Life history, reproductive biology, habitat use and fishery status of eastern sea garfish (*Hyporhamphus australis*) and river garfish (*H. regularis ardelio*) in NSW waters

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FRDC Project No. 2001/027
March 2005

NSW Department of Primary Industries - Fisheries Final Report Series
No. 73
ISSN 1449-9967

NSW DEPARTMENT OF PRIMARY INDUSTRIES

Australian Government
Fisheries Research and Development Corporation

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Authors: John Stewart, Julian M. Hughes, Charles A. Gray & Chris Walsh

Published By: NSW Department of Primary Industries (now incorporating NSW Fisheries)

Postal Address: Cronulla Fisheries Research Centre of Excellence
PO Box 21 Cronulla NSW 2230

Internet: www.dpi.nsw.gov.au

ISSN 1449-9967

(Note: Prior to July 2004, this report series was published as the 'NSW Fisheries Final Report Series' with ISSN number 1440-3544)

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ACKNOWLEDGEMENTS

We would like to thank the large number of commercial fishers who assisted throughout this study, and we especially thank Phil & Paul Zaccagnini, Graham and Paul Pemberton, Barry & Craig Aish, Russell Massey and Paul McGarry for their continued support during the project.

Mr Chris Walsh provided expert technical assistance during the first year of the study. Marcus Miller and Paul Lokys assisted at times of need. Martine Jones and Brenden Parsons from the University of Wollongong assisted in much of the research done in Lake Illawarra. Messers Glenn Campbell and Bruce Urquhart provided expert casual assistance at regional fishermen's co-operatives.

We thank Dave Barker and Darren Reynolds for assistance in keeping garfish in the aquaria facilities at the Cronulla Fisheries Centre.

Dr Kevin Rowling provided useful comments on drafts of this report.

NON-TECHNICAL SUMMARY

01/027	Life history, reproductive biology, habitat use and fishery status of eastern sea garfish (*Hyporhamphus australis*) and river garfish (*H. regularis ardelio*) in NSW waters.

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OBJECTIVES:

(1) To provide new information on the biology and life history of garfish species in NSW waters, particularly the two dominant species eastern sea garfish and river garfish, including:
- reproductive biology (NSW DPI);
- time of spawning (NSW DPI);
- age at maturity (NSW DPI);
- initial estimates of growth rate (NSW DPI), and;
- key habitat requirements, particularly the role of seagrasses and other vegetated areas as juvenile nursery areas and as feeding and spawning sites for adults (University of Wollongong).

(2) To provide the research basis for a future stock assessment of eastern sea and river garfish in NSW waters, including:
- a validated ageing technique (NSW DPI);
- estimates of size, age structure and reproductive state of landed catches for both species (NSW DPI), and;
- initial assessment of environmental impacts of the fishery and possible impacts on the fishery (NSW DPI & University of Wollongong).

(3) To provide advice to the fishing industry, fishers and NSW Fisheries on the management of the garfish fishery, including recommendations for research and monitoring to assist in achieving a sustainable fishery in NSW waters (NSW DPI & University of Wollongong).

NON TECHNICAL SUMMARY:

Outcomes Achieved
The NSW DPI have achieved all of the outcomes that were proposed at the start of the study. This study has, for the first time ever, examined the biology and fisheries for garfish (Hemiramphidae) in NSW, Australia. We now have good information on the general biology, including age, growth and reproduction, of eastern sea, river and snub-nosed garfish in NSW. Collation of the reported commercial catch statistics allowed for an assessment of the trends in fishery production and to make inferences about the relative availability of these species to commercial fishers. Monitoring of the sizes and ages of garfish being landed by commercial fishers has provided baseline information from which future assessments may be based. Results to date have been well received by industry and NSW DPI fishery management. There has already been a change in the legal mesh size allowed in garfish hauling nets, as a direct result of research done in this project.

There have been major concerns over the status of garfish stocks in NSW waters since the late 1990's. These concerns stemmed from dramatic declines in commercial landings of eastern sea garfish, together with claims from fishers that the fishery was severely depleted. Reported landings

of the two other commercially exploited garfish in NSW, eastern river and snub-nosed garfish, had also declined during this period. Unfortunately, despite over a century of exploitation, little was previously known about the biology or life history of the garfish species harvested in NSW, and no research had been done on the fisheries themselves. This study aimed to address these knowledge gaps and to provide information that would lead to improved management of the resource.

The fisheries for eastern sea, river and snub-nosed garfish should be considered as three distinct fisheries within NSW. Eastern sea garfish are taken almost exclusively in the Ocean Hauling Fishery whereas river and snub-nosed garfish are taken almost exclusively within the Estuary General Fishery. The fishery for eastern sea garfish is seasonal and peaks during the summer and autumn months. The fishery is dictated by the availability of eastern sea garfish along the NSW coast. The fisheries for river and snub-nosed garfish are also seasonal and peak during the winter and spring months when they aggregate in shallow estuarine waters to spawn.

An in-depth analysis of reported commercial catch statistics indicated that the fishery for eastern sea garfish has been in serious decline. Total annual landings have declined from a peak of 280 tonnes during 1992/93 to a historical low of 21 tonnes during 2002/03. A similar decline has been observed in several indices of catch per unit of effort (CPUE). The best index of CPUE is suggested to be the weight of eastern sea garfish reported per day of fishing using the garfish hauling net. This index is only available since 1997 and was at a low of 45kg/day during 2002/03. Reported total commercial landings of river and snub-nosed garfish in NSW have also declined since the late 1990's, however this decline was associated with a decline in the number of active fishers. The recommended index of CPUE of weight of garfish reported per day of fishing using the garfish bullringing net does not show a decline during this period.

Garfish growth rates were determined using sectioned otoliths to estimate age. None of the garfish species in NSW had been aged previously and validated ageing protocols were therefore developed. Validation was done using several methods: (i) marking captive, wild caught, sea and river garfish with vital stains (tetracycline and alizarin) and periodically examining their otolith growth; (ii) monthly otolith marginal increment analyses; (iii) examining changes in the otolith edge status through the year and; (iv) examining the otoliths from known young-of-the-year fish. The results showed that opaque zones in otoliths of all 3 species were formed during winter/spring but did not become visible on the otolith edge until summer. This information allowed the development of a model of otolith growth and protocols for converting counts of opaque zones into age classes.

Estimates of age produced maximum ages of 4 years for eastern sea garfish and 7 years for river and snub-nosed garfish. Growth was rapid in all 3 species studied with sexual maturity being achieved after only 1 year. Females of each species grew faster and achieved larger sizes than males. Growth of sea garfish was also modelled using monthly measurements of the sizes observed in commercial landings. A cohort could be seen entering the fishery at around 20 cm fork length between May and September and could be seen to increase in size by around 1cm each month. Estimates of the von Bertalanffy growth function parameters derived using this length-based data were similar to those estimated using our age-based data.

Eastern sea, river and snub-nosed garfish were examined to describe aspects of their reproductive biology. All three species were shown to be multiple batch spawners with prolonged (up to 7 months) spawning seasons between winter and early summer. Batch fecundity estimates increased linearly with fish length. The maximum batch fecundity estimates were around 3,500 eggs for eastern sea garfish and around 2,500 eggs for river and snub-nosed garfish. Sex ratios of eastern sea garfish in commercial landings were overall close to 1:1 but were skewed towards males (1:0.81) in landings north of Sydney. Sex ratios of river and snub-nosed garfish in commercial landings were heavily skewed towards females. Males and females of each species attained sexual maturity at similar sizes and appeared capable of spawning during their first full spawning season.

Estimates of the sizes and ages in commercial landings were made for each year of the study. Eastern sea garfish were, on average, smaller in landings taken from north of Sydney each year. Eastern sea garfish were observed to recruit to the fishery generally between May and September at around 20 cm FL, and this cohort could be followed through time for at least 12 months. The largest fish were most abundant between February and April each year. The commercial fishery for eastern sea garfish during 2001/02 and 2002/03 was based almost exclusively on fish aged 1+ years (60%) and fish in their 1st year (nearly 40%) with a few fish in their 3rd year of life. The sizes of river garfish in commercial landings were consistent between years at each location sampled. This constancy is likely to have been a result of the selectivity of the fishing gears. River garfish in commercial landings ranged from less than 1 year to 7 years old with approximately 60-80% being in their 3rd and 4th years of life. The sizes of snub-nosed garfish in commercial landings varied each year of the study, and this was likely due to different fishers, using different fishing gears, being active each year of the study. Commercial landings of snub-nosed garfish during 2001/02 and 2002/03 were dominated (75%) by fish aged 1+ and 2+ years old. Landings of snub-nosed garfish during 2003/04 were notable for a lack of 1 year old fish and an increase in fish in their 4th year.

Total annual mortality rates were estimated using catch curves based on the age composition in commercial landings for each species and year studied. Estimates of natural mortality were made based on the assumption that only 5% of fish will attain their maximum age and also using an empirical relationship based on water temperature and growth rate parameters. Fishing mortality was determined by subtracting natural mortality from total mortality rates. The results indicated that annual mortality rates for eastern sea garfish were extremely high, with approximately 96% of eastern sea garfish greater than 1 year old dying each year. Estimates of mortality from fishing were up to 3.5 times greater than those estimates of natural mortality, suggesting that eastern sea garfish have been greatly over-exploited. Annual mortality rate estimates for river and snub-nosed garfish were considerably less than those for eastern sea garfish. Fishing mortality may be slightly greater than natural mortality for river and snub-nosed garfish, indicating that the fisheries are fully exploited and require monitoring.

We used estimates of growth and mortality rates with information on the reproductive biology of each species to generate preliminary stock assessments based on per recruit analyses. Sea garfish egg per recruit (EPR) and spawner biomass per recruit (SBPR) models indicated present levels of between 10 – 25% of the unexploited stock. These low levels, combined with high levels of fishing pressure and the life-history of this species (short-lived with recruitment likely to be variable and dependant upon environmental conditions) suggest that the stock of eastern sea garfish has been in danger of recruitment failure. Stocks of river and snub-nosed garfish are also heavily exploited with EPR and SBPR levels predicted to be at around 40% of unexploited levels.

Finally, the size-selection properties of several mesh sizes used in garfish hauling nets were studied. The results showed that 25 mm mesh (legally allowed under a concession) retained large numbers of juvenile eastern sea garfish. A 32 mm mesh proved too large, having very low catch rates and meshing a large proportion of the catch. A 28 mm mesh selected fish at around their size at sexual maturity and was recommended as the optimum mesh size for use in the fishery. As a direct result of this research the concession to use 25 mm mesh in garfish hauling nets has been removed.

KEYWORDS: Garfish, *Hyporhamphus*, *Arrhamphus*, biology, fishery

1. INTRODUCTION

1.1. Background

This was a joint project to be carried out by Dr Ron West at the University of Wollongong as Principal Investigator and Drs. Charles Gray and John Stewart of the NSW Department of Primary Industries (NSW DPI – now incorporating what was formally known as NSW Fisheries). The information presented in this report represents the NSW DPI component of the project.

A large number of garfish species have been reported to occur in eastern Australian waters, including eastern sea garfish (referred to simply as sea garfish throughout this report - *Hyporhamphus australis*), river garfish (*H. regularis ardelio*), southern sea garfish (*H. melanochir*), Dussumier's garfish (*H. dussumieri*), snub-nosed (or short-beaked) garfish (*Arrhamphus sclerolepis*) and robust garfish (*Hemiramphus robustus*) (Collette, 1974; Hutchins and Swainston, 1986; Kailola et al., 1993; Kuiter, 1993). Sea garfish and the sub-species of river garfish are endemic to this region and are the dominant garfish species targeted by commercial and recreational fishers in NSW waters. Sea garfish are also captured in low numbers in north-eastern Victoria and southern Queensland, while the sub-species of river garfish is also landed in eastern Victorian lakes. No reliable data exists on the contribution of the other garfish species to overall catches in NSW, although it is thought to be very small and to vary between the northern and southern regions.

Total commercial landings of garfishes from NSW waters have historically been between 250 and 300 tonnes per year (Pease and Grinberg, 1995). At these catch levels, the NSW garfish fishery has a potential value of more than $1 million per year. It is a seasonal fishery in which about 100 commercial fishers are reportedly involved (Tanner and Liggins, 1998).

Sea and river garfish are captured year round, but peaks in landings generally occur during spring and summer. The fisheries for sea and river garfish are seasonal and it is possible that they target pre-spawning aggregations of fish. Sea garfish are primarily caught from January to May by ocean hauling along the central and southern NSW beaches. River garfish are landed between May and November, mainly by bullringing in large estuaries, such as the Clarence River, Wallis Lake, Tuggerah Lakes, Lake Illawarra and St. Georges Basin. In the past decade, both the domestic and export markets for NSW garfish has grown steadily and resulted in improvements in market prices for these main species. Anecdotal evidence and studies on similar species in other states suggest that garfishes may have key habitat requirements that make them particularly vulnerable to impacts in inshore and estuarine areas. For example:

- many of the garfish species feed in seagrass areas and some directly on seagrass leaves;
- southern sea garfish lay eggs on seagrass leaves (and possibly on macroalgae fronds) in sheltered estuarine and inshore areas;
- river garfish are predominantly restricted to estuaries and rely on seagrass areas as spawning and feeding sites; and,
- several garfish species are found in the seagrass beds as juveniles, but are often captured in low numbers due to selective sampling methods.

In NSW, fishing for garfish is presently managed through a combination of gear restrictions and closures (both area and seasonal). However, there is very little information available on which to base these management strategies, as there have been no previous studies of garfish, or the garfish fishery, in NSW waters. This project will provide data that will be of direct benefit in managing the harvesting of this species.

1.2. Need

There are now major concerns over the status of the garfish species in NSW waters, particularly the state of the populations of the two main exploited species. For example, landings of river garfish from NSW estuaries peaked at around 140 tonnes in 1974/75 and have steadily declined since that period. In the past decade, on average less than 30t per year of this species have been caught. In addition, there has been a sudden and dramatic decline in the catches of sea garfish in the last decade, from 280t in 1992/93 to only 44t in 1999/2000.

Unfortunately, despite more than a century of exploitation, little is known about the biology, life history, or habitat requirements of NSW garfish species, and no research had been done on the fishery itself. With the dramatic decline in catches and the concern about the degradation of key estuarine habitats, there was an urgent need to do research on garfishes in NSW waters, particularly on the two exploited species, sea garfish and river garfish.

In this joint project carried out by the University of Wollongong and NSW DPI, we propose to address this research gap, by providing information on the biology and life history of these two NSW species of garfish, and to make recommendations that will help to achieve sustainability of this medium sized yet lucrative fishery.

