fry at various sizes between 12 and 20 mm TL when fed a formulated dry diet.

6.2 MATERIALS AND METHODS

6.2.1 *Fish and facilities*

The fish were obtained from hormone-induced spawnings of captive broodstock held at the Northern Fisheries Centre, Cairns. The larvae were reared in salt water until approximately 10 mm TL, when they were transferred to fresh water and transported to the Freshwater Fisheries and Aquaculture Centre, Walkamin, where they were maintained in 1500 L tanks at 26–30°C. Prior to the commencement of each trial, the fish were fed live *Artemia* nauplii and zooplankton harvested from freshwater ponds.

The experiment was conducted indoors in steep-sided, conical-based tanks, 800 mm deep and of 130 L capacity (Fig. 6.1). Water was exchanged at the rate of 4 L/min via a central stand pipe which was screened to prevent the escape of fish. The experimental temperature was maintained at 28.0 ± 0.5°C. Air was supplied via an air-stone in the bottom of each tank. Photoperiod was 12L/12D. Artificial feed was delivered by automatic feeders positioned over each tank.

6.2.2 *Weaning procedure*

Literature reports (Awang 1987, Maneewong 1987) have indicated that a gradual transition from live to formulated feeds is appropriate for weaning barramundi. In the absence of information to the contrary, it was assumed that a gradual transition would be the procedure adopted for the size-at-weaning trial. Nevertheless, a preliminary trial, conducted primarily to test facilities and procedures, was undertaken with the secondary aim of determining whether a gradual or sudden transition was a more appropriate procedure for weaning barramundi fry onto dry diets. Because it was undertaken as a preliminary trial, replication of the sudden transition treatment was not considered a priority.

The gradual transition treatment (T1) was frozen zooplankton (mixed taxa, obtained from a freshwater pond) offered in conjunction with a dry diet (Skretting® 0.3-0.6 mm salmon starter diet) for 5 days; during the 5th to 7th days of the trial the volume and frequency of zooplankton offered was decreased; and from the 8th day the zooplankton was discontinued and the dry diet only dispensed for a further 5 days. The sudden transition treatment (T2) was the dry diet only fed from day 1 and maintained for 12 days. T1 was replicated 4 times, but T2 was not replicated (for reasons as explained above). Each tank was stocked with 105 fish, TL 15.8 ± 0.7 mm, at the start of the experiment. Feed was offered every hour for 12 hours (darkness one hour after the last feed). The tanks were cleaned each morning by scrubbing the walls, turning off the air and water and siphoning out the settled debris. Dead fish were collected and counted. At Day 8 five fish were sampled from each tank and dissected to determine whether they had commenced feeding on the dry diet. The fish were counted and measured when the trial was terminated. Any difference between the number of missing fish at the end of the trial and the number of dead fish recorded during the trial was assumed to be attributable to cannibalism.

6.2.3 *Size and weaning success*

The experimental design consisted of 4 treatments replicated 4 times. The treatments were fish of different initial TLs (mean ± s.d.) as follows (CV = coefficient of variation);

T1: 12.8 ± 0.94 mm, $n = 53$, CV = 7.3%

T2: 13.6 ± 1.36 mm, $n = 71$, CV = 10.0%

T3: 16.7 ± 1.42 mm, $n = 50$, CV = 8.5%

T4: 19.6±1.42 mm, n = 60, CV = 7.3%

Because of a shortage of facilities, it was not possible to test the four treatments simultaneously on the same batch of fish. Thus, four trials (corresponding to the four treatments) were conducted over a two-month period, using fish from different spawnings.

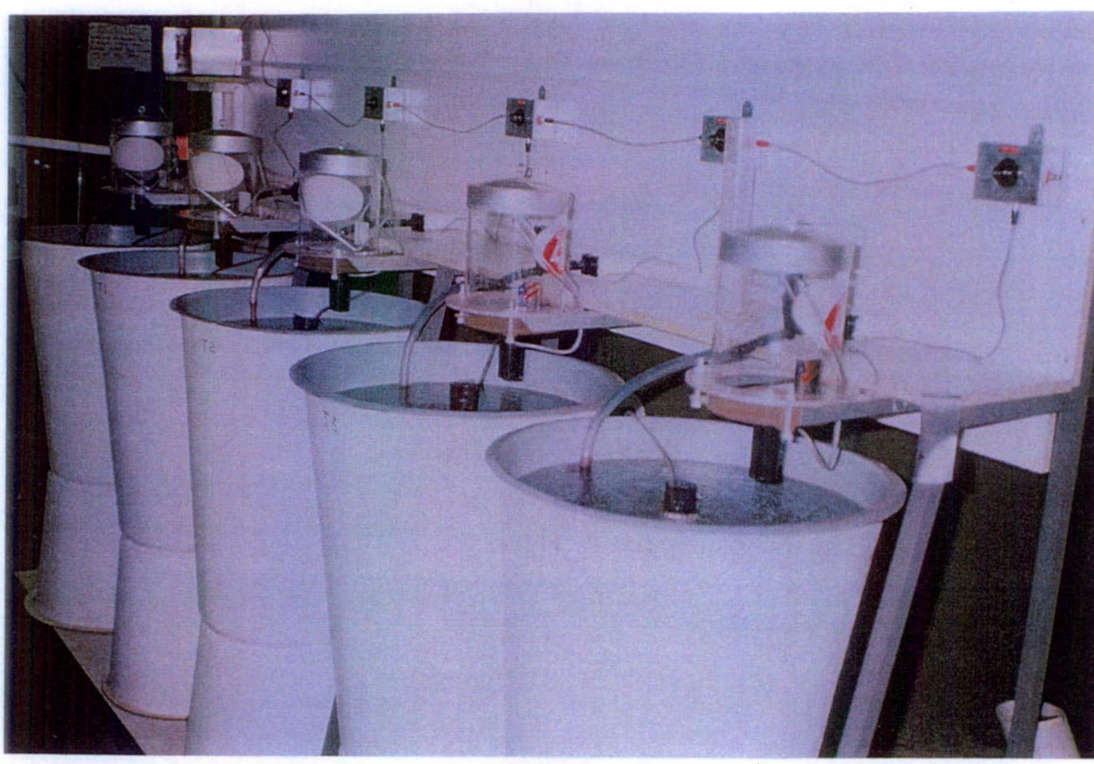

Figure 6.1 Experimental arrangement, showing the conical rearing containers, automatic feed dispensers and electronic control boxes for each dispenser.

At the start of each trial, 200 healthy fish were placed into each of the four replicate tanks and maintained on zooplankton for one day. Any mortalities during this period, assumed to be due to handling, were replaced. Thereafter, feeding of zooplankton was stopped and the dry diet (Skretting 0.3–0.6 mm salmon starter diet) was dispensed every hour for 12 hours (darkness one hour after the last feed). At each feeding, 5 g of food was dispensed, which was in excess of the requirements of all sizes of fish. The trials were conducted for 10 days, which was sufficient time for all surviving fish to be fully adapted to the dry diet. Tank maintenance and data collection were as above.

Survival data were analysed by analysis of variance (arcsin transformation of percentage data), and means compared using the LSD(T) test (Siegel 1992). Non-linear regression analysis was used to determine the relationship between percentage survival through the weaning period and initial size. Total lengths were transformed to equivalent wet weights (WWt) using the equation derived in Chapter 3 ($WWt = 0.028TL^{2.82}$) and daily growth rates (G), expressed as percentages, determined from the equation

$$G = (\ln WWt_f - \ln WWt_i)/(t_f - t_i)$$

where WWt_i and WWt_f are the initial and final wet weight of fry and $(t_f - t_i)$ is the duration of the experiment in days.

6.3 RESULTS

6.3.1 *Weaning procedure*

The survival and growth of barramundi fry in the gradual and sudden transition weaning regimes are listed in Table 6.1. Survival was similar in all tanks, with the exception of one replicate in the gradual transition treatment, in which cannibalism accounted for most losses. The percentage of surviving fish which adapted to the artificial diet varied from 90–100% in both treatments. In the sudden transition treatment it was apparent from the behaviour and distended stomachs of the fish that feeding on the artificial diet was established by Days 2–3. In contrast, in the gradual transition treatment only 8 of the 20 fish sampled at Day 8 had started feeding on the artificial diet. Growth was markedly superior in the sudden transition treatment, in which the fry were three times heavier than those in the gradual transition treatment at the end of the 12 day trial.

6.3.2 *Size and weaning success*

The percentage survival and the percentage of fish which died due to starvation and cannibalism are listed in Table 6.2. Analysis of variance of the percentage survival data indicated that there was a significant difference ($P < 0.001$) in survival between the treatments. Least significant difference tests showed that the treatments separated into two groups with significantly different ($P < 0.05$) mean survivals, namely T4 and

Table 6.1 Percentage of feeding and non-feeding barramundi, and final lengths (TL, mm) and wet weights (WWt, mg) of the feeders, after 12 days exposure to either a gradual or a sudden transition from frozen zooplankton to an artificial diet. The figures are means ± standard deviations.

Treatment	Survivors				Mortalities
	Feeders (%)	Final TL (mm)	Final WWt (mg)	Non-feeders (%)	(%)
Gradual transition					
Rep. 1	49	21.4 ± 3.4	170 ± 88	1	50
Rep. 2	88	20.4 ± 3.5	149 ± 70	2	10
Rep. 3	90	19.6 ± 4.3	140 ± 95	10	0
Rep. 4	93	19.8 ± 2.5	133 ± 50	7	0
Sudden transition					
Rep. 1	85	30.2 ± 5.0	448 ± 201	0	15

T3 being different from T2 and T1. The relationship between TL and percentage survival was described by the equation

$$y = 96.85 - 155981(0.540^{L}) \quad (r^2 = 0.88, P < 0.01)$$

where y = percentage survival and L = TL in mm (Figure 6.2).

Survival within treatments was uniform, with the exception of the fourth replicate in T2, wherein the survival was 79% compared with 46%, 51% and 55% for the other replicates (Figure 6.2). There was no obvious explanation for the higher survival in this one replicate. Daily growth rates varied between 11.1% and 17.7% in the four treatments (Table 6.3), with the lowest rates being for T1 and T4 (the smallest and largest fish, respectively) and the highest for T2 and T3 (the intermediate sized fish).

The initiation of feeding was evident by day 3 in all treatments. At this stage visual observation indicated that about 5–10% of the fry had started feeding in T1, about 30–40% in T2, and the majority in T3 and T4. Fish in each tank congregated as a loose school near the water surface awaiting food, but once it was dispensed they fed throughout the water column.

Weaker, non-feeding fish were darkly pigmented. In T1, there was a marked increase in mortality of these fish during days 5–7, peaking at day 6. There was little mortality thereafter, as virtually all remaining fish were feeding. There was no similar peak in mortality of non-feeding fish in the other treatments. Cannibalism was significantly different ($P < 0.001$) in T2 (26%) to that recorded in the other treatments (2–7%).

The aeration systems were effective in lifting the sinking food particles back into suspension, thus giving the fry longer exposure to the food at each feeding period than would have been the case if the food was allowed to fall through the water column to the base of the tanks. A slimy, organic film developed each day on the walls of the tanks, as a consequence of the high organic load. The circular current swept food particles onto the film, where they attached, effectively becoming unavailable to the fry. This effect became more pronounced as the film redeveloped after each daily cleaning.

Table 6.2 Survival and mortalities due to starvation and cannibalism (expressed as percentages) of barramundi fry of various sizes during 10 day weaning trials. The figures are means ± standard errors.

Treatment	Initial TL (mm)	% Survival	% Mortalities due to Starvation	% Mortalities due to Cannibalism
T1	12.8 ± 0.9	38.9 ± 5.8	59.8 ± 5.4	2.8 ± 2.6
T2	13.6 ± 1.4	57.6 ± 14.6	16.8 ± 11.0	25.6 ± 7.7
T3	16.7 ± 1.4	97.0 ± 3.8	0.8 ± 0.8	2.3 ± 3.8
T4	19.6 ± 1.4	92.3 ± 4.0	1.0 ± 0.6	6.9 ± 4.6

Table 6.3 Initial and final total lengths (TL, mm) and computed initial and final wet weights (WWt, mg) and daily growth rates (expressed as a percentage based on weight) of barramundi fry of various sizes during 10 day weaning trials. The figures are means ± standard errors.

Treatment	Initial TL (mm)	Final TL (mm)	Initial WWt (mg)	Final WWt (mg)	Daily growth rate (%)
T1	12.8 ± 0.9	19.9 ± 0.5	36 ± 9	128 ± 10	12.7 ± 0.7
T2	13.6 ± 1.4	25.1 ± 1.3	42 ± 10	250 ± 36	17.7 ± 1.4
T3	16.7 ± 1.4	31.3 ± 0.3	80 ± 18	463 ± 12	17.6 ± 0.3
T4	19.6 ± 1.4	29.1 ± 0.2	123 ± 20	375 ± 9	11.1 ± 0.2

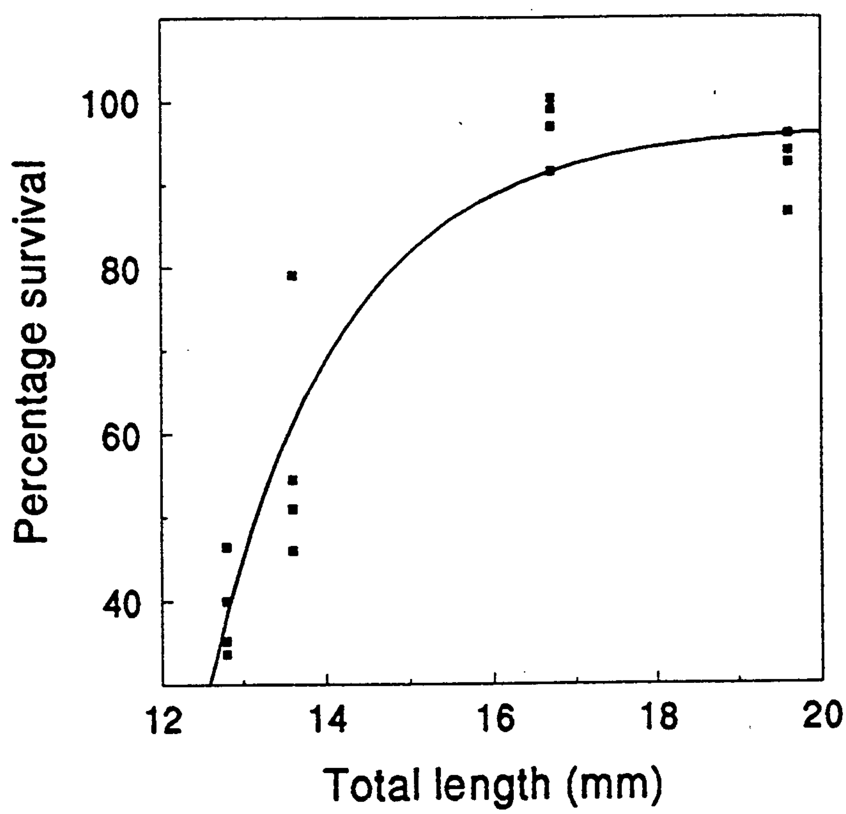

Figure 6.2 Percentage survival through weaning onto dry diets for four different size-groups of barramundi fry.