1.3. Objectives

Responsibility for achieving the projects objectives were divided between the NSW DPI and the University of Wollongong (UOW).

(1) To provide new information on the biology and life history of garfish species in NSW waters, particularly the two dominant species eastern sea garfish and river garfish, including:
- reproductive biology (NSW DPI);
- time of spawning (NSW DPI);
- age at maturity (NSW DPI);
- initial estimates of growth rate (NSW DPI), and;
- key habitat requirements, particularly the role of seagrasses and other vegetated areas as juvenile nursery areas and as feeding and spawning sites for adults (University of Wollongong).

(2) To provide the research basis for a future stock assessment of eastern sea and river garfish in NSW waters, including:
- a validated ageing technique (NSW DPI);
- estimates of size, age structure and reproductive state of landed catches for both species (NSW DPI), and;
- initial assessment of environmental impacts of the fishery and possible impacts on the fishery (NSW DPI & University of Wollongong).

(3) To provide advice to the fishing industry, fishers and NSW Fisheries on the management of the garfish fishery, including recommendations for research and monitoring to assist in achieving a sustainable fishery in NSW waters (NSW DPI & University of Wollongong).

2. THE GARFISH FISHERIES IN NEW SOUTH WALES

John Stewart & Julian Hughes

SUMMARY

The commercial fisheries for garfish in NSW are described in terms of the species targeted and the gears used to catch them. Commercial fishers' compulsory monthly catch return data are analysed to describe temporal and spatial patterns in landings of sea, river and snub-nosed garfish. These catch return data are also used to calculate indices of catch per unit effort (CPUE) that may be indicative of changes in the relative abundance of garfish available to the commercial fisheries in NSW. Port-based monitoring of the sizes of garfish being landed by commercial fishers was used to provide baseline information that will be used in future assessments of the garfish fisheries in NSW. Relationships between various morphological measurements and body weight are determined, for the first time, to aid in future assessments.

The fishery for sea garfish in NSW is mainly a part of the Ocean Hauling Fishery and uses garfish hauling nets to target fish. These garfish hauling nets can be used either from boats or the shore, although the vast majority of fishers are currently boat-based. The fishery is distinctly seasonal and varies from between December and May on the south coast of NSW and between March and June with a few winter/spring catches on the north coast of NSW. Reported annual commercial landings have declined from around 280 tonnes in the early 1990's to a historical low of only 21 tonnes in 2002/03. The number of active participants in the fishery has also declined markedly during this period, but so too have several indices of CPUE. Our recommended index of CPUE (reported catch per day using garfish hauling nets) can only be calculated since 1997 and shows yearly declines from 80kg per day in 1997/98 to a low of only 45kg per day during 2002/03. Preliminary data from 2003/04 suggests some improvement. Much of this decline appears to have been due to very low landings on the south and far north coasts of NSW (towards the extremities of this species reported distribution).

Sea garfish in commercial landings generally ranged between 20 to 30 cm fork length (FL), however the distribution of these sizes varied between areas and years. Sea garfish landed from north of Sydney were consistently, on average, smaller than those landed from south of Sydney. Sea garfish were observed to recruit to the fishery generally between May and September at around 20 cm FL, and this cohort could be followed through time for at least 12 months. The largest fish were most abundant in catches between February and April each year.

The fisheries for river and snub-nosed garfish are almost exclusively within the Estuary General Fishery in NSW and use bullringing nets to target fish. There is a ban on the taking of 'garfish' in estuaries by commercial fishers during December and January each year. The commercial fishery for river garfish is relatively small (18 tonnes during 2002/03), distinctly seasonal and peaks during the winter months. There are few commercially important estuaries for river garfish in NSW, with Lake Illawarra, Wallis Lake, Tuggerah Lakes and the Port Stephens estuary being the only estuaries of significance. Commercial landings of river garfish have declined each year since 1999/00, and this appears to have been due to a reduction in effort. Our recommended index of CPUE of catch per day of fishing using the method of bullringing showed a slight increase in 2000/01 and has since been stable since at around 30 to 35kg per day.

The sizes of river garfish observed in commercial landings were consistent between years in the estuaries sampled. River garfish caught using the method of bullringing were generally between 18

and 27 cm FL. River garfish landed from Wallis Lake were, on average, smaller than those landed from Lake Illawarra.

The commercial fishery for snub-nosed garfish is small, averaging less than 10 tonnes each year since 1997/98. Nearly all (>90%) of the entire reported commercial catch in NSW is from the Clarence River. There are currently few dedicated participants in the fishery, with only 7 fishers reporting more than 90% of the total catch during 2002/03. The fishery is seasonal and peaks during the winter months. Reported landings and CPUE have been stable since 1999/00. A major problem in the commercial catch reporting system was identified, with most snub-nosed garfish caught in the Clarence River being reported as river garfish. Snub-nosed garfish are now to be listed as a separate species on the Estuary General Fishery catch return form.

The sizes of snub-nosed garfish landed by fishers using bullringing nets in the Clarence River ranged between 18 and 28 cm FL, and varied during each year of the study. This variation was likely due to different commercial fishers being active during different years and each using slightly different net configurations.

2.1. Introduction

There are three main species of garfish found in the waters of NSW. The eastern sea garfish (*Hyporhamphus australis*) and the river garfish (*H. regularis*) are distributed along the entire coast of NSW, whereas the snub-nose garfish (*Arrhamphus sclerolepis*) is restricted to the north of the state (Kailola et al., 1993). These three species inhabit different waters, the sea garfish is almost totally marine, the river garfish is generally confined to brackish estuarine systems, and the snub-nose garfish is mainly a freshwater fish. Two other Hemiramphids are occassionally found in commercial catches of eastern sea garfish, they are the southern sea garfish (*H. melanochir*) in the south of the state and the robust garfish (*Hemiramphus robustus*) in the northern half of the state.

These three main species of garfish are caught commercially using nets that fish the upper layers of water. There is also a recreational hook and line fishery for garfish. Prior to 1995, the fisheries in NSW were open to any licensed commercial fishers. Subsequently, in an effort to limit fishing effort, access to the ocean hauling and estuary general fisheries was capped by their declaration as restricted fisheries. At present, fishers require specific endorsements on their commercial licenses to use garfish nets. There are currently no size-limits on garfish in NSW, however historical size limits of 8.5 inches for river garfish, 10 inches for sea garfish and 9 inches for snub-nosed garfish (measured from the tip of the upper jaw to the end of the upper half of the tail) were removed sometime during the late 1960's or early 1970's. There are currently no recreational bag limits for garfish in NSW.

The status of river garfish stocks in NSW is listed as "unknown" due to a lack of information on the fishery and biology of the species. The status of snub-nosed garfish stocks is also unknown and this study aims to address some of these knowledge gaps. Sea garfish, however, have been designated as being "overfished/depleted" and a formal recovery program has been initiated under the NSW Ocean Hauling Fishery Management Strategy (OH FMS) (Appendix 3). This garfish recovery program has been designed to significantly reduce the adverse effects of fishing on the stock. Restrictions such as year-round weekend closures, the restriction of fishers to one ocean hauling region, and a change in permissible mesh size from 25 to 28mm will act to reduce fishing effort. Measures to limit the activation of latent effort are also included to ensure that harvest levels will not climb to unsustainable levels as the stock recovers.

Unfortunately, despite over a century of exploitation and recent concerns for the stocks, no research has been done on the garfish fisheries in NSW. This chapter aims to address some of these gaps by describing the methods used, reported annual landings and fishing effort, and the sizes of fish currently being harvested.

Garfish have historically been measured in several different ways, i.e. fork length or length to caudal fork (FL - Berkeley & Houde, 1978; McBride & Thurman, 2003), standard length (SL – Jones et al., 2002; Collette, 1973), from the tip of the lower jaw to the fork in the tail (NSW Fisheries historical data), and total length (TL - minimum legal sizes). Jones (1990) measured from the tip of the upper jaw to the extremity of the caudal fin, yet reported this as standard length. It is important, therefore to provide morphometric relationships for these measurements to allow comparisons between studies. Relationships between body weight and length are required for converting length data to weight data.

2.2. Materials & methods

2.2.1. NSW Fisheries catch statistics

Commercial fishers in NSW are required to submit monthly returns detailing their catch and effort (Fig. 2.1). These forms currently provide information on the areas fished (Fig. 2.2), the number of days each method of fishing was used (e.g. garfish hauling net) and the quantity of each species landed by that method during the month. These returns have been used since 1997 and provide the best information on catch and effort to date. Forms used between 1990 and 1996 did not associate species catch with days of effort or fishing method, and prior to 1990 it was only possible to determine species catch per month.

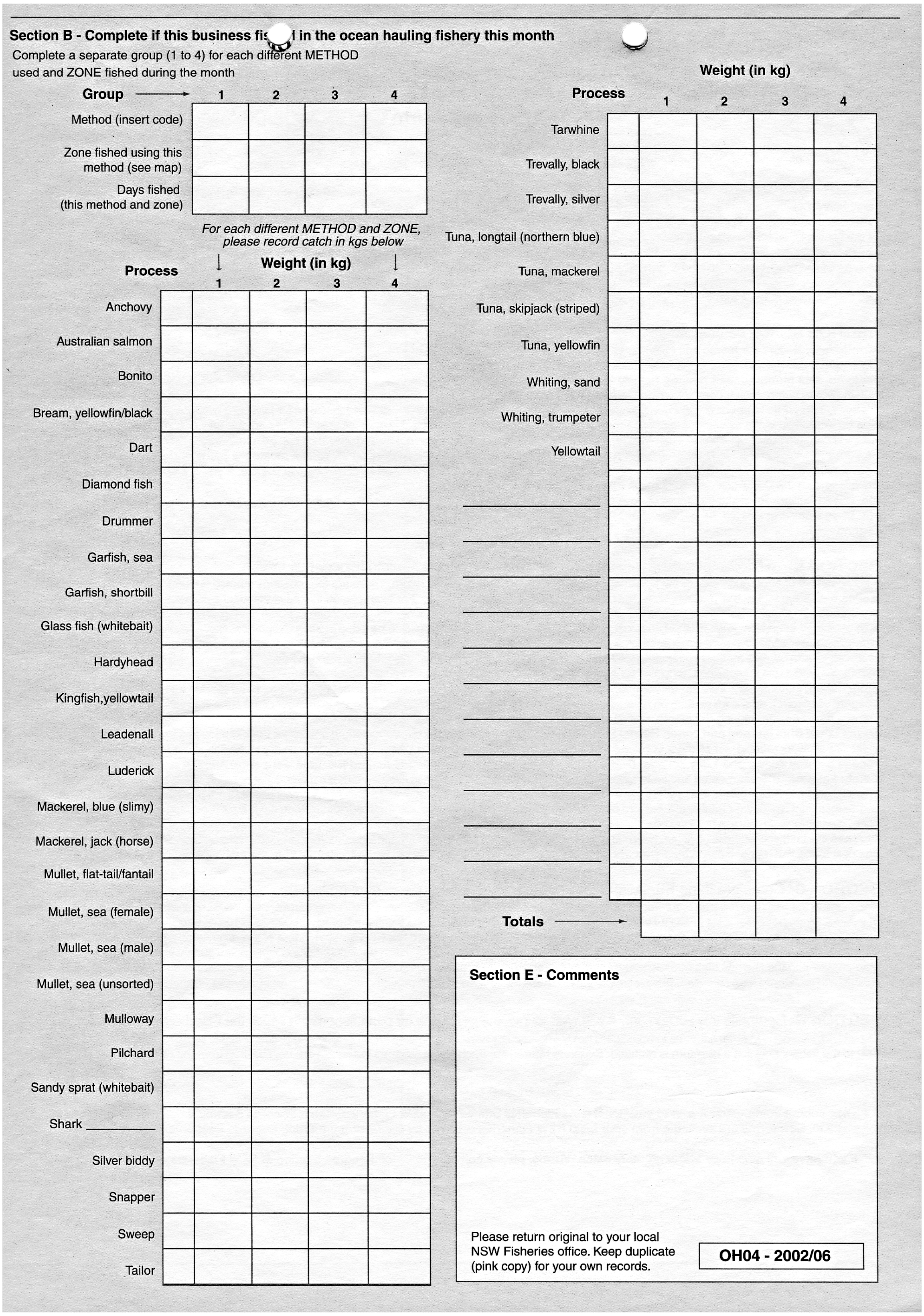
The quality of this information is difficult to ascertain but is certainly most reliable since 1997. Unfortunately, quality control and data validation within the commercial fishers catch return system of NSW DPI are often at low levels – due to a lack of resources. Misreporting, either deliberately or unintentionally, may be a problem. For example, it is common for skippers and their crew to report the same total quantities of landings on their individual catch returns, thereby multiplying the true amount taken by however many are in the crew. It is currently not possible to identify this form of misreporting without contacting every fisher. Data entry errors are also common and are not routinely identified. Many fishers also report very small quantities of each species each year (i.e. 1kg), presumably in order to demonstrate that they are active participants in the fishery. Such reporting may affect estimates of CPUE based on catch per fisher. There is also a significant time-lag between when fishing occurred and when the information is available. Currently this time lag is generally at least 6 months.

Careful examination of catch return records for sea, river and snub-nosed garfish identified many (but certainly not all) errors. These have since been corrected. The lack of quality control is concerning, however we assume a constant error rate through time, and use these catch statistics to describe temporal and spatial patterns in landings, and to make inferences about the relative abundance of garfish in NSW.

Reported landings were obtained from the August 2004 extraction of Comcatch (the commercial catch records database at NSW DPI - NSW Fisheries). Seasonal distributions of landings of sea garfish for the years 1999/00 to 2002/03 were divided into north (ocean zones 1 to 5) and south (ocean zones 6 to 10 – see Fig. 2.2) to mirror our port sampling protocols (see below). The distributions of sea garfish landings by ocean zone and river and snub-nosed garfish landings by estuary were examined for these recent years.

An index of catch per unit of effort (CPUE) was estimated for all garfish based on fishers reported catch and effort. Average catch per fisher (total reported landings divided by the number of fishers reporting each species of garfish each year) was used as an initial index of CPUE. A more refined estimate was average catch per fisher for the top 10 catchers each year. The number of fishers to take 90% of the catch each year was used to examine the distribution of effort among those fishers landing garfish.

A better estimate of CPUE may be catch per day of effort and this can be approximated from fishers catch returns after 1996/97. We chose methods that are exclusively used to target garfish and chose the primary methods of garfish hauling for sea garfish and bullringing for river garfish. Snub-nosed garfish effort was restricted to the method of bullringing from the Clarence River only.