6.4 DISCUSSION

There are a variety of protocols that can be used for weaning fish onto artificial diets, but generally a gradual transition from live food to formulated feed or minced fish has been advocated for barramundi (Awang 1987, Maneewong1987). However, the appropriateness of this procedure was not vindicated by the results of the weaning procedure trial. Growth was markedly superior in the fish exposed to the sudden transition to artificial food, although the percentage of fish which were successfully weaned did not differ between the sudden and gradual transition treatments. In the sudden transition treatment, in which there was no alternative food source, the fish had commenced feeding on the artificial diet within 2–3 days of starting the trial. In contrast, in the gradual transition treatment the fish apparently consumed the frozen zooplankton in preference to the artificial food when the two were supplied simultaneously. This observation was supported by the low percentage (40%) of fish feeding on the day after the zooplankton feeding was discontinued. That is, weaning effectively commenced only after the zooplankton feeding was stopped and the artificial diet was the sole food being offered.

The experimental design used in the size and weaning success trial was compromised by the fact that the treatments were tested on batches of fish from different spawnings. It is a common phenomenon in fish culture that larval fish originating from different parents, or even from the same parents but different spawning events, may exhibit different levels of fitness (often referred to as 'larval quality'). Quality is usually appraised in terms of vigour (swimming strength, ability to orientate, response to stimuli) and health (absence of mortalities, disease and deformities). To avoid 'experimental noise' due to variation in fitness, researchers generally aim to test treatments on high-quality fish from the same spawning. In the present trial, it was not possible to use fish from the same spawning because of a shortage of experimental tanks and automatic feeders. Nevertheless, I am confident that the survivals determined in the different treatments faithfully reflect the influence of initial size, because of the consistency within treatments and similar survivals shown in other weaning events which were not part of this experiment.

The survival curve for barramundi fry presented in Figure 6.2 indicates that greater than 90% survival during weaning onto dry diets can be expected when using fish larger than 16.2 mm TL at the initiation of weaning. The shape of the curve confirmed that survival through the weaning period is enhanced if weaning is delayed until the fish have adopted the lurking predator mode of feeding. This is also supported by the increasing rapidity with initial size with which feeding on the dry diet was commenced by the majority of fish. The asymptotic shape of the curve indicates that there is negligible gain in survival if weaning is initiated with fish larger than about 16–17 mm TL. The results of this experiment are similar to those of Verreth and van Tongeren (1989) who showed that larvae of the African catfish, *Clarias gariepinus*, could be successfully adapted onto dry diets after two days feeding on live foods, and that delaying weaning beyond that stage did not improve survival.

Cannibalism was more severe in T2 than in the other treatments. This was possibly due to the comparatively wide size range of fish in this treatment at the start of the trial (coefficient of variation for T2 was 10%, while for T1, T3 and T4 it was 7.3%, 8.5% and 7.2%, respectively). Moreover, the rapid adaptation of fish in T3 and T4 onto the dry diet would have militated against the establishment of cannibalism.

The daily growth rates of 11–18% for fish in the size and weaning success trial are comparable with the 13–15% reported in Chapter 3 for fry reared intensively in the laboratory on live zooplankton. This indicates that with respect to growth the fish were not compromised by the change to, or nutrient composition of, the dry diet. The comparatively slow growth rate of the largest fish (T4) could not be explained by any obvious physical factors; one possible explanation is that it was a consequence of this batch of fish being genetically less fit than the others.

Rearing of barramundi fry on live foods is a costly process, as it requires major commitment of both manpower and facilities. Hence, hatchery operators generally attempt to wean the fry onto artificial diets as soon as practicable, which is at about 10 mm TL (Awang 1987, MacKinnon 1987a, Maneewong 1987, Tucker *et al.* 1988). This study has shown, however, that survival through the weaning period is considerably enhanced if the initiation of weaning is delayed until the fry are 16–17 mm TL. Hatchery operators need to interpret these results from a commercial perspective. However, it is apparent that the economic advantage of survival of say 90% with 16–17 mm TL fry would outweigh the reduced rearing costs associated with weaning fish at 13 mm TL and concomitant survival of say 50%. Indeed, a steady-state comparison of hatcheries producing 530 000 weaned fingerlings per season indicates that there is an overall benefit of approximately $70 000 per annum in weaning at 17 mm compared with 13 mm TL (Appendix 1). The disparity would be even greater if weaning is initiated when the fry are 10 mm TL.

CHAPTER 7. USE OF CIRCULUS SPACING ON SCALES TO DISCRIMINATE BETWEEN HATCHERY AND WILD BARRAMUNDI

7.1 INTRODUCTION

Stocking hatchery-reared fingerling fish is a widely practised management technique for enhancing recreational fisheries' stocks and restoring populations of endangered species. Determining the efficacy of such programs depends on recognising the hatchery fish after stocking. In the past, fingerling fish have been marked by mutilation or excision of fins, by insertion of micro-wire tags, and with chemicals (for instance, stains, dyes and tetracycline antibiotics) applied either externally or internally (Wydoski and Emery 1983). These techniques are subject to error from mortality and tag loss and are quite labour intensive.

As early as 1913 it was realized that growth patterns on scales could be used to identify races of salmonids (Gilbert 1913, referenced in Henry 1961). Subsequent studies showed that the rearing environment (analogous to the racial history) effectively induced an innate tag, as a consequence of the high correlation between environmental conditions, growth rates of fish and scale growth (Henry 1961, Major *et al.* 1972, Doyle *et al.* 1987). The features on the scales reflecting growth rates are circuli, which are fine ridges laid down in a circular pattern around the centre or focus of scales (Jearld 1983). Later developments led to methods for distinguishing between populations of various salmonid species by analysing patterns of scale shape and circulus spacing using discriminant function techniques (Amos *et al.* 1963, Cook and Lord 1978). These methods have recently been shown to be capable of distinguishing hatchery and wild striped bass *Morone saxatilis* stocks, and even assigning cultured fish to their hatchery of origin (Ross and Pickard 1990). The development of specific software applications has facilitated use of the methods, which require extremely sensitive measurements of shape and distance.

The aim of the present study was to determine if patterns of circulus spacing on barramundi scales could be used to distinguish hatchery and wild fish. If valid, this discrimination technique would be of considerable benefit to the management of barramundi in areas where hatchery fish are released to supplement wild stocks.

7.2 MATERIALS AND METHODS

7.2.1 *Scale origin and preparation*

The wild fish were obtained from the Cairns region (17°S, 146°E) northern Queensland. A scale set was obtained from approximately 120 fish collected between August 1979 and May 1980. The total lengths (TL) of the fish ranged from 150 to 450 mm.

The hatchery fish were bred at the Northern Fisheries Centre (NFC), Cairns, in November 1988. Larval rearing was conducted in salt-water tanks at the NFC. When 20 days old (spawning = Day 0, hatching = Day 1), the fish (about 10 mm TL) were transferred to freshwater at the Walkamin Research Station. They were reared indoors until approximately 20 mm TL, then stocked into a pond. Scale samples were collected from 100 fish (range 120– 220 mm TL) in March 1989.

Scales from both wild and hatchery fish were taken from the region immediately posterior to the pectoral fin. Scales were washed in water and 4–6 non-regenerated scales from each fish were mounted between glass microscope slides for examination and analysis.

7.2.2 *Data acquisition*

Data were acquired using the Optical Pattern Recognition System (OPRS) software, microcomputer, video camera and monitor, frame grabber, digitiser pad and mouse (Biosonics 1989). The video camera was attached to a microscope (*2 objective). The frame grabber transformed video images of scales to digital images, which were displayed on the monitor. Linear distance on the image display was calibrated with a stage micrometer. All measurements were obtained using the mouse and menu-driven software.

The cleanest scale from each set was chosen for image analysis. Measurements were conducted along two 1 mm lines (Fig. 7.1), creating two data sets. The first set, herein termed *straight-line data*, was derived along a line located adjacent to the radius, where the circuli curve and are most widely spaced. The other, herein termed *45° reference-line data*, was from a line at an angle of 45° to the first, or at approximately 90° to the anterior-posterior axis. Because the distance from the centre of the focus to the first complete circulus varied between scales, the origin of the measuring line was located just inside the first circulus. The program automatically located the circuli by differences in luminance, although manual control was necessary to correctly mark circuli with inadequate contrast between light and dark zones, such as at overlapping or broken circuli.

7.2.3 *Circulus formation and fish length*

To examine the relationship among circulus formation, TL and age, 10 scales from each of 43 hatchery-reared fish were examined. Circuli were counted on each scale from the focus to the margin adjacent to the radius. The fish were 25 to 38 days old and from 11 to 40 mm TL (scales had not formed in fish smaller than 11.0 mm TL). Because of the small size of these fish, it was not possible to take the scales from a confined area on the body.

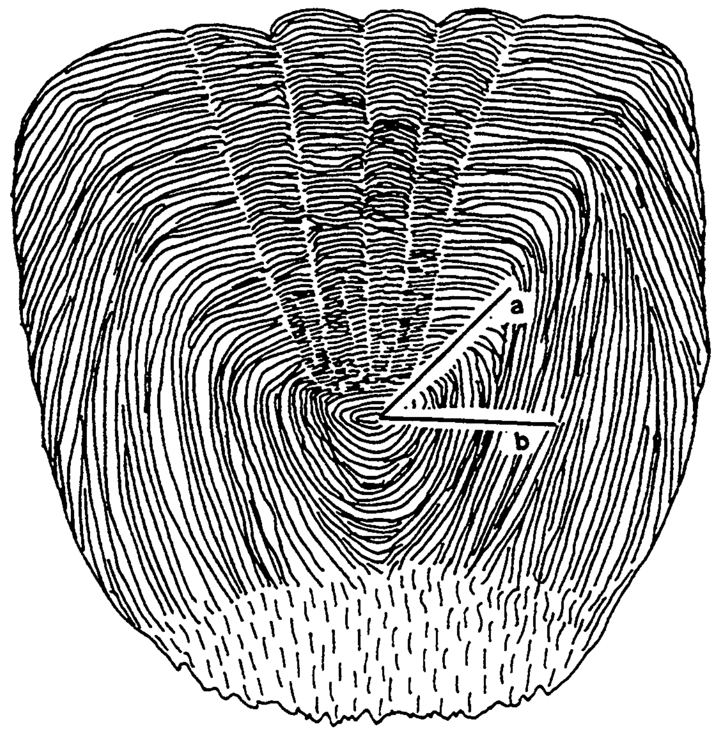

Figure 7.1. Diagrammatic representation of a barramundi scale. Straight-line data were derived along line *a* and 45° reference-line data along line *b*.

7.2.4 *Data analyses*

Discriminant function analysis developed by Cook (1982) and Cook and Guthrie (1987), and available as part of the OPRS software package (Biosonics 1989), was conducted to separate hatchery from wild barramundi. The procedure uses a jackknifing technique, termed 'leaving-one-out' by Lachenbruch (1967, 1975), to calculate the discriminant function. This iterative procedure uses the total data set as the training and test sets and produces better estimates with less bias than other commonly used techniques. Discriminant function coefficients calculated for all variables in each type of analysis were the basis for selecting variables to enter into the discriminant function analysis. Results of the analysis were displayed as stock separation estimates in an error rate classification table.

The relationship between the number of circuli, TL and age was evaluated using regression analysis. The number of circuli used in the analysis was taken as the mean of the number of circuli on the 10 scales taken from each fish.

7.3 RESULTS

Initial screening of the scales from the wild fish showed that scales from fish larger than approximately 350 mm TL were unreadable with the equipment available. The thickness of the scales and the irregularly positioned pigment spots interfered with light transmittance, effectively disrupting the pattern of circulus spacing. After rejection of the unreadable scales, analysis was conducted on a set of 88 0+ wild fish (150–350 mm TL). The set comprised of 68 fish from the 1978–79 spawning season and 20 fish from the 1979–80 spawning season. Determining the position of circuli on scales from wild fish smaller than 350 mm TL and from all the hatchery fish (120–220 mm TL) was readily accomplished.

The basic measures analysed for these scales were various sets of single, double and triple inter-circulus distances. For the paired circulus measures, distances between circuli were combined two at a time beginning at the centre of the scale (e.g. pair 1 = (1+2), pair 2 = (3+4), and so on). With triplet measures, the circulus distances were combined three at a time, from the centre.

Separation of hatchery from wild barramundi scales was examined using combinations of variables that displayed high negative or positive unstandardised discriminant coefficients. The following combinations of circulus distances were tested.

Straight-line data

A/ Singles 13, 14, 15, 16, 18

B/ Pairs (7-8), (9-10), (13-14), (15-16)

C/ Triplets (1-3), (4-6), (7-9), (13-15), (16-18)

45° Reference-line data

D/ Pairs (1-2), (9-10), (13-14)

E/ Pairs (1-2), (3-4), (9-10), (13-14)

F/ Triplets (1-3), (7-9), (13-15), (16-18)

The straight-line luminance data provided better separation than did the 45° reference-line data, particularly when using triplets and pairs (Table 7.1). The straight-line data were also easier to derive, as the positioning of the line, adjacent to the radius, was simple, and the spacing of the circuli was clearer and with less overlapping than along the 45° reference-line.

Using the triplet combination, 83% of the hatchery scales and 82% of the wild scales were correctly classified (17 and 18% errors, respectively). The paired circulus combinations were separated with 83% correct for hatchery scales and 77% correct for wild scales. The classification rates for the 45° reference-line luminance data ranged from 74–77% of hatchery scales classified correctly to 74–76% of the wild scales correctly scored.

Table 7.1. Percentage of wild and hatchery barramundi correctly identified using data derived from the spacing of circuli on scales and linear discriminant analysis.

Test	**Wild** (*n* = 88)	**Hatchery** (*n* = 100)	**Composite**
Straight-line data			
Test A (Singles)	68	68	68
Test B (Pairs)	77	83	80
Test C (Triplets)	82	83	83
45° reference-line data			
Test D (Pairs)	74	77	76
Test E (Pairs)	75	77	76
Test F (Triplets)	76	74	75

Multiple linear regression analysis revealed that 94% of the variation in the number of circuli was attributable to TL ($P < 0.001$, partial $r^2 = 0.9413$). Adding age to the equation did not improve its descriptive power ($P > 0.05$, partial $r^2 = 0.0047$). The relationship between the number of circuli and TL was described by the linear equation

$$y = -2.64 + 0.63x,$$

where y = number of circuli and x = TL (mm) (Fig. 7.2).