Section B - Complete if this business fished in the ocean hauling fishery this month

Complete a separate group (1 to 4) for each different METHOD used and ZONE fished during the month

Group →	1	2	3	4
Method (insert code)				
Zone fished using this method (see map)				
Days fished (this method and zone)				

For each different METHOD and ZONE, please record catch in kgs below

	Process	Weight (in kg) 1	2	3	4
Anchovy					
Australian salmon					
Bonito					
Bream, yellowfin/black					
Dart					
Diamond fish					
Drummer					
Garfish, sea					
Garfish, shortbill					
Glass fish (whitebait)					
Hardyhead					
Kingfish,yellowtail					
Leadenall					
Luderick					
Mackerel, blue (slimy)					
Mackerel, jack (horse)					
Mullet, flat-tail/fantail					
Mullet, sea (female)					
Mullet, sea (male)					
Mullet, sea (unsorted)					
Mulloway					
Pilchard					
Sandy sprat (whitebait)					
Shark ________					
Silver biddy					
Snapper					
Sweep					
Tailor					

	Process	Weight (in kg) 1	2	3	4
Tarwhine					
Trevally, black					
Trevally, silver					
Tuna, longtail (northern blue)					
Tuna, mackerel					
Tuna, skipjack (striped)					
Tuna, yellowfin					
Whiting, sand					
Whiting, trumpeter					
Yellowtail					
________					
________					
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________					
________					
Totals →					

Section E - Comments

Please return original to your local NSW Fisheries office. Keep duplicate (pink copy) for your own records.

OH04 - 2002/06

Figure 2.1. A section of the monthly catch return form completed by fishers working in the Ocean Hauling Fishery.

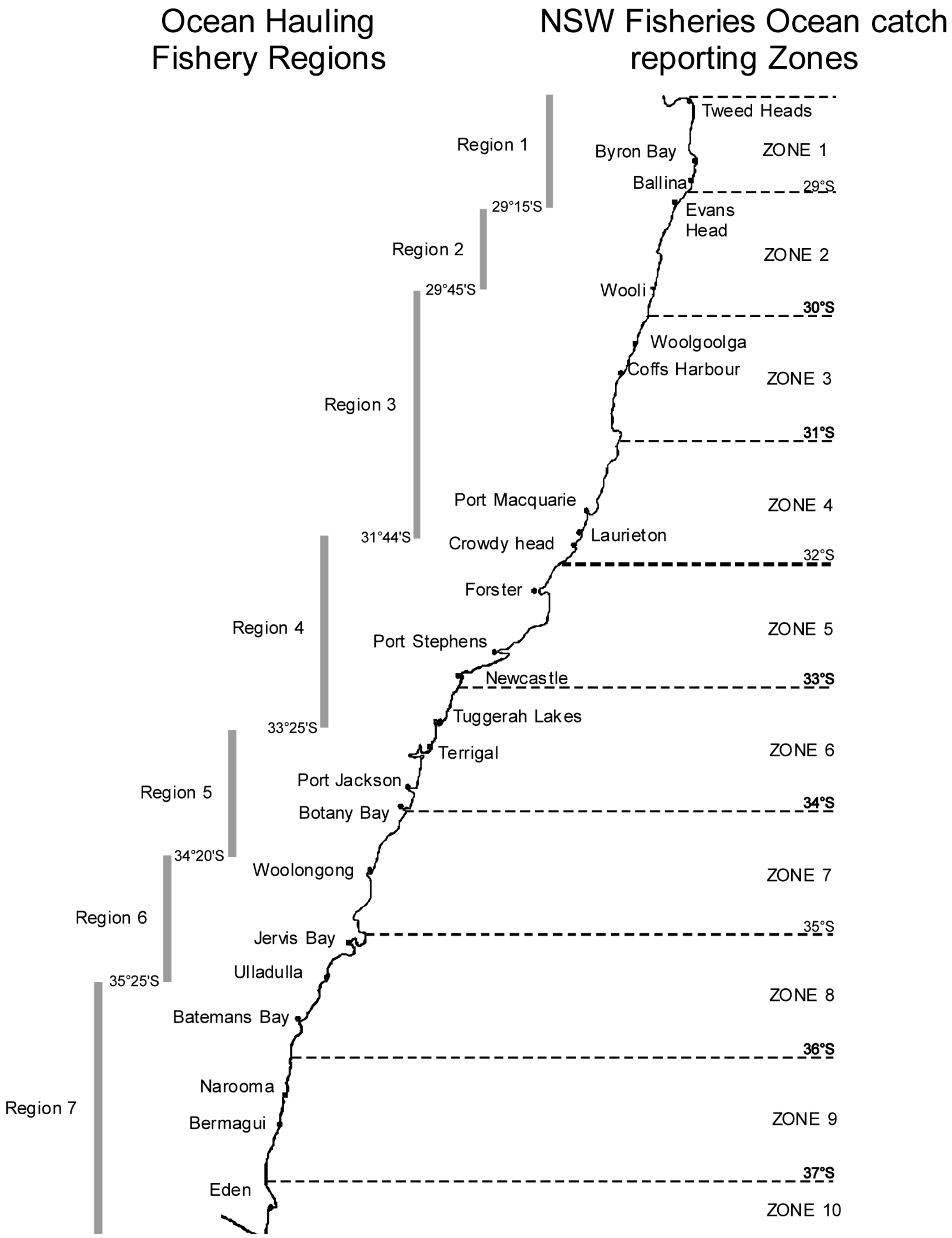


Figure 2.2. Regions and ocean zones for reporting commercial landings in NSW.

2.2.2. Sizes in commercial landings

2.2.2.1. Present study

To ensure representative samples, the lengths of garfish in commercial landings were measured at their point of landing. This was considered necessary because garfish sold at market may not have been representative of the total catch, due to sorting and grading prior to being sold. Separate markets sometimes exist for bait (small fish) and export (large fish). Catches were sampled by either fisheries observers onboard vessels or by trained staff at fishermen's businesses and co-operatives.

Sea garfish were measured from wherever they were caught in NSW, but the sampling was focussed on the Wallis Lake, Nelson Bay, Wollongong, Jervis Bay and Ulladulla regions. River garfish were measured from Lake Illawarra, Tuggerah and Wallis Lakes, and snub-nosed garfish were measured from the Clarence River.

Unsorted sub-samples of between 10 and 20kg were taken from each catch and the fish measured. Fish were measured as fork length (FL - the distance from the upper jaw to the fork in the tail - Figure 2.3), to the nearest ½ centimetre below the true length. Total numbers in the catch were calculated by simple proportions. Twenty fish were chosen at random from each catch for biological assessment. Each of these 20 fish had its sagittal otoliths removed for age estimation and its gonads examined for assessment of its reproductive condition.

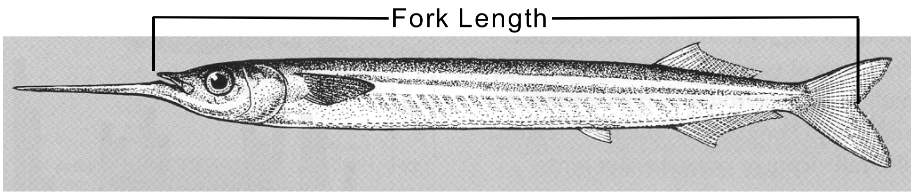


Figure 2.3. Diagram of a garfish showing measurement of fork length

The sporadic nature of the fisheries for garfish and subsequent difficulty in obtaining samples at their point of landing, together with the time-lag in obtaining reliable catch statistics, meant that scaling the sampled catch to an overall state-wide estimate by relative catches of the fishers sampled was not feasible (e.g. some well-known catchers of sea garfish in NSW had not submitted monthly catch returns since 1998/99). We assumed that our sampling effort was relative to the effort in the fisheries for each species, and that combining samples would therefore provide accurate approximations of the regional fisheries. We are confident that this was the case for all river and snub-nosed garfish, but had difficulty in getting samples of sea garfish from the Nelson Bay region (a major area for landing sea garfish). We therefore divided landings of sea garfish into those from Nelson Bay north (northern region) and south of Nelson Bay (southern region) when determining the size-compositions in commercial landings.

2.2.2.2. Historical data

Limited information on the sizes of sea garfish consigned for sale at the Sydney Fish Market during 1955 was available for comparison with the present study. These garfish were measured from the lower jaw to the fork in the tail and the lengths were converted to FL using the relationship determined in this study.

Lengths of sea garfish sold at the Sydney Fish Market were also measured between February 2000 and January 2002 as part of the NSW Fisheries commercial fishery monitoring program. Many of these fish were also dissected for biological assessment and the resulting GSI information was incorporated into the chapter on reproductive biology.

There are no historical data available on the sizes of river or snub-nosed garfish landed in NSW.

2.2.2.3. Sydney fish market size-gradings

Fishers consigning sea garfish for sale at the Sydney Fish Markets are supposed to grade their fish by size according to the schedule supplied by the markets. Assuming that the fish sent to the Sydney Fish Markets are representative of the sizes of fish being landed by the fishery, then monitoring the quantities of each size-grading of sea garfish sold through the Sydney Fish Markets should reflect landings from the fishery. Information on the monthly quantities of each size-grading sold through the Sydney Fish Market that were supplied by NSW fishers was obtained from the Sydney Fish Market web-site (www.sydneyfishmarket.com.au). The website also provided information on average price for each size-grading.

2.2.3. Morphometric Relationships

A variety of body measurements were recorded for a range of sizes of sea, river and snub-nosed garfish. Measurements (in mm) taken included fork length (FL - from tip of upper jaw to the fork in the caudal fin), total length (TL - from the tip of the upper jaw to the extremity of the caudal fin), standard length (SL - from the tip of the upper jaw to the caudal base), lower jaw to fork length (LJFL - from the tip of the lower jaw to the fork in the caudal fin), and total body weight.

2.3. Results

2.3.1. Description of the main fishing methods

Two main methods are used to commercially catch garfish in NSW: garfish hauling nets and bullringing nets.

A garfish hauling net is a net specifically designed to catch garfish. Garfish hauling nets were historically deployed from, and retrieved to, a beach. However since the mid-1980's fishers have modified the garfish hauling net to be more like the traditional lampara-type net that can be used from boats (Fig. 2.4). Beach-based fishers are considered to be less efficient than boat-based fishers because they are restricted to the shore and have to wait until garfish swim within range of their nets before catching them. Boat-based fishers actively seek garfish and use berley (such as bran) to aggregate the fish and increase their catchability. The permissible mesh size dimensions of a garfish hauling net is not less than 28 mm. Until recently (2003) a concession to use 25 mm mesh in these nets was available, however this concession was withdrawn following recommendations from a study on the selectivity of various mesh sizes (Appendix 4). The maximum length of a garfish hauling net is 300 m with ropes that do not exceed 300 m.

A bullringing net is essentially a boat-based mesh net used to target garfish, generally in shallow water. The standard bullringing net consists of mesh between 28 mm and 36 mm and has a standard length of 275 m and ropes of 25 m. The first end of the net to be shot away is normally deeper in meshes than the other end, allowing the net to close around and underneath the garfish when it is retrieved. Fishers will go to an area where they can see garfish, or where they suspect fish to be, drop one end of the net with a buoy, run the net in a circle and immediately pick the buoy up and retrieve the net to the boat. The net is positively buoyant and has a weighted footrope so that it sits vertically in the water. Fishers sometimes splash the water to scare the fish into the mesh. This procedure is used during both the day and night. The method of bullringing has recently (2003) been banned in the ocean hauling fishery. There is a closure on using this method to take garfish in estuaries between December and January each year and a weekend closure in many estuaries.

Recreational fishers target garfish using lines and small baited hooks for use as both bait and for consumption.

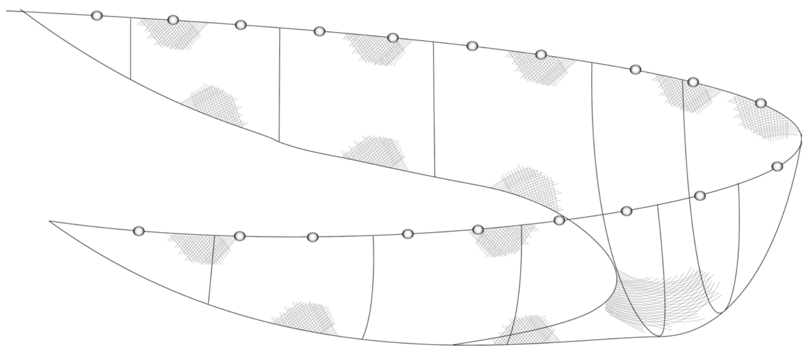


Figure 2.4. Line diagram of a garfish haul net used by boat-based fishers targeting sea garfish. Drawing by John Matthews.

Sea garfish

2.3.2. NSW Fisheries catch statistics

Reported commercial landings of sea garfish were relatively low prior to the late 1970's (Fig. 2.5). Landings increased rapidly during the 1980's reaching a peak of 280 t during 1992/93. Since then there has been an overall pattern of decline (despite landings during 1994/95, 1997/98 & 2000/01 being slightly higher than in the preceding year), and landings are currently at very low levels (21 t during 2002/03).

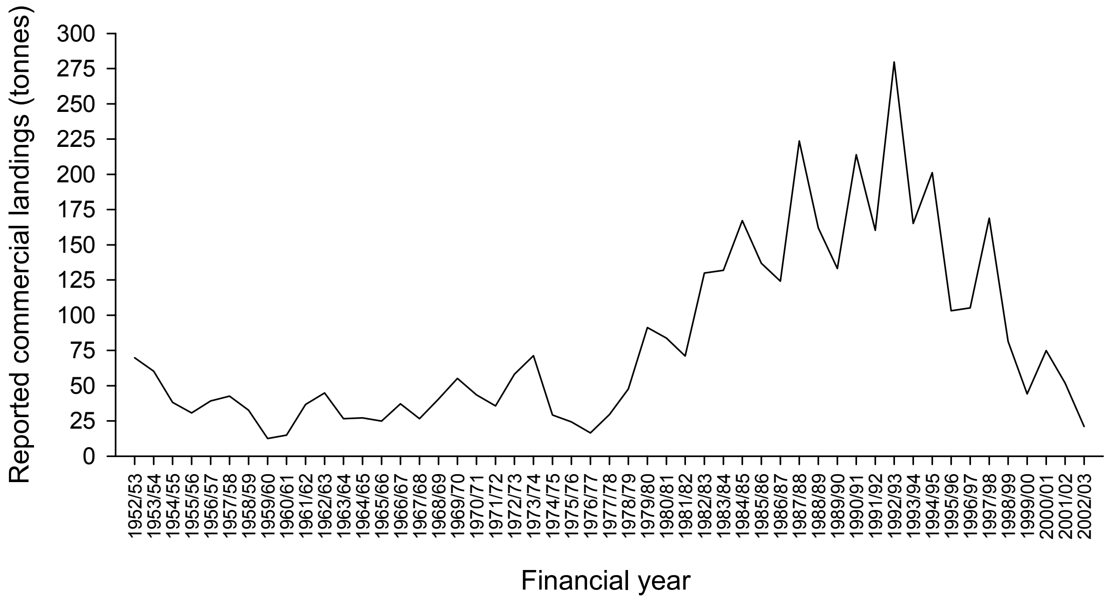


Figure 2.5. Reported commercial landings of sea garfish in NSW.