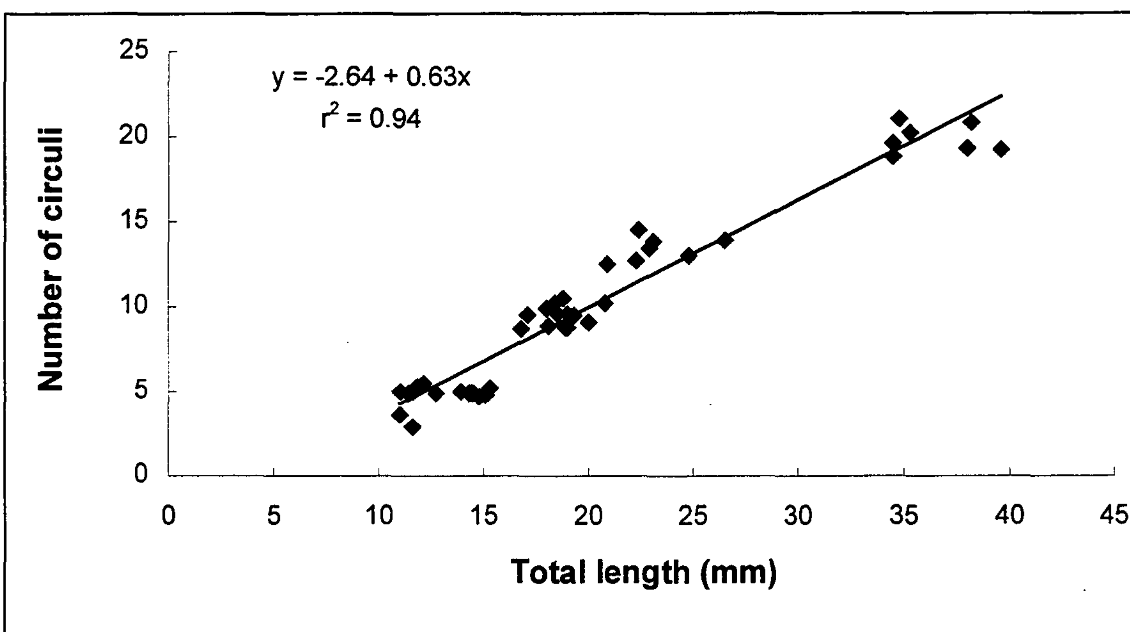

Figure 7.2. Relationship between the number of circuli on scales and TL of 43 fingerling barramundi 25–38 days old. Each datum is the mean of 10 scales.

7.4 DISCUSSION

The separation of hatchery from wild scales achieved with these data (83% for hatchery and 82% for wild) was encouraging, especially since only luminance line data were used. This compares favourably with other stock discrimination investigations using the same technique. For instance, Schwartzberg and Fryer (1993) separated natural and hatchery stocks of chinook salmon *Oncorhynchus tshawytscha* with 80–94% accuracy; Cook and Lord (1978) separated three riverine stocks of sockeye salmon *Oncorhynchus nerka* with 64–80% accuracy; Whaley (1988) separated a lake strain and riverine strain of brown trout *Salmo trutta* reared under virtually identical hatchery conditions with 94–98% accuracy. Ross and Pickard (1990) used scale shape information analysed as Fourier transformations in addition to variables associated with circulus spacing to obtain 87–91% accuracy in separating yearling hatchery and wild striped bass stocks.

It is noteworthy that certain of the circulus distances repeatedly occurred in the sets of variables tested. For example, circuli 13 and 14 occurred in all of the 6 variable sets analysed and circuli 15 and 16 were found in four of the six. Circuli 13–16 would have been formed when the fish were 25–30 mm TL, which would have coincided with the first 5–10 days after the hatchery fish were transferred from the laboratory to the ponds. This suggests that hatchery fish might have been incidentally marked during that portion of the rearing procedure.

Initial formation of scales in barramundi occurred at about 11 mm TL, and thereafter circulus formation was related to length. In walleye *Stizostedion vitreum* squamation occurs at about 20 mm TL (Glenn and Mathias 1985), while for three species of salmonids it occurs at 37–42 mm TL (Bilton 1988). The comparatively small size at which barramundi forms scales, coupled with the fact that juveniles can be reared over a wide range of temperatures (at least 24–32°C), indicates that barramundi may be particularly amenable to batch marking of scales.

One obvious problem with barramundi, however, is that circuli on scales from fish larger than 350 mm TL could not be read with the present methods. Only minimal scale preparation — washing in water — was used in this study. Whaley (1991) has shown that the use of pancreatin (an enzyme that breaks down protein substances adhering to scale surfaces) in conjunction with sonic agitators increased the percentage of readable scales in a rainbow trout *Oncorhynchus mykiss* population from 4% for uncleaned scales to 70% for cleaned scales. Similar techniques may also improve the readability of scales from barramundi larger than 350 mm TL, although it is likely that the absolute thickness of barramundi scales will remain a problem for analytical techniques dependent on light transmittance close to the focus of scales. These older scales are thicker through the focus than towards the margins, and this made it difficult to focus the microscope on all circuli at once. Other workers have avoided similar problems with salmonids by making impressions of scales on preheated plastic or acetate slides and reading intercirculus measures directly from the impressions (e.g. Lear and Misra 1978, Fisher and Pearcy 1990).

The difficulty experienced in reading circuli on scales from large barramundi does not apply to similar-sized fishes with smaller scales, such as salmonids. In Australia, species with suitably small scales include silver perch *Bidyanus bidyanus,* golden perch *Macquaria ambigua,* Australian bass *Macquaria novemaculeata,* sand whiting *Sillago ciliata* and dusky flathead *Platycephalus fuscus*. All of these species are currently used to enhance recreational fisheries, and patterns of circulus spacing are being employed for monitoring stocking success (Willett 1994a, 1995, 1996; Palmer 1995)

If it proved possible to induce permanent tags in the patterning of the circuli on scales of hatchery-reared fish, many of the questions associated with the assessment of stocking programs (in particular, management techniques, estimates of post-stocking survivals and population sizes) could be more readily answered. Overseas researchers have shown that manipulating the rearing environment can induce specific marks on fish scales and otoliths. For instance, Skurdal and Andersen (1985) have demonstrated that scales of brown trout can be marked by varying the temperature during egg incubation and rearing of the alevins, and Volk *et al.* (1987) showed that sudden temperature shifts can induce banding on otoliths of juvenile chum salmon *Oncorhynchus keta*.

Similar research has recently been taken up in Australia as part of the Queensland Government's recreational fisheries enhancement programs. Willett (1993) showed that pond-reared silver perch from three hatcheries in south-east Queensland could be distinguished with accuracies in the range 56–63%. Removing the geographically intermediate hatchery increased the accuracy to 85–91%, leading him to conclude that better discrimination is achieved if the environmental differences (in this case, temperatures) are well defined. He followed this up with a laboratory-based study (Willett 1994b) in which he grew silver perch fry for 4 weeks at temperatures of 20°, 25° and 30°C. Classification of the scales based on circuli spacing was 54–58%, 58–72%, and 94–96% accurate at each of the respective temperatures. The reduced classification accuracy at 20°C and 25°C was a consequence of similar growth rates, which in turn resulted in some overlap of lengths of fish from the two treatments. He speculated that simultaneously altering other variables (for example, feed ration) to induce disparate growth rates would further enhance the ability to batch-mark hatchery-reared fishes (Willett 1994b).