The Ocean Hauling Fishery is the predominant fishery taking sea garfish in NSW and has landed more than 88% of the catch since 1999/00. The remaining 12 % was taken in the Estuary General Fishery.

The fishery for sea garfish on the south coast of NSW generally starts in December, peaks around April and finishes around June. The fishery on the north coast starts later (March), peaks during April and declines steadily during the winter months. Landings between 1999/00 and 2002/03 have been low (Figs. 2.5 & 2.6) and the fishery has been essentially non-existent between August and November with only small, sporadic landings reported on the north coast of NSW.

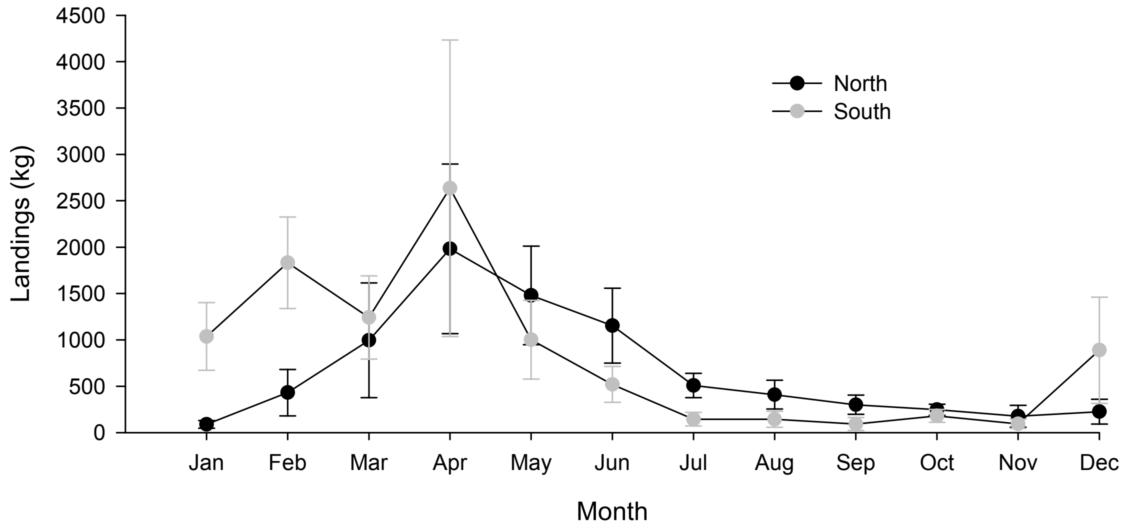


Figure 2.6. Mean (± SE) reported monthly landings of sea garfish from the north and south coasts of NSW between 1999/00 and 2002/03.

Landings of sea garfish between 1999/00 and 2002/03 were mainly from ocean zones 5, 7 and 8 (Fig. 2.7). Ocean zone 5 reported the largest tonnage and includes landings from the Port Stephens estuary.

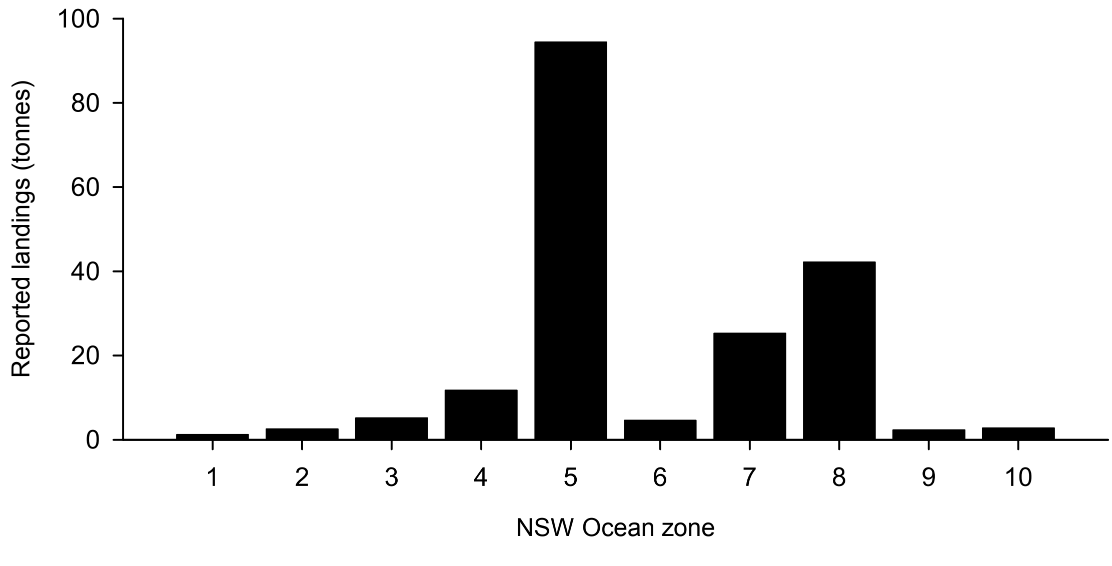


Figure 2.7. Total reported landings of sea garfish by NSW ocean zone between 1999/00 and 2002/03. Landings from each ocean zone include estuarine landings from that area.

Commercial landings between 1984/85 and 1998/99 show that ocean zones 5, 7 and 8 have historically landed the majority of sea garfish in NSW (Fig. 2.8). The relative proportion of the south coast (ocean zones 6 to 10) landings compared to the total landings have declined significantly since 1998/99.

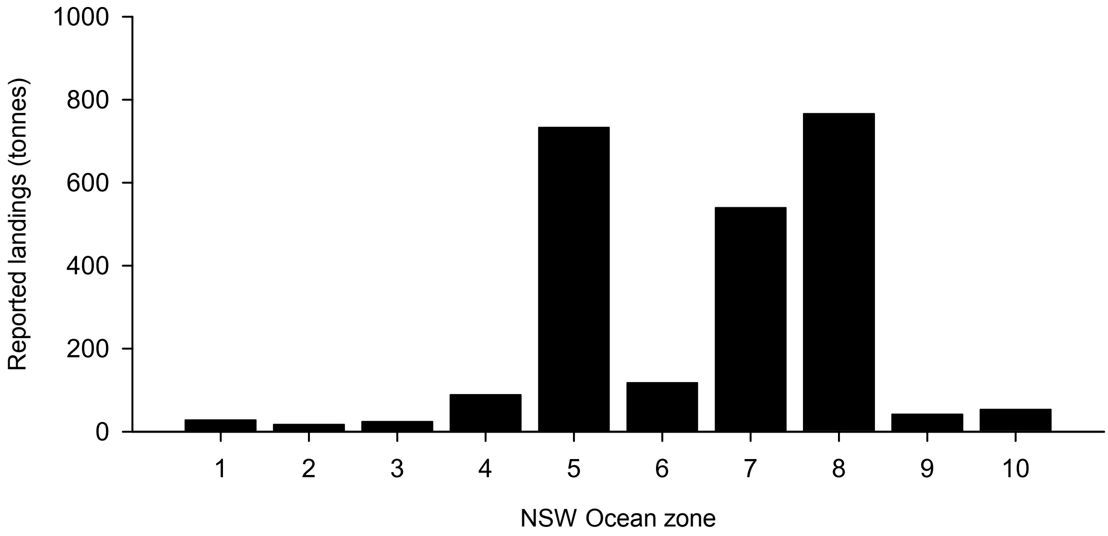


Figure 2.8. Total reported landings of sea garfish by NSW ocean zone between 1984/85 and 1998/99. Landings from each ocean zone include estuarine landings from that area.

Effort targeting sea garfish has declined markedly since 1991/92, with the number of fishers reporting sea garfish on their catch returns declining from 151 in 1992/93 to 45 during 2002/03 (Table 2.1). The fishery currently has a historically low participation rate with only 19 fishers taking 90% of the catch during 2002/03 and only 5 fishers taking more than 50% of the reported catch.

Table 2.1. Total reported landings of sea garfish in NSW, the number of fishers reporting sea garfish on their catch returns and the number of fishers to take 90% of the catch each year since 1991/92.

Year	Landings (t)	No. fishers reporting sea garfish	No. fishers to take 90% of catch
1991/92	160.23	130	37
1992/93	279.80	151	40
1993/94	165.19	104	33
1994/95	201.21	123	37
1995/96	103.21	125	31
1996/97	105.28	111	49
1997/98	167.24	142	40
1998/99	80.59	75	30
1999/00	42.37	60	25
2000/01	74.89	60	20
2001/02	51.86	58	21
2002/03	20.99	45	19

The index of CPUE of average catch per fisher shows an overall decline from a high of just over 1800kg in 1992/93 to a low of just over 400kg during 2002/03 (Fig. 2.9). The more refined index of average catch per fisher for the top 10 fishers each year mirrors the trend in reported landings each year (Fig. 2.5) and shows a high of just over 15 t per fisher in 1992/93, declining to a low of around 1.5 t per fisher in 2002/03 (Fig. 2.9). There is some evidence of slight increases in this measure of CPUE (and in total landings – Fig. 2.5) every 2 or 3 years (i.e. 1992/93, 1994/95, 1997/98 and 2000/01), however the overall trend is one of declining catches.

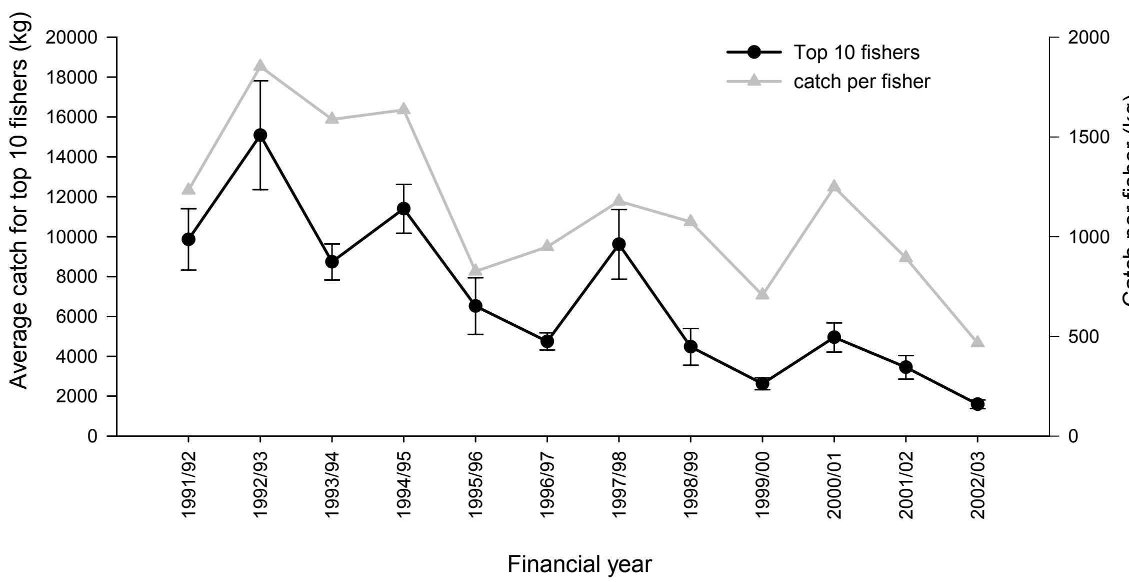


Figure 2.9. Average (± S.E.)reported catch of sea garfish per fisher, and average reported catch for the top 10 fishers each year in NSW between 1991/92 and 2002/03.

The index of CPUE based on reported landings and days of effort using the method of garfish hauling since 1997/98 shows a similar trend to those indices based purely on catch per fisher (Fig. 2.10). Preliminary data from 2003/04 indicates that this may have increased to around 77kg/day.

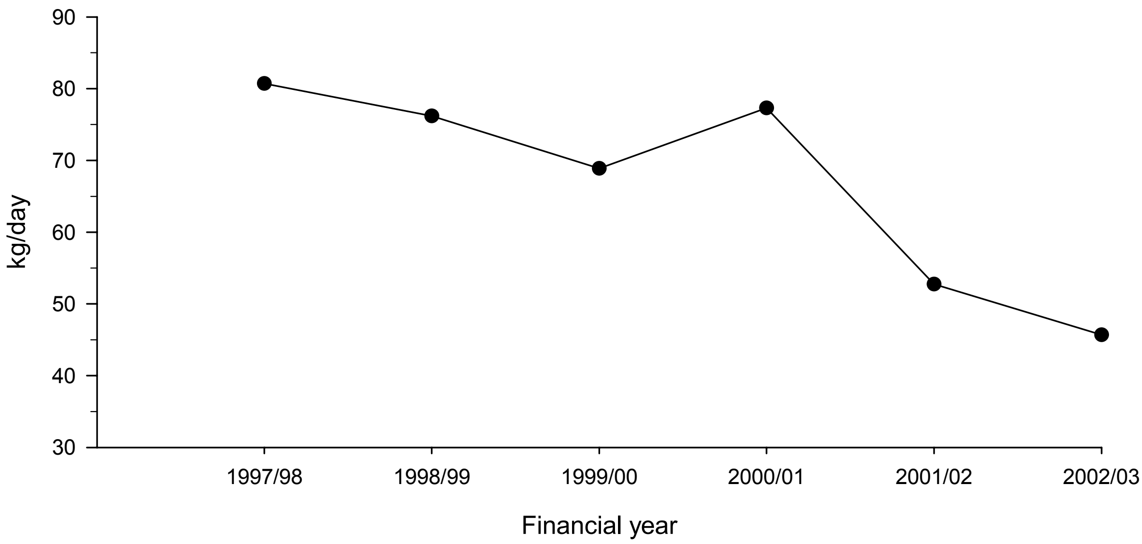


Figure 2.10. Reported landings per day of sea garfish using the method of garfish hauling since 1997/98.

Within the recreational sector, a twelve-month survey of recreational fishing in NSW was conducted in 2000/01 and indicated that recreational fishers in NSW harvested approximately 22.7 tonnes of "garfish" including sea garfish. (Henry & Lyle, 2003). There is no historical information on the recreational harvest of 'garfish' in NSW.

2.3.3. Sizes in commercial landings

The sizes of sea garfish in commercial landings were measured between December 2001 and March 2004 at their point of landing. The sizes of sea garfish landed varied between fishers, days and even shots within days, but were generally similar at any given time and place. As an example, the sizes of sea garfish measured from the same port during January 2002 showed 4 catches of similar size compositions and one with a greater proportion of large fish (Fig. 2.11).

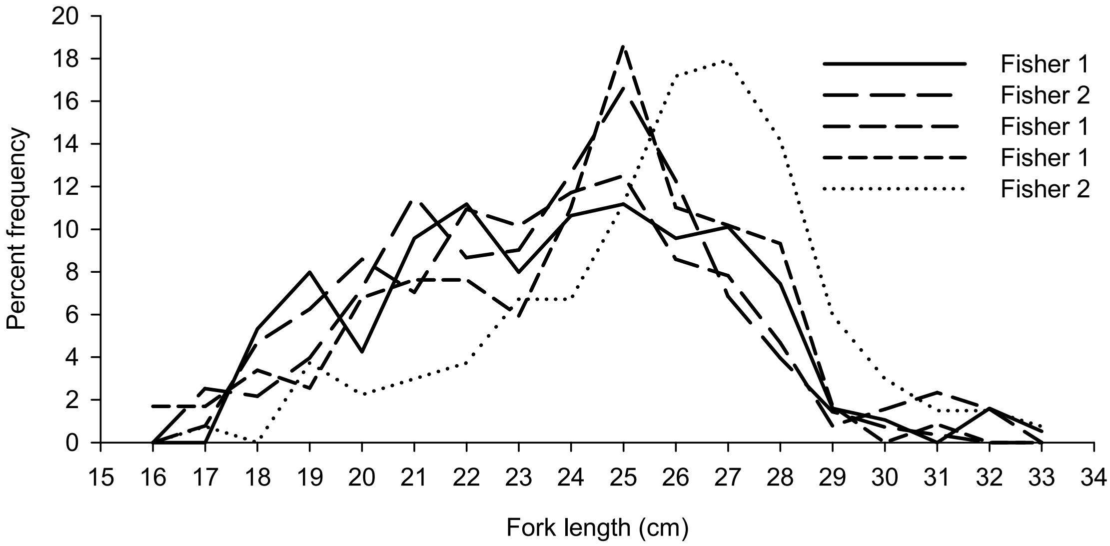


Figure 2.11. The sizes of sea garfish measured from commercial landings taken from one port in NSW during January 2002.

Sampled catches from all regions in NSW were pooled into months and showed distinct monthly trends in changes in size-composition (Fig. 2.12). Smaller fish were seen to recruit to the fishery around May at a size of around 20 cm FL and, if assumed to represent a cohort, could be followed through time. The fishery was dominated by larger fish (>25 cm FL) between February and April. No samples were collected during August, October or November in any year because the fishery was inactive during these months.

Information on the sizes of sea garfish sent to the Sydney Fish Markets was available from a small number of catches from 1955 and also from a previous study done between February 2000 and December 2001. Information was also available on the sizes of sea garfish sent to the Sydney Fish Markets between February and May 2004 from the NSW DPI commercial fishery monitoring program. The sizes of sea garfish landed differed between the northern and southern regions (Fig. 2.13). Fish from the northern region were, on average, smaller than those measured from the southern region in each year. Sea garfish from the northern region in 2000/01 and 2003/04 were, on average, larger than those landed from this region during the other years.

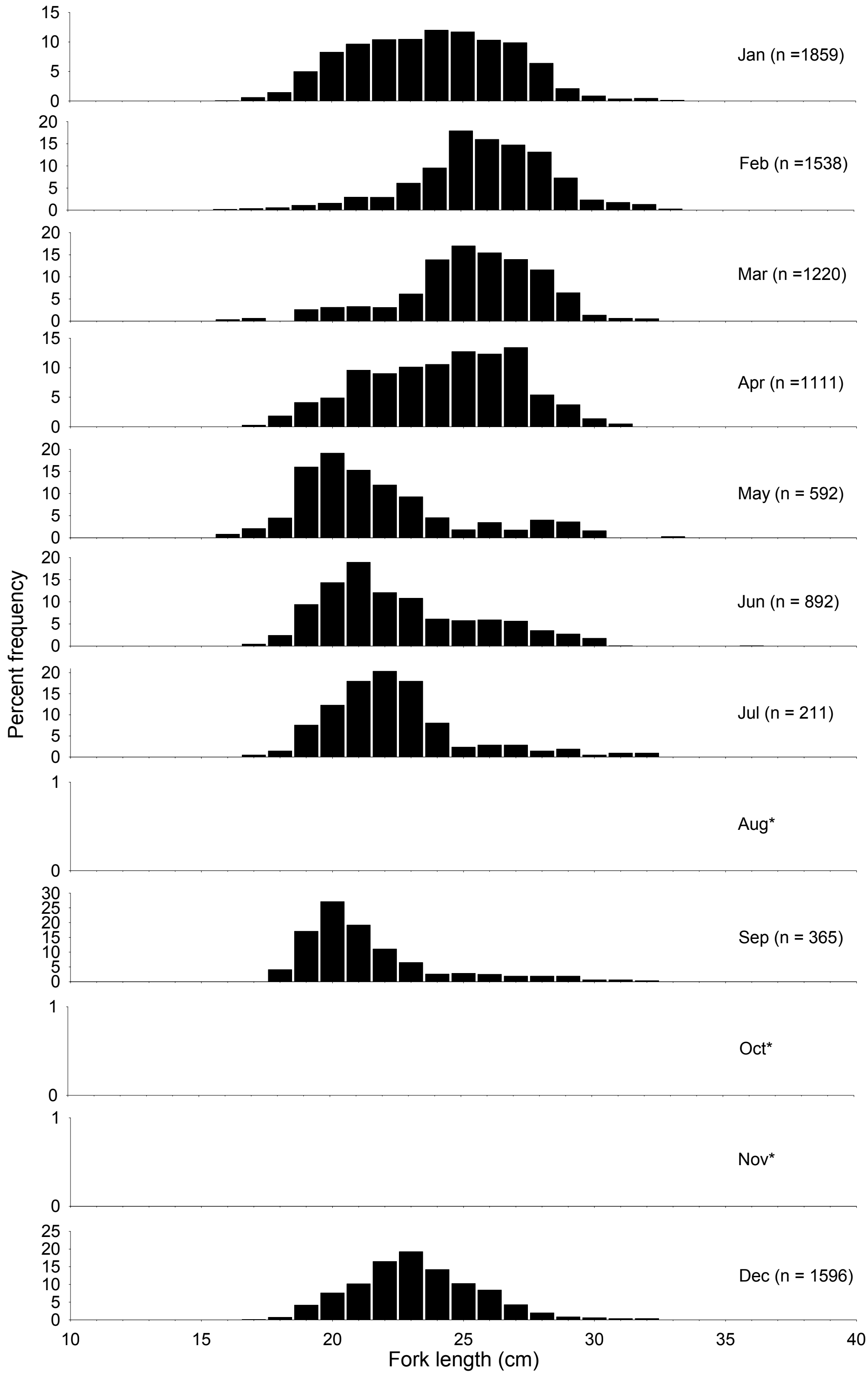


Figure 2.12. The sizes of sea garfish measured at their point of landing between December 2001 and March 2004 pooled by month of sampling. *Note that no samples were collected during August, October or November in any year.

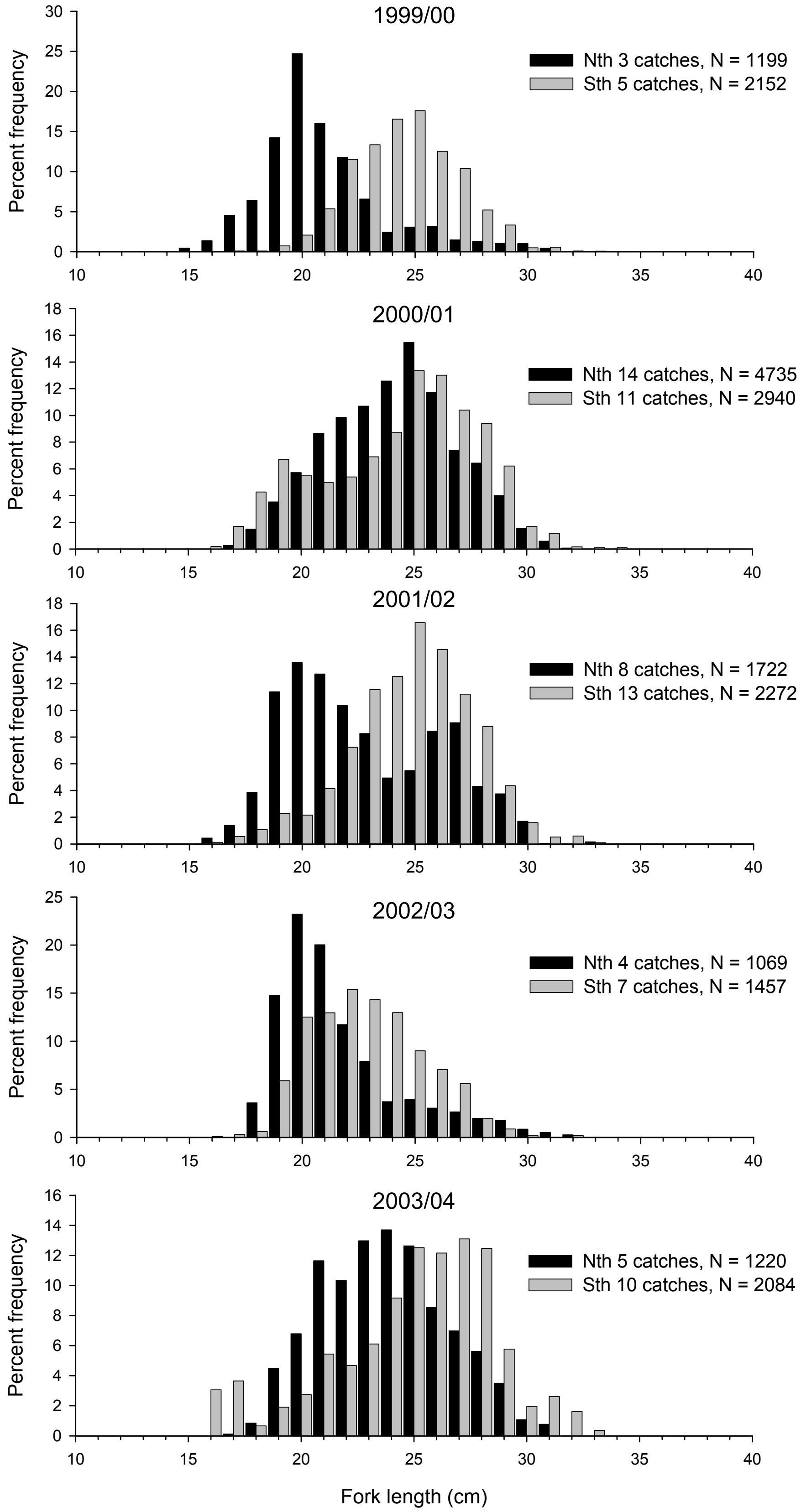


Figure 2.13. The sizes of sea garfish measured from commercial landings taken from the northern and southern regions of NSW between 1999/00 and 2003/04.

The proportion of the total NSW catch of sea garfish (determined from fishers catch returns) from the northern and southern regions varied greatly between years (Table 2.2). Only 36 and 33% of the total catch was taken in the southern region during 2001/02 and 2002/03 respectively. The data for 2003/04 may not to be complete (due to outstanding fishers catch returns at the time of analysis) and should therefore be viewed cautiously.

Table 2.2. The proportion of the total NSW catch of sea garfish reported from Nelson bay north wards (North) and south of Nelson Bay (South) 1999/00 to 2003/04.

	1999/00	2000/01	2001/02	2002/03	2003/04
North	0.46	0.58	0.64	0.67	0.22
South	0.54	0.42	0.36	0.33	0.78

These proportions were used to weight the size-composition data (in Fig. 2.13) to gain state-wide estimates of the sizes of sea garfish landed and to compare with the limited information from 1955. The sizes of sea garfish measured at the Sydney Fish Markets during 1955 were generally between 23 and 30 cm FL. The distribution of sizes is clearly influenced by the minimum legal size limit of 10 inches at the time (measured from the tip of the upper jaw to the end of the tail) that corresponds to approximately 23 cm FL (Fig. 2.14). The estimated sizes of sea garfish landed in NSW between 1999/00 and 2003/04 was generally between 20 cm and 30 cm FL each year (Fig. 2.14). The distribution of sizes varied between years, with 2002/03 having a larger proportion of small fish in landings than in other years. There is no evidence that the maximum sizes of sea garfish in landings have changed significantly since 1955.

There were significant linear relationships between the mean sizes of sea garfish landed each year (see Fig. 2.14) and the indices of CPUE of average catch per fisher for the top 10 fishers each year, and the catch (kg) per day garfish hauling, between 1999/00 and 2003/04 (Fig. 2.15).