Since the present study was restricted to investigation of scale circulus pattern analysis as a means of discriminating hatchery from wild barramundi, only early growth zones were examined. Other workers have shown that analysis of the shapes of whole otoliths or scales can also be used to differentiate stocks or genetic races (Jarvis *et al.* 1978, Riley and Margraf 1983, Bird *et al.* 1986, de Pontual and Prouzet 1987, Maceina and Murphy 1989, Campana and Casselman 1993, Margraf and Riley 1993). In Australia, the barramundi resource consists of a series of genetically distinct stocks (Shaklee and Salini 1985, Russell and Garrett 1988, Keenan 1994). Scale or otolith shape analysis (also a function within OPRS software) may provide an alternative means of separating these stocks or delineating the composition of other multi-stock assemblages.

In summary, hatchery-reared and wild barramundi could be distinguished by the pattern of circulus spacing near the origin of the scales. The technique, which relies on luminance data generated from the light and dark zones created by the circuli, was suitable for barramundi less than 350 mm TL. However, with the technique employed herein, scales from fish larger than 350 mm TL were too thick and pigmented to provide reliable luminance data. Consequently, analysis of circulus patterns on scales has only limited applicability in assessment of fisheries stocked with barramundi, unless methods are developed to clean larger scales and thus improve readability. On the other hand, it is an extremely versatile tool for separating mixed stocks of species that have small scales as adults.

CHAPTER 8 SYNTHESIS

8.1 INTRODUCTION

This study evaluated the proposal to introduce the Nile perch, *Lates niloticus*, from Africa, and examined aspects of rearing juvenile barramundi, *Lates calcarifer*, for aquaculture and enhancement of recreational fisheries in Australia. It is now appropriate to review the results in terms of their overall contribution in the following fields:

i. management of the barramundi resource, aquaculture development and recreational fisheries — because of the applied nature of the study, most emphasis is placed on this area;

ii. knowledge of the biology of barramundi; and

iii. theoretical aspects of fish conservation, fish propagation and fisheries enhancement.

Finally, within the context of the above, some future areas for research are identified. Much of the following discussion is summarised in Table 8.1, in which the outcomes of the study are tabulated within the generic headings of management, biology, theory and future research.

8.2 NILE PERCH STUDIES (CHAPTER 2)

The introduction of Nile perch into Lake Victoria has had dramatic consequences for the ecology of the lake and its riparian inhabitants. Prior to the introduction, Lake Victoria (and Lake Malawi) contained the most species-rich lacustrine fish faunas in the world. As a result of the introduction, over 200 of the original 300+ (possibly 400+, see Seehausen and Witte 1995) endemic haplochromine species have disappeared from Lake Victoria in less than a decade (Witte *et al.* 1992a). Goldschmidt *et al.* (1993) described this as the largest extinction event amongst vertebrates this century. The massive reduction in biodiversity has led to international campaigns to conserve the native fishes of Lake Victoria (Ribbink 1987, Bruton 1990, Kaufman 1992), but such activities cannot realistically be expected to contribute to maintenance of biodiversity within the lake because of the scale of the problem and the difficulties associated with reintroductions (Craig 1992).

While the impact on the fish fauna was to a large extent predicted by early opponents of the introduction (e.g. Fryer 1960, Anderson 1961), there have been flow-on effects which were not foreseen (Witte *et al.* 1995). Diets and feeding behaviour of piscivorous birds (Goudswaard and Wanink 1993, Wanink and Goudswaard 1994) and otters (Kruuk and Goudswaard 1990) have changed. Drastic shifts in the food web within the lake have taken place and continue to do so (Ligtvoet and Witte 1991), and may in fact be linked to apparent water quality changes, particularly increasing algal blooms (Goldschmidt *et al.* 1993, Ochumba 1995). The fish harvest from the lake has increased 3–4 times since the establishment of the Nile perch (Ligtvoet and Witte 1991), but it is currently not clear if it is sustainable at the present level. Indeed, recently available information indicates that the yield may already be decreasing (see Tables 2.4 and 2.5, also Kunhongania and Chitamwebwa 1995). Pitcher and Bundy (1995) analysed historical catch-per-unit-effort data for the lake and concluded that if the fishery continues to expand in the 1990s as it did in the 1980s it will collapse as a consequence of overfishing rather than ecosystem instability. Obviously, research on trends in the fishery and the continuing shifts in trophic relationships is required to fully assess the impact of the introduction.

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Socio-economic changes have also been far-reaching, although the pros and cons of these are still being debated. The early views on disruption to riparian communities and deforestation associated with fuel-wood demand for curing Nile perch (Barel *et al.* 1985) were countered by others arguing the economic benefits of development of the fishery (Acere 1988), which are considerable. Reynolds *et al.* (1995) calculated that the net economic benefit to the riparian states of the post-Nile perch fishery was US$200 million up to 1989, and that it would accrue to a billion dollars by the early 2000s. On the other hand, Harris *et al.* (1995) pointed out that much of the foreign exchange earnings actually went to foreign companies supplying the gear and infrastructure to support the fishery. In addition, they identified many other negative impacts at the household, community and national levels.

Extinction of fish species in lakes as a result of the introduction of exotic fish has been recorded in other areas, such as Lake Kyoga in Uganda, Lake Lanao in the Philippines, Lake Atitlan in Guatamala, Lake Luhondo in Ruanda, and Gatun Lake in Panama (see review in Witte *et al.* 1992a). In Australia, local exterminations of fishes (and possibly crayfish) have occurred in Lake Eacham as a consequence of the introduction of non-endemic Australian fishes (Barlow *et al.* 1987). In Lake Pedder, Tasmania, two indigenous galaxiid fishes have been extirpated as a result of interaction with brown trout (*Salmo trutta*) and the introduced *Galaxias brevipennis* (S. Chilcott, Inland Fisheries Commission, Tasmania, pers. comm. 1996). These scenarios, while not as dramatic as the Lake Victoria situation, further illustrate the possible consequences of introductions of fish to exotic environments.

From a management perspective, the approach taken in this study of marrying the biology of a species proposed for introduction with information on the ecology of recipient environments enabled determination of the probable range and possible impacts of the Nile perch had it been released in Australia. Based on the information presented, it is unequivocal that the release of Nile perch in Australia posed an unacceptable risk to aquatic ecosystems over a large part of the country. The alternative approach of enhancing recreational fisheries through the breeding and release of fingerling barramundi was clearly a better management option.

8.3 REARING JUVENILE BARRAMUNDI (CHAPTERS 3–6)

The trials on feeding behaviour and diet of barramundi fry undertaken in this study have provided valuable new information relevant to hatchery management, as well as contributing to knowledge on the biology of the species. In management terms, the most important result was the identification of the change in diet and behaviour at about 17 mm TL, as this change had implications for pond-rearing and weaning procedures. To reiterate, barramundi smaller than 17 mm TL are zooplanktivores, exhibit no escape response, and rest on the substrate at night. Larger than 17 mm TL, they consume larval insects in addition to zooplankton, and they have a well-developed escape response. The vulnerability of fish smaller than 17 mm TL to predation by dragonfly nymphs was demonstrated in aquarium trials, as was the ability of fish larger than 17 mm TL to avoid predation. The responses of both size groups were mirrored in pond-rearing trials, in which fish stocked at 10 mm TL showed very poor survival (14%), while those stocked at 20 mm TL exhibited 99% survival.

The feeding behaviour of barramundi fry also had practical implications for weaning onto dry diets. The change in feeding behaviour at about 17 mm TL indicated that weaning may be more successful if initiated at that stage, rather than with fish of approximately 10 mm TL (the usual size for initiation of weaning reported in the literature). Trials conclusively demonstrated an asymptotic response in weaning success with respect to size, with the asymptote at 16–17 mm TL.