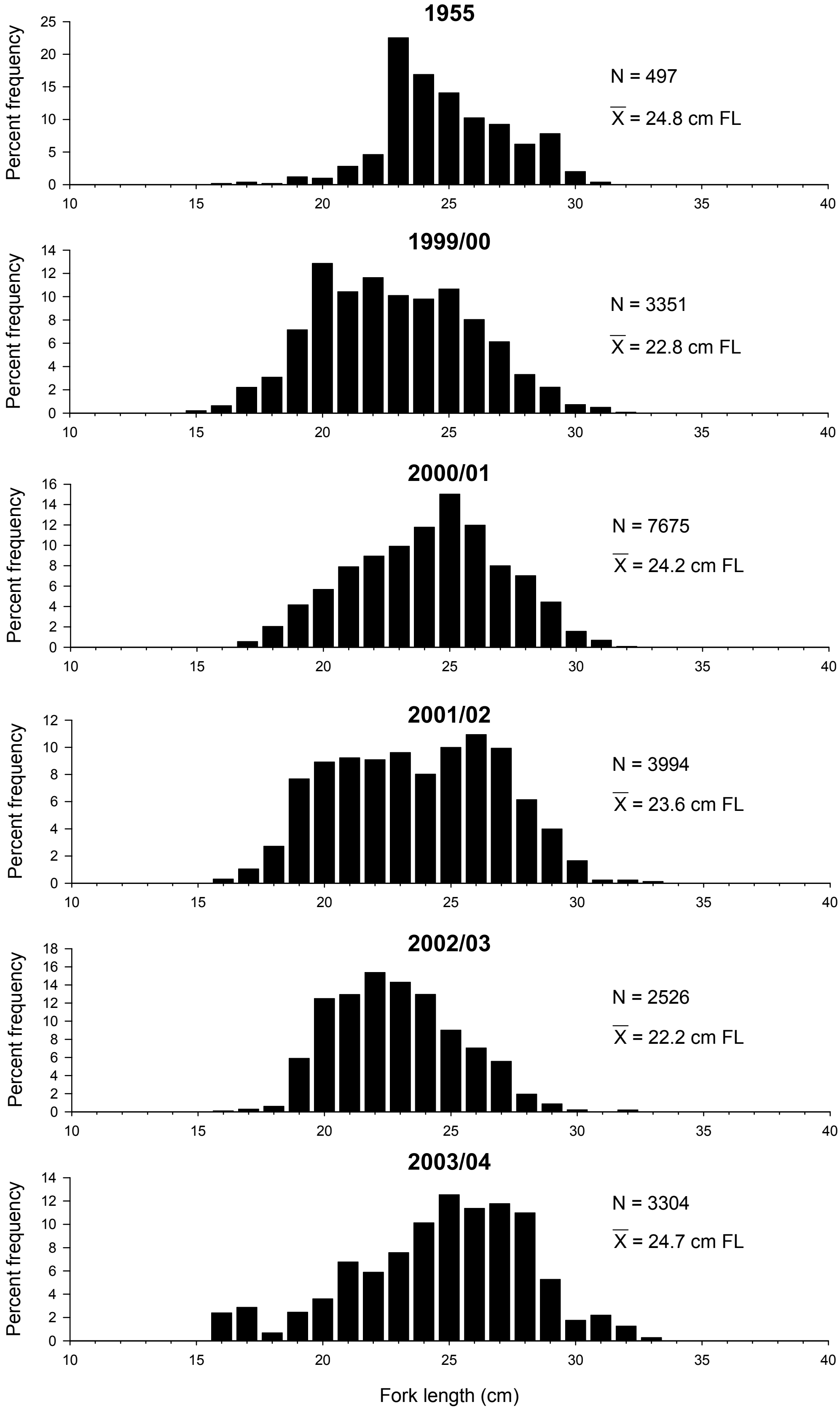


Figure 2.14. Yearly state-wide size compositions of sea garfish in commercial landings 1999/00 to 2003/04.

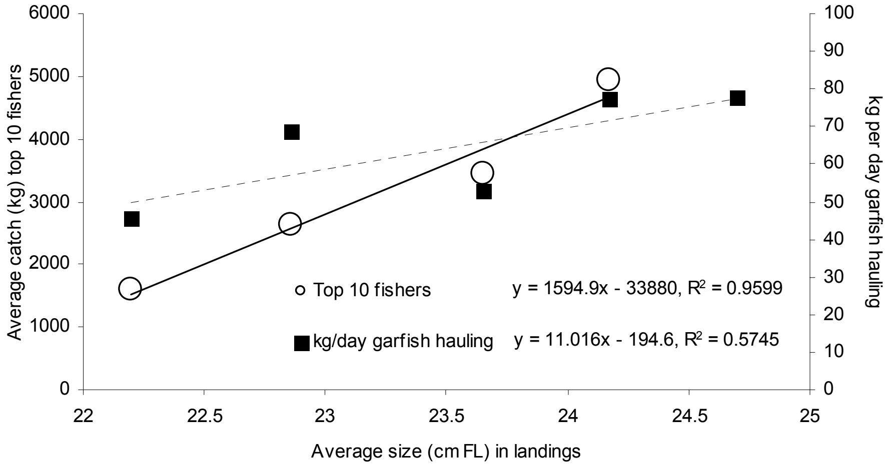


Figure 2.15. Relationships between the average size of sea garfish in commercial landings and the indices of CPUE of average catch (kg) per fisher for the top 10 fishers each year, and the catch (kg) per day of reported garfish hauling, 1999/00 to 2003/04.

2.3.4. Sydney fish market size gradings

The relative proportion (by weight) of each size-grading of sea garfish supplied by NSW fishers that were sold through the Sydney Fish Markets between 1999/00 and 2003/04 showed that 'large' fish always predominated (Fig. 2.16). The relative proportion of extra large fish sent to the Sydney Fish Markets each year was closely associated with the average sizes measured in landings (see Fig. 2.14).

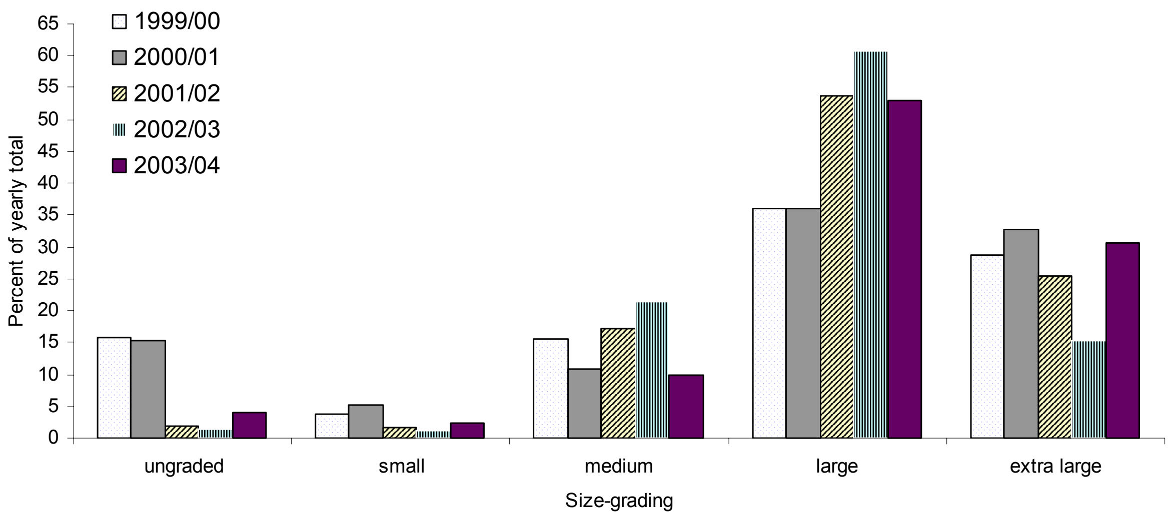


Figure 2.16. Yearly percent (by weight) of each size-grading of sea garfish supplied by NSW fishers that were sold through the Sydney Fish Markets between 1999/00 and 2002/03.

Average prices for each size-grade sold through the Sydney Fish Markets show that extra large fish get the best prices (Table 2.3). Extra large fish during 2003/04 fetched on average more than 6 times the price of small sea garfish. Measurements of different size-gradings of sea garfish consigned for sale at the Sydney Fish Markets showed variation between suppliers.

Table 2.3. Average yearly prices for each grading (with observed size-ranges in FL) for sea garfish sold through the Sydney Fish Markets between 1999/00 and 2002/03.

Year	Ungraded	Small 16 – 25cm	Medium 20 – 25cm	Large 22 – 28cm	Extra large 25 – 34cm
1999/00	$4.41	$2.53	$3.53	$5.52	$6.80
2000/01	$2.23	$2.19	$3.00	$4.82	$6.41
2001/02	$4.11	$2.45	$3.99	$6.16	$8.40
2002/03	$4.41	$3.63	$4.72	$7.36	$10.77
2003/04	$5.55	$1.35	$3.95	$5.86	$8.41

2.3.5. Nematode worms in sea garfish

Sea garfish sampled during the study were frequently found to have their gut cavities full of nematode worms. Commercial fishers claimed to have only noticed the worms in such large numbers during the past few years, when there have been large declines in landings. This suggested that the presence of these worms may have been a factor in the apparent decline in abundance of sea garfish. Samples of these worms were sent to specialists at the University of Queensland who identified them as being female philometrid nematode worms of an unidentified species. They did not observe any males in the samples sent to them. The intermediate hosts of philometrids are copepods and we assume that sea garfish become infected by eating infected copepods. Copepods become infected by eating the tiny larvae released by female worms. Some species of philometrid nematodes that infect gonads are known to effect the number of eggs in hosts, however these philometrids were found in the gut cavities of sea garfish. Generally, philometrid worms are not associated with any serious harm to their hosts, however this has yet to be proven for this species. Sea garfish that we observed to be heavily infected had full stomachs and well developed gonads. Routine sampling of sea garfish landings should record the presence of these philometrid nematodes in future.

River garfish

2.3.6. NSW Fisheries catch statistics

Reported landings of river garfish in NSW between 1952/53 and the early 1970's were relatively stable and averaged around 88 tonnes per year (Fig. 2.17). There was a very large decline in reported landings in 1975/76, the cause of which is unknown. Since that time landings have been reasonably stable at around 37 tonnes per year, although the last few years (1999/00 to 2002/03) indicate a slight decline in landings.

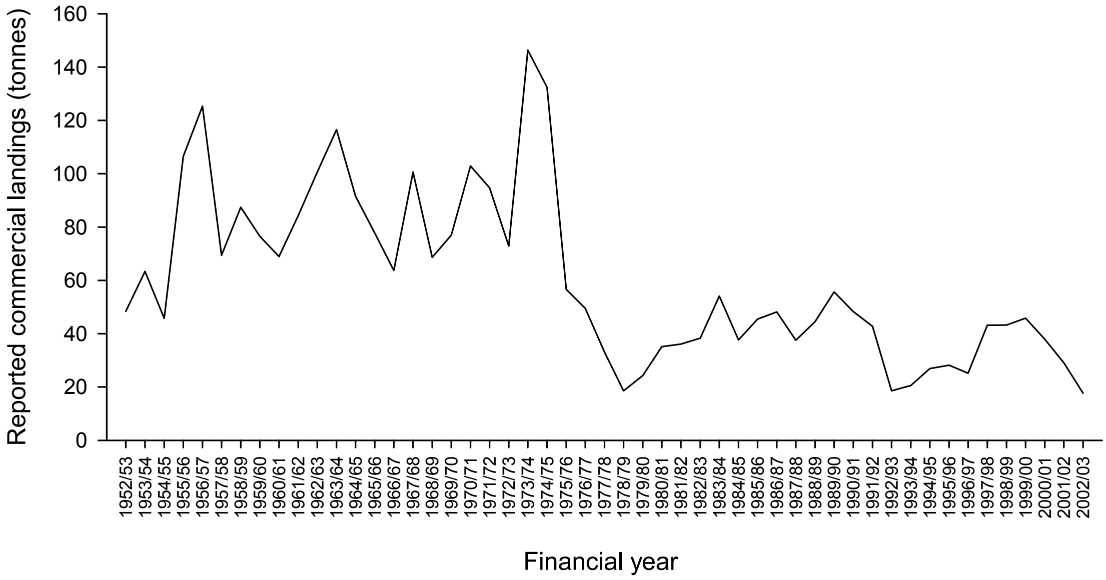


Figure 2.17. Reported commercial landings of river garfish in NSW.

Reported landings of river garfish show that the fishery is seasonal and peaks between June and October (Fig. 2.18). Extremely low landings during December and January are due to the closed season for taking garfish in estuary waters using nets during these months.

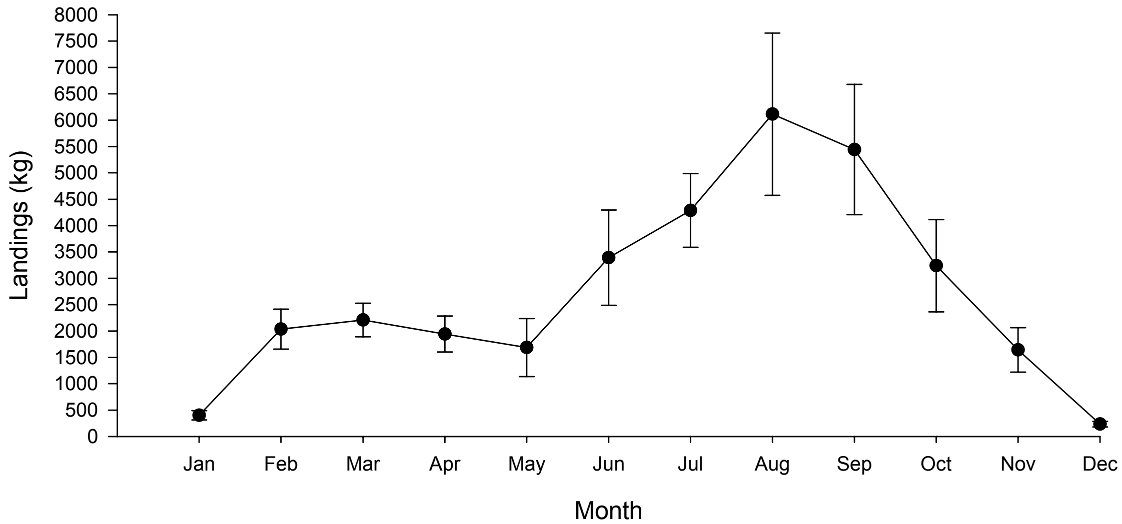


Figure 2.18. Mean (± SE) reported monthly landings of river garfish in NSW between 1999/00 and 2002/03.

The entire catch of river garfish in NSW is taken in the Estuary General Fishery of NSW. Since 1999/00 approximately 72% of the catch has been reported using the method of bullringing and 20% in hauling nets (general purpose, trumpeter whiting or garfish).

The two major contributing estuaries to the total catch of river garfish in NSW since 1999/00 have been Tuggerah Lakes and Lake Illawarra (Fig. 2.19). It is likely that almost all river garfish reported from the Clarence River were incorrectly reported and were, in fact, snub-nosed garfish (as personally reported by fishers and fishermen's co-operatives in the region). Other estuaries with significant river garfish fisheries include Wallis Lake, St Georges Basin (closed to commercial fishing since May, 2002), Port Stephens and the Camden Haven River.

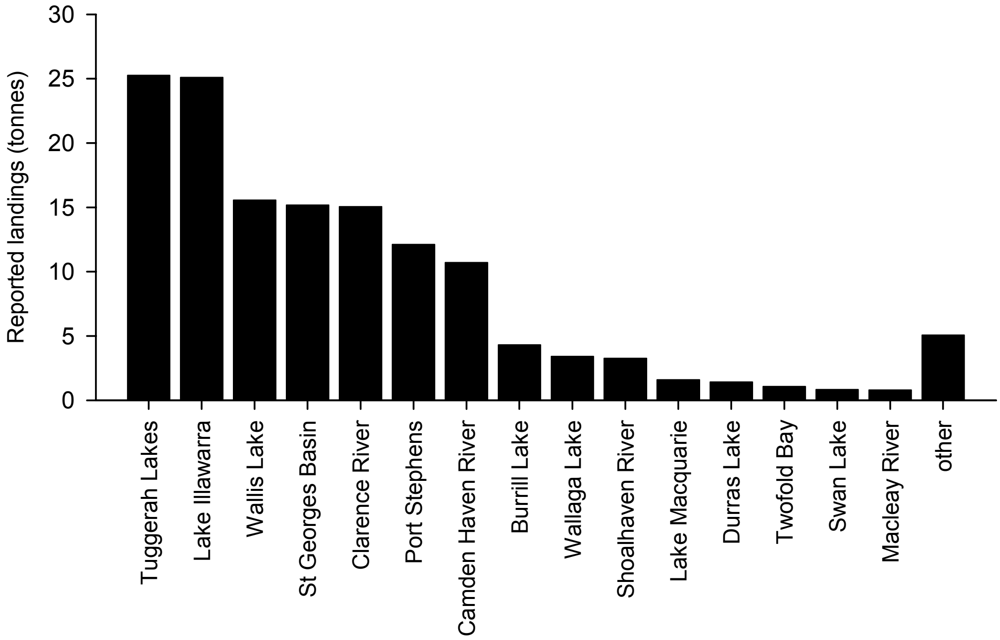


Figure 2.19. Total reported landings of river garfish in NSW by estuary between 1999/00 and 2002/03.

During this study (2001/02 and 2002/03) the fishery for river garfish from Tuggerah Lakes was relatively small (Fig. 2.20). The landings from the Clarence River were almost certainly all snub-nosed garfish, and we therefore sampled 3 of the most commercially important estuaries for river garfish during the study.

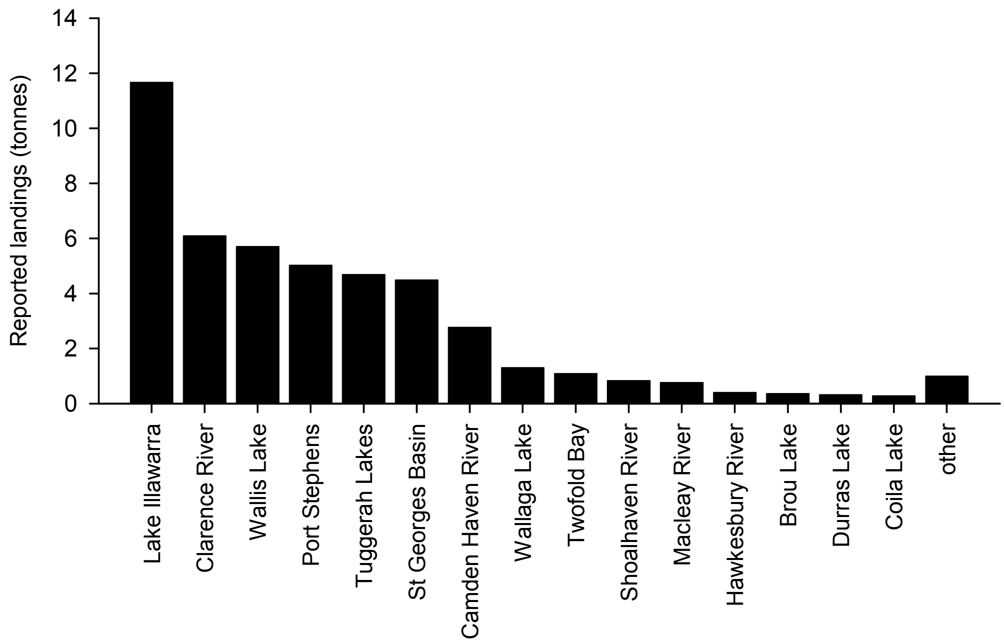


Figure 2.20. Total reported landings of river garfish in NSW by estuary during this study (2001/02 and 2002/03).

The number of commercial fishers reporting river garfish catches was relatively constant at around 150 between 1991/92 and 1999/00, but has declined each year since, to a low of 94 fishers in 2002/03 (Table 2.4). The number of fishers to take 90% of the catch has also been relatively constant but has declined slightly during the past 2 years.

Table 2.4. Total reported commercial landings of river garfish in NSW, the number of fishers reporting river garfish on their catch returns, and the number of fishers to take 90% of the catch each year since 1991/92.

Year	Landings (t)	No. fishers reporting river garfish	No. fishers to take 90% of catch
1991/92	42.76	171	47
1992/93	18.62	151	53
1993/94	20.56	133	41
1994/95	26.96	137	43
1995/96	28.21	124	39
1996/97	25.14	135	52
1997/98	43.16	185	49
1998/99	43.27	172	51
1999/00	45.81	173	41
2000/01	37.91	145	46
2001/02	29.08	120	39
2002/03	17.71	94	29

Two indices of CPUE (catch per fisher, and average catch for the top 10 fishers each year) showed similar overall trends, however a steady decline each year since 1999/00 is best seen in the average catch per top 10 fishers (Fig. 2.21). The pattern in CPUE through time resembles the pattern of overall landings (Fig. 2.17).

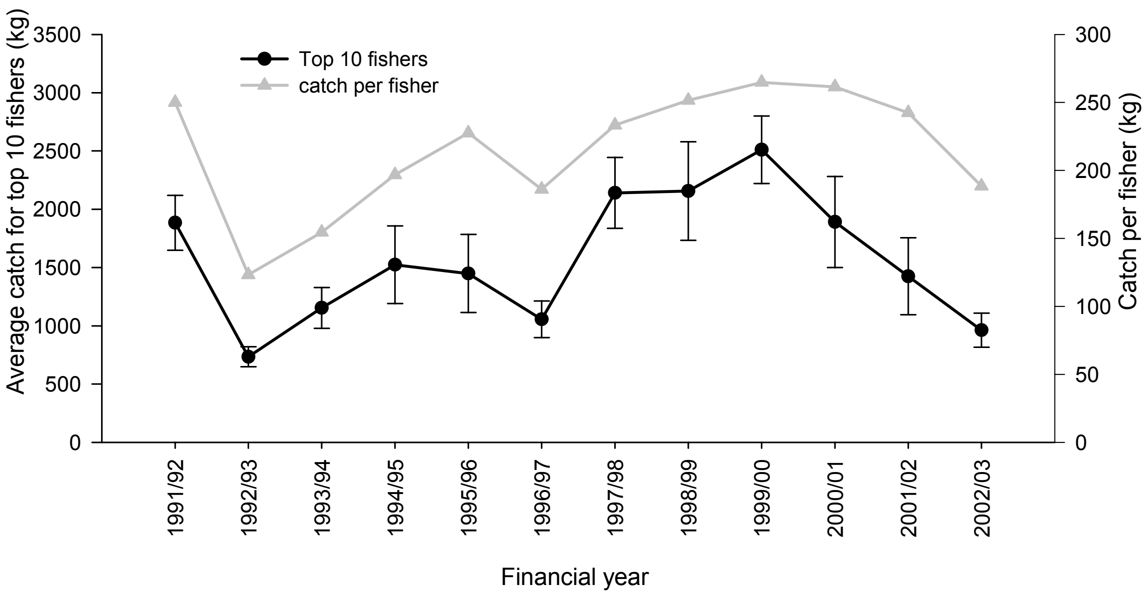


Figure 2.21. Average catch of river garfish per fisher, and average catch (± S.E.) for the top 10 fishers each year between 1991/92 and 2002/03.

The index of CPUE based on catch and days of effort from the method of bullringing since 1997/98 shows a different trend (Fig. 2.22) to those indices based purely on catch per fisher that do not take actual effort into account (Fig. 2.21). The average catch of river garfish per day of bullringing has varied between around 20 and 35 kg since 1997/98. This index of CPUE has been stable since 2000/01.

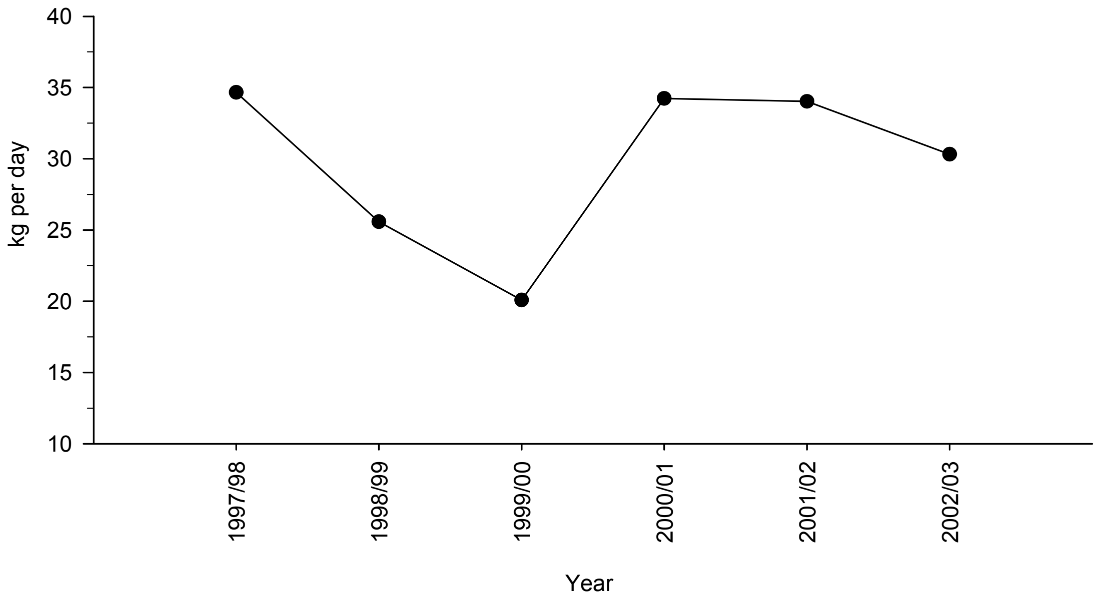


Figure 2.22. Reported landings per day of river garfish in NSW using the method of bullringing since 1997/98.

2.3.7. Sizes in commercial landings

River garfish from Lake Illawarra were of similar size ranges each month sampled, except during November 2001 when the 1 catch measured was, on average, slightly larger (Fig. 2.23). Monthly samples were pooled to compare yearly size compositions (Fig. 2.24).

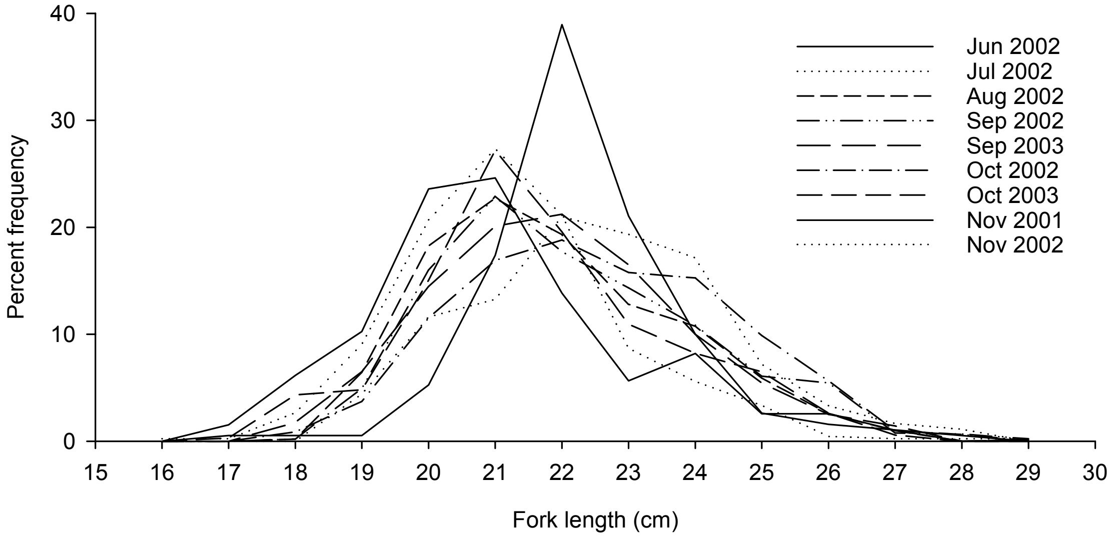


Figure 2.23. The sizes of river garfish sampled each month from Lake Illawarra between November 2001 and October 2003.

There was very little variation in the size composition of river garfish landed from Lake Illawarra during the study (Fig. 2.24). There was also little difference in the sizes of river garfish landed from Wallis Lake between years (mean of 21.0 cm FL during 2002/03 and 20.7 cm FL during 2003/04 – data not shown) and the data were therefore pooled. We only measured the sizes of fish from 1 catch from Tuggerah Lakes during the project.

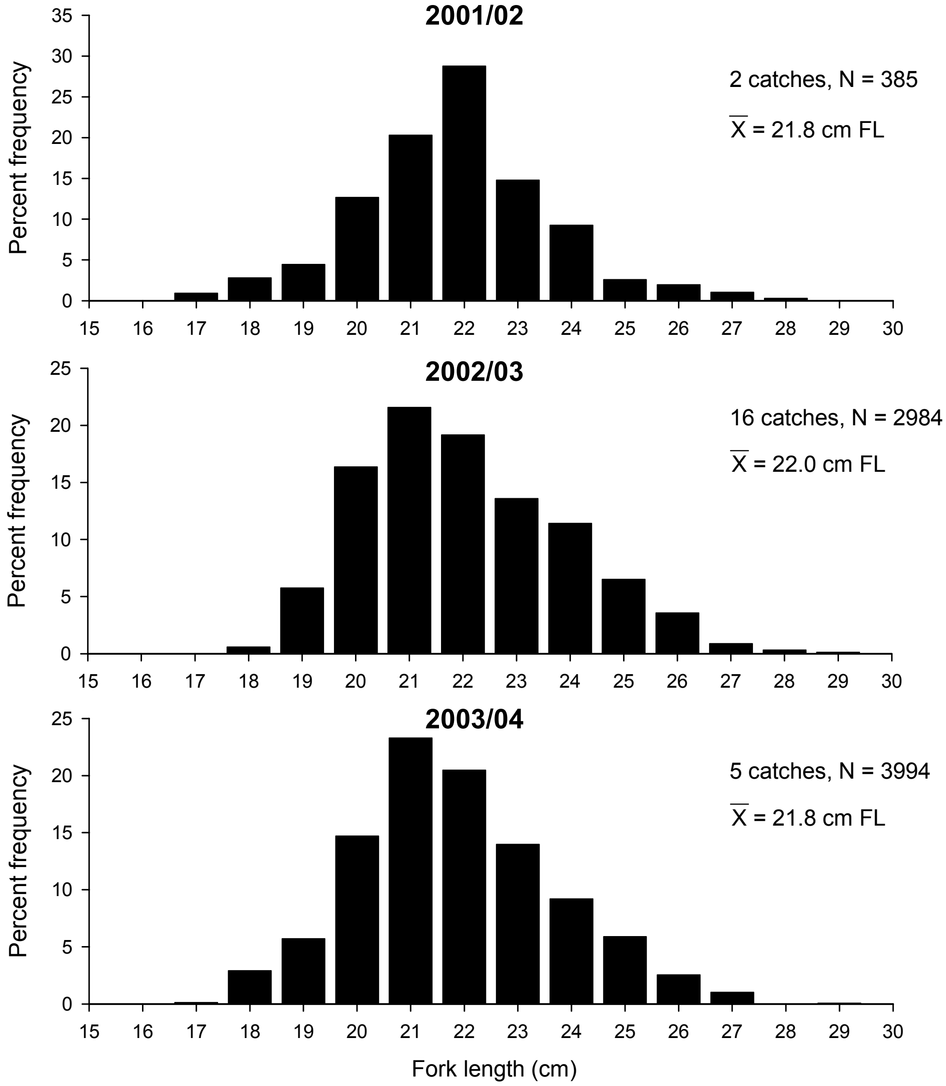


Figure 2.24. Size composition of commercial landings of river garfish from Lake Illawarra between 2001/02 and 2003/04.