The information on diet and behaviour of the barramundi fry, and its practical application in hatchery management, highlight the importance of basic biological studies for determining appropriate techniques for aquaculture of a particular species. In the present case, the susceptibility of barramundi fry to predation by dragonfly larvae meant that traditional freshwater pond rearing techniques did not work. Research was required to elucidate the necessary modifications to rearing procedures to successfully marry the biology of the species with the ecology of the rearing environment. Similarly, species-specific larval production requirements have been shown in the aquaculture of other species. For instance, initial swim-bladder inflation in Australian bass *Macquaria novemaculeata* is about 70% under conditions of darkness, salinity greater than 25 ppt and low to zero aeration, but only approximately 15% in a 12:12 light:dark photoperiod; inflation is also reduced at salinity of 10 ppt and under high aeration (Battaglene and Talbot 1990). Murray cod *Maccullochella peeli* ovulates within a very narrow, defined period of time after hormonal injection, and fertilisation must then be accomplished within 1–2 hours of ovulation (Rowland 1988). These examples further illustrate the need for basic and species-specific research in aquaculture, particularly for species for which little biological information is available.

The gut evacuation rates for barramundi fry indicate a functional relationship between feeding strategy and prey availability. The small, obligate zooplanktivores have a fast rate of passage under conditions of continuous feeding, but a comparatively slow rate when not feeding (i.e. they are numbers maximisers). Larger fry, at a size capable of eating larval insects, have a more constant rate of gut passage whether feeding continuously or on single meals (i.e. they are energy maximisers). It would be beneficial to extend the gut passage and energetics studies to larger fish, as this would facilitate definition of appropriate feeding frequencies for barramundi being reared on pelleted diets.

It was also interesting that extending the photoperiod for barramundi fry resulted in increased food intake, but that it did not increase growth rate. A review of the literature showed that extending the photoperiod during nursery rearing of fry (i.e. fish which have metamorphosed) usually has no effect on growth rate (although for larval fish prior to metamorphosis it often does increase growth rate). The increased food intake at dusk is of particular significance for farming: barramundi farmers have observed that juvenile barramundi exhibit a more vigorous feeding response at dusk, and consequently feeding at dusk is now the normal procedure at most production facilities. Furthermore, it is possible that juvenile barramundi may assimilate food more efficiently at night when the fish have discontinued feeding (slower gut passage rate) and are comparatively inactive (at least at the fry stage). It has been shown that the South American fish *Piaractus brachypomus* grows faster and converts food more efficiently when fed at night, compared with feeding during the daytime or over 24 hours (Baras *et al.* 1996). The different performance was proposed as being a result of either variable energy assimilation at different periods of the day or a decrease in energy expenditure when food was given at night, possibly due to the correspondence between the nocturnal feeding schedule and the activity rhythm pattern of *P. brachypomus*. Studies have shown that feeding schedule significantly influences growth patterns and food conversion rates in many species of fishes (see review by Boujard and Leatherland 1992). These examples, and the information generated on barramundi in the present study, emphasise the need for fish culturists to optimise on-farm management procedures in accordance with the particular biological properties of the species being farmed.

It should be noted that during the course of this study other researchers within Australia were investigating methods of improving larval rearing procedures for barramundi (Palmer *et al.* 1992, Rimmer 1996). The technique of intensive larval rearing in indoor hatcheries followed by a freshwater fry production stage is now of minor importance. Nowadays, the majority of barramundi fingerlings produced in Australia are grown extensively in brackishwater (about 18–25 ppt salinity) larval rearing ponds. The ponds are stocked with 1–2 day old larvae, and harvested 20–25 days later at which time the fry are about 25–35 mm TL (Rimmer 1996). The fry are then transferred to nurseries for weaning onto artificial diets prior to further grow-out, or stocked into impoundments and rivers for fisheries enhancement purposes (Russell and Rimmer 1997). The use of brackishwater larval rearing ponds has greatly reduced the costs associated with fry production, and contributed significantly to the expansion of barramundi farming in the country (Rimmer 1996).

8.4 RECREATIONAL FISHERIES ENHANCEMENT WITH BARRAMUNDI (CHAPTERS 1 AND 7)

One of the overall aims of the barramundi rearing studies undertaken by the QDPI has been to provide fish for stocking of water impoundments and rivers for enhancement of recreational fisheries. Production techniques covering controlled spawning of captive broodstock (Garrett and Connell 1991, Garrett and O'Brien 1994), larval rearing (Rimmer 1996) and juvenile rearing (this thesis) have been documented and taken up by industry. Juvenile barramundi are now available for most of the year, opening up the possibility for large-scale fishery-enhancement activities.

Stocking to enhance fisheries can be in closed systems (e.g. natural lakes, freshwater impoundments) or open systems (e.g. rivers, estuaries or the sea). In both systems, one of the fundamental questions concerning enhancement techniques is the effect of size at stocking on survival. Obviously, the larger the fish at the time of stocking the more expensive it is to produce, so management agencies are keen to stock fish at the smallest size possible while still getting satisfactory post-stocking survival. Many agencies maintain that the larger fish show better survival, which is certainly evident in investigations conducted with various species released in marine waters (e.g., Lundqvist *et al.* 1994, Yamashita *et al.* 1994, Hoff and Newman 1995, Leber 1995). On the other hand, Willett (1996) showed that post-stocking survival of silver perch stocked at 34 mm or 50 mm TL in two Queensland impoundments was the same.

Even in cases where larger fish show better survival, there is still a trade-off between post-stocking survival and cost which needs to be assessed in determining the optimum size for release (Hume and Parkinson 1988).

An assessment of the effect of size of barramundi at release on post-stocking survival was conducted in Copperlode Dam, north Queensland, as an ancillary project to the present study. Size groups were distinguished by stocking at different times. Fry 10 mm TL at stocking showed zero survival, due to predation by schools of rainbowfish *Melanotaenia splendida* which was observed at the time of stocking. However, fish 20 mm TL (too large to be consumed by rainbowfish) showed 80–90% survival when monitored 6–12 months after stocking (A. Hogan, Freshwater Fisheries and Aquaculture Centre, Walkamin, pers. comm. 1993).

Further studies are now being undertaken on stocking of barramundi in an open system, the Johnstone River, in north Queensland. The aims are to determine the optimal stocking strategy with respect to size and release site, and whether stocked barramundi enhances the recreational fishery (Russell 1995). The tagging system being used is micro-wire tags injected into the cheek musculature, which has been shown to be the most suitable technique for physically marking multiple batches of barramundi (Russell and Hales 1992). Analyses of data for three years of stocking indicated that the size of fish at stocking (30–40 mm TL and 50–60 mm TL) did not affect survival (Russell and Rimmer 1997). Furthermore, estuarine, freshwater and upper tidal habitats all appear to be suitable locations for stocking, although more data are required to determine if any one site is superior (Russell and Rimmer 1997).

The use of circulus spacing as an innate tag to distinguish different batches or stocks of fish proved reliable for barramundi, as it has for many other species (see Chapter 7). Its application with barramundi is, however, limited to fish smaller than 350 mm TL, as beyond that size the scales are too thick and pigmented to be reliably read using light transmittance techniques. In view of this finding, it would be beneficial to evaluate the use of pancreatin for cleaning barramundi scales. This was not done in the present study, as Australian quarantine authorities currently prohibit the import of pancreatin because of its porcine origin (D. Willett, Southern Fisheries Centre, Deception Bay, pers. comm. 1996).

On the other hand, the scale-circulus pattern-analysis technique has proved particularly useful for a range of other Australian freshwater and marine fish which have small scales as adults. These include silver perch *Bidyanus bidyanus*, golden perch *Macquaria ambigua* (Willett 1995), summer whiting (*Sillago ciliata*) and dusky flathead (*Platycephalus fuscus*) (D. Willett, Southern Fisheries Centre, Deception Bay, pers. comm. 1996).

In conclusion, enhancement of recreational fisheries in closed systems will continue to be an important part of fisheries management. In open systems, it is likely to become more prominent given the initial success of stockings with barramundi in northern Queensland (Russell 1995, Russell and Rimmer 1997), and the increasing use of marine stocking overseas. Tagging of fish to facilitate monitoring will continue to be based on a variety of techniques (innate tags, internal or external physical tags) depending on the species and information requirements of the program.

Table 8.1 Tabulation of the contribution of the major elements of this thesis to management, biology of barramundi and ecological theory, and aspects of future research requirements.

Management	Biology of barramundi	Ecological theory	Future research
Chapters 1–2			
Nile perch in Lake Victoria provides a stark example of ecological impacts resulting from introduction of exotic fish; multitude of flow-on effects; socio-economics complex		Graphic example of predation being the primary agent responsible for extinction of a large number of species and reduction in faunal biodiversity	Sustainability of fishery in Lake Victoria – will biomass reduction result in a significant decrease in Nile perch catches?
			Preservation and rehabilitation of endangered species – maintenance of biodiversity
			Description of socio-economic impacts – lessons for other areas
Examination of Nile perch biology plus information on proposed recipient environments in Australia enables prediction of probable range and possible impacts			
Chapters 3–6			
Feeding behaviour and diet influences the optimum size for weaning barramundi onto artificial diets	Feeding behaviour and diet of juvenile barramundi (10–50 mm TL) changes with size, with a major switch from roving zooplanktivore to lurking predator at 16–18 mm TL		For new species, feeding behaviour and diet (under laboratory, pond and/or natural conditions) should be an integral part of aquaculture research

Management of dragonfly predation necessary for freshwater pond rearing – need to stock fish at 16 mm TL and/or minimise period between filling and stocking pond.	Feeding behaviour indicated that escape response not developed until approx 16 mm TL; this confirmed in trials testing susceptibility to predation by dragonfly nymphs	Innate behavioural response of barramundi (marine spawner) and sooty grunter (freshwater spawner) to dragonfly nymphs – lack of recognition and recognition respectively of a predator	Documentation of the impact of dragonfly predation in pond rearing of freshwater fish larvae, and development of control methods
	Gut passage rate changes with feed availability and size of fry	Barramundi fry shift from numbers maximisers to energy maximisers as they grow – inter-relationship between biology and environment	Define optimum frequency for feeding grow-out barramundi, including potential for compensatory growth (i.e. increased food consumption and growth rate following a period of no feeding)
Prolonging daylength increases food intake of juvenile barramundi, but growth rate is not increased		Literature review indicates that increasing daylength increases growth rates of larval fish but not juvenile fish	
Diel feeding patterns have implication for management of feeding regimes on farms, and possibly lighting in indoor production systems	Diel feeding patterns — juvenile barramundi feed throughout the day, peak intake in the evening, cease feeding in darkness		Define diurnal activity rhythms for all size ranges of farmed barramundi Is food assimilation efficiency increased at night in barramundi?
Chapter 7 Circulus spacing provides a mechanism for recognising separate stocks of barramundi released into common water bodies — but technique presently only applicable to barramundi smaller than 350 mm TL	Pattern of circulus spacing near the origin of scales is determined by the natal rearing environment		Influence of size at stocking on survival Contribution of stocked fish to fishery Carrying capacity of recipient waters

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APPENDIX 1

Economic comparison of weaning at 13 mm and 17 mm TL

A steady-state economic comparison was conducted to determine the difference in costs associated with weaning at 13 mm and 17 mm T.L. A steady-state comparison is an analytical technique used in economics to determine the cost differential associated with two or more different management techniques. It takes into account only the costs which differ, thus it is not an estimate of the total costs associated with the technique (in the present case, it is not an estimate of the total costs of fingerling production).

For the purposes of the comparison, it was assumed that both management regimes (ie., 13 mm and 17 mm weaning) produced a total of 530 000 fingerlings, average size 31 mm TL, from five batches of fish (ie., 106 000 fish per run) during one breeding season. All biological estimates relating to growth rates, feeding rates and mortalities were derived from data in Chapters 3 and 6. Operational costs (feed, labour and enrichment diets) and fixed costs (capital items and depreciation rates) were obtained from equipment suppliers and information provided by commercial barramundi farmers.

A list of the costs associated with each weaning regime is given in Table A1. Summation of costs indicates that there is a considerable economic advantage in delaying weaning until the barramundi fry are about 17 mm TL. Under the scenario assumed in this comparison, there is a saving of approximately $70 000 per annum in initiating weaning at 17 mm rather than 13 mm TL.

Table A1. An estimate of costs associated with producing 530 000 barramundi per season, with fry being weaned onto dry, formulated diets at either 13 mm or 17 mm TL.

Item	**Costs ($) associated with weaning at**	
	13 mm TL	**17 mm TL**
Variable Costs		
Mortalities[1]	84 211	9 755
Live feed - *Artemia*		
Enrichment diets for *Artemia*	0	1 000
Dry diet (weaning)	3 525	3 045
Dry diet (post-weaning)	482	0
Casual labour @ $11/hr	0	413
Other	0	0
Fixed Costs		
Administration	0	0
Electricity	0	0
Sundry fuel & oil	0	0
Permanent hired labour	0	0
Repairs and maintenance	0	0
Depreciation	247	56
Other	0	0
Operating Costs	**88 465**	**19 419**
plus interest on capital base (8%)	169	39
plus interest on working capital base (8%)	0	0
plus owner/operator costs	0	0
Adjusted operating costs	**88 634**	**19 458**
Net difference		**69 176**

[1] Mortality data

- 13 mm fish, 55% mortality through weaning. Therefore, (530 000 x 100/45) = 1 177 778 fry required at initiation of weaning. Fish are valued at 1c/mm. Assuming fish die at 13 mm (ie., they do not initiate feeding on the dry diet), value of mortalities = (1 177 778 x 55/100 x 0.13) = $84 211.

- 17mm fish, 8% mortality through weaning plus 2.5% mortality during 13-17 mm *Artemia* feeding stage.

  Therefore (530 000 x 100/92) = 576 087 fry required at initiation of weaning.

  Assuming fish die at 17 mm, value of mortalities through weaning = (576 087 x 8/100 x 0.17) = $7835.

At the start of the 13-17 mm growing period, required (576 087 x 100/97.5) = 590 828. Assuming fish die at 13 mm, value of mortalities = (590 828 x 2.5/100 x 0.13) = \$1920.

Therefore, total value of mortalities = \$7835 + \$1920 = \$9755

APPENDIX 2

Published Papers

This Appendix contains copies of four papers which have been published based on results reported in this thesis. The papers are as follows.

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

Barlow, C.G. and Gregg, B.A. 1991. Use of circuli spacing on scales to discriminate hatchery and wild barramundi, *Lates calcarifer* (Bloch). *Aquaculture and Fisheries Management* **22**: 491-498.

Barlow, C.G., Rodgers, L.J., Palmer, P.J. and Longhurst, C.J. 1993. Feeding habits of hatchery-reared barramundi *Lates calcarifer* (Bloch) fry. *Aquaculture* **109**: 131-144.

Barlow, C.G., Pearce, M.G., Rodgers, L.J. and Clayton, P. 1995. Effects of photoperiod on growth, survival and feeding periodity of larval and juvenile barramundi *Lates calcarifer* (Bloch). *Aquaculture* **138**: 159-168.

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