The sizes of river garfish from Lake Illawarra were, on average, considerably larger than those landed from Wallis Lake (Fig. 2.25). River garfish from the 1 sample from Tuggerah Lakes were relatively small.

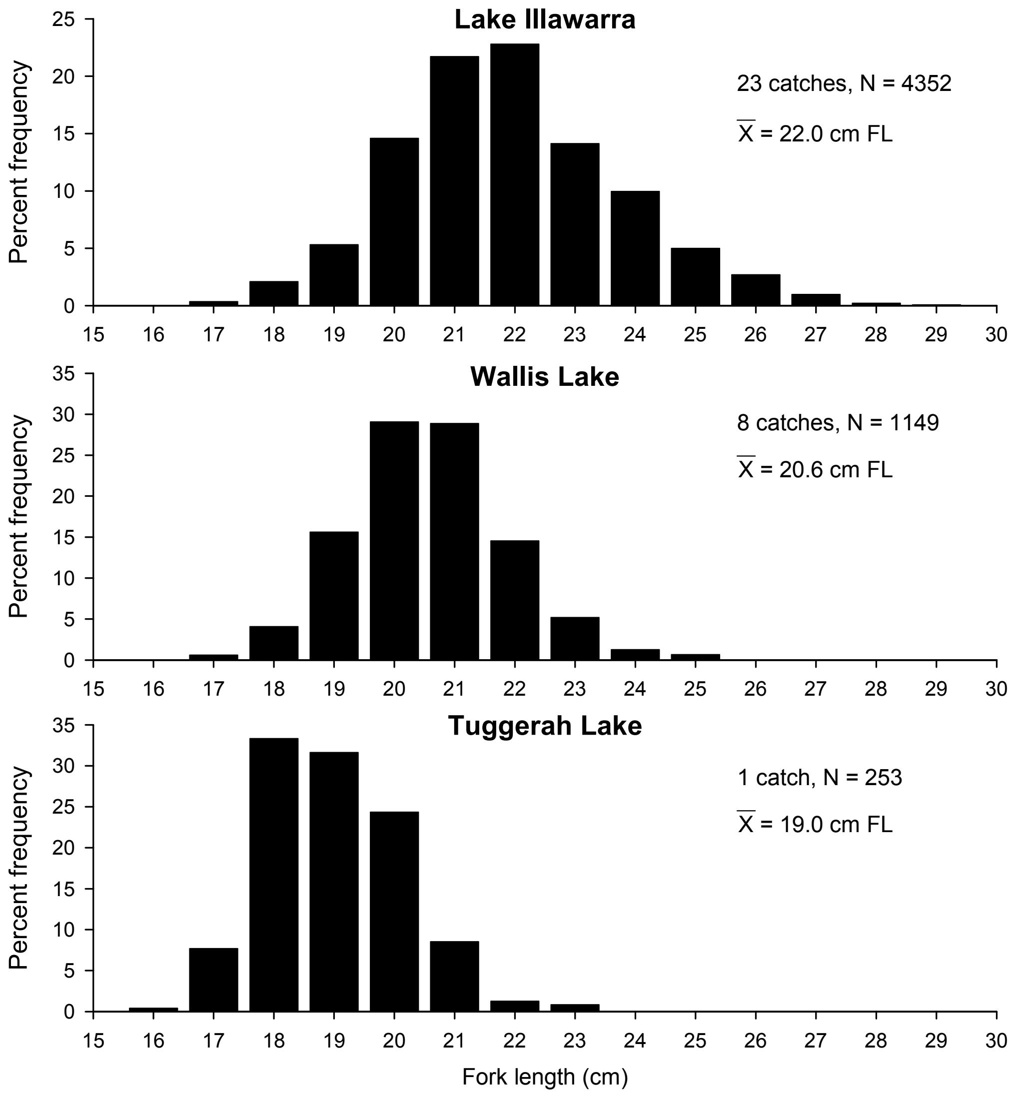


Figure 2.25. The size composition of river garfish landed from Lake Illawarra, Wallis Lake and Tuggerah Lakes during the study.

Snub-nosed garfish

2.3.8. NSW Fisheries catch statistics

Reported landings of snub-nosed garfish have varied considerably since the early 1950's, from a low of less than 5 t during 1954/55 to a seemingly anomalous peak of more than 45 t during 1971/72 (Fig. 2.26). It is not known whether this peak is due to a reporting error. Recently, reported landings declined in 1997/98 and have remained low ever since. This is almost certainly due in part to the misreporting of snub-nosed garfish caught in the Clarence River as river garfish. To correct for this, the reported catch of river garfish from the Clarence River was added to the reported catch of snub-nosed garfish and the resulting trend indicates a much more gradual decline in landings (Fig. 2.26).

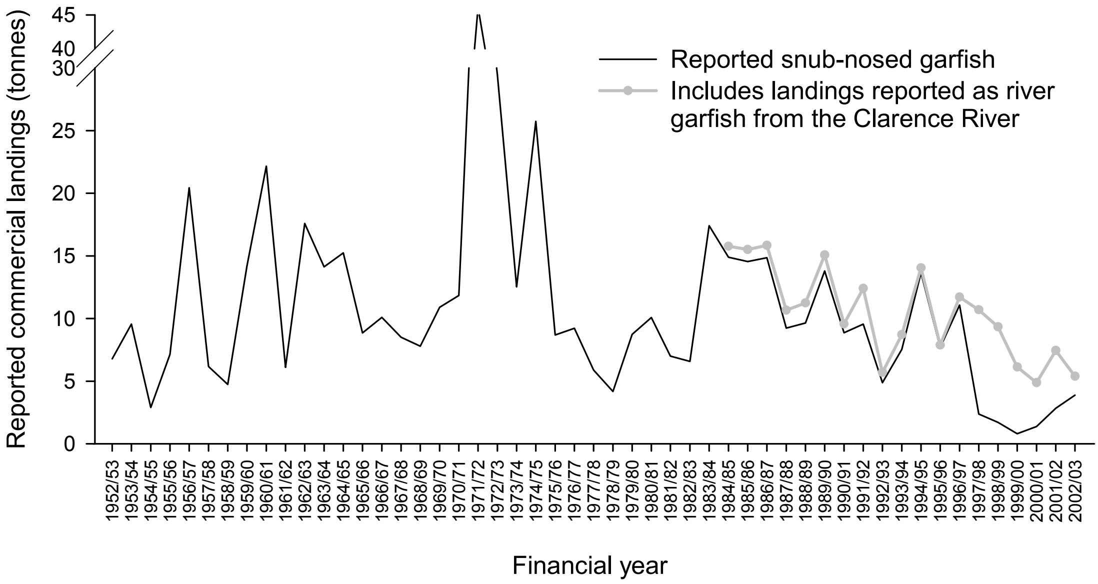


Figure 2.26. Reported commercial landings of snub-nosed garfish in NSW. The second plot from 1984/85 onwards includes landings reported as river garfish from the Clarence River.

Reported landings of snub-nosed garfish in NSW show that the fishery is seasonal, with peak landings between August and October and then again in February (Fig. 2.27). Large standard errors of the means show that there has been considerable variation in monthly landings during the past few years, however the data from 1984/85 onwards show the same seasonal trends. Extremely low landings during December and January are due to the closed season for taking any species of garfish in estuaries using nets during these months.

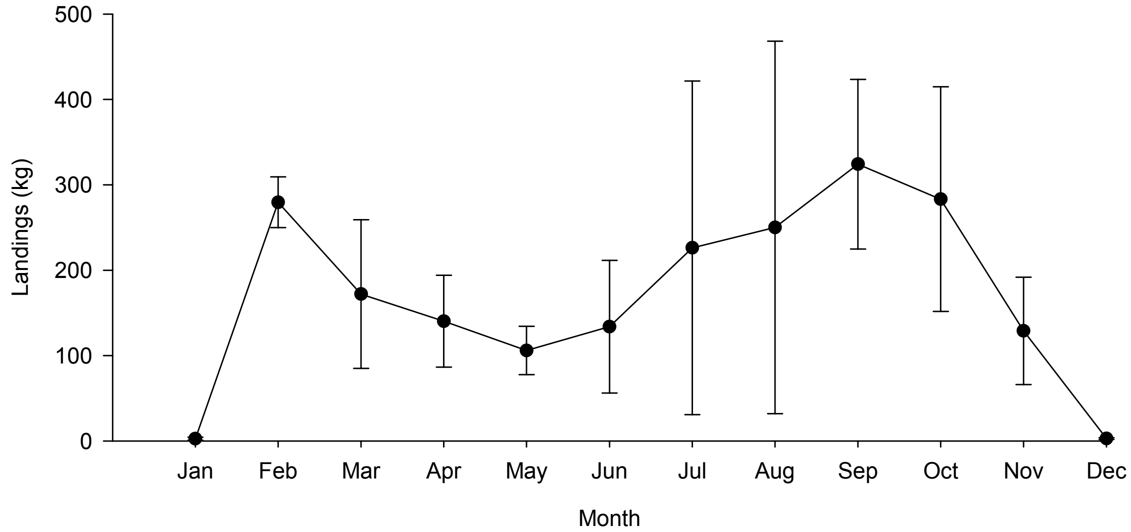


Figure 2.27. Mean (± S.E.) reported monthly landings of snub-nosed garfish in NSW between 1999/00 and 2002/03.

The Estuary General Fishery reported 94.5% of the commercial catch of snub-nosed garfish in NSW between 1999/00 and 2002/03, the Ocean Haul Fishery 5% and the Estuary Prawn Trawl Fishery 0.5%. During this period 87% of snub-nosed garfish were reportedly captured using the method of bullringing, 5% from hauling nets (general purpose, trumpeter whiting or garfish), 4% from mesh nets, 3.5% from the garfish haul net, and the remainder from estuarine prawn trawl and prawn set pocket nets.

The Clarence river reports more than 90% of the NSW landings of snub-nosed garfish (with adjustments for misreporting as river garfish) (Fig. 2.28). The Camden Haven River reports around 7% of the states landings, with the final 3% being reported mainly from the Hastings and Macleay Rivers and Wallis Lake.

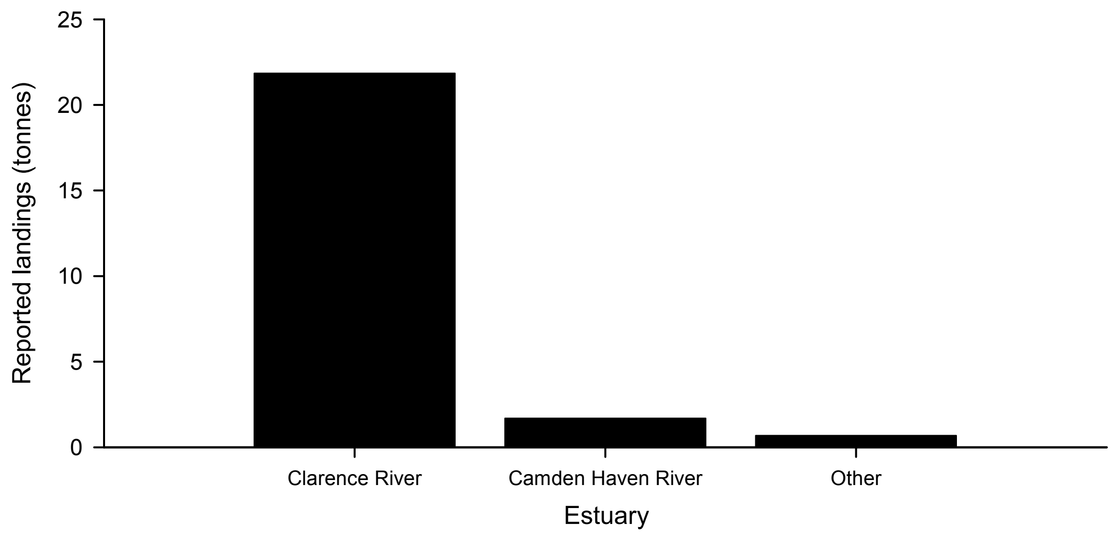


Figure 2.28. Total reported landings of snub-nosed garfish in NSW by estuary between 1999/00 and 2002/03.

The number of fishers reporting snub-nosed garfish catches (including river garfish reported from the Clarence River) has declined since the mid 1990's (Table 2.5). The fishery has relatively few major participants and during 2002/03 90% of the catch was taken by only 7 fishers. Each year there were many fishers who reported less than 5kg of snub-nosed garfish.

The average catch of snub-nosed garfish for the top 10 fishers each year (Fig. 2.29) showed a similar trend to the adjusted total landings for snub-nosed garfish (Fig. 2.26). The overall catch per fisher reporting snub-nosed garfish was highly variable.

Table 2.5. Total reported landings of snub-nosed garfish in NSW (including those reported as river garfish from the Clarence River), the number of fishers reporting snub-nosed garfish on their catch returns, and the number of fishers to take 90% of the catch each year since 1991/92.

Year	Landings (t)	No. fishers reporting snub-nosed garfish	No. fishers to take 90% of catch
1991/92	12.40	53	12
1992/93	5.69	67	12
1993/94	8.70	62	12
1994/95	14.04	71	12
1995/96	7.87	68	9
1996/97	11.70	61	10
1997/98	10.68	70	14
1998/99	9.33	65	11
1999/00	6.12	72	13
2000/01	4.88	49	11
2001/02	7.44	43	12
2002/03	5.38	30	7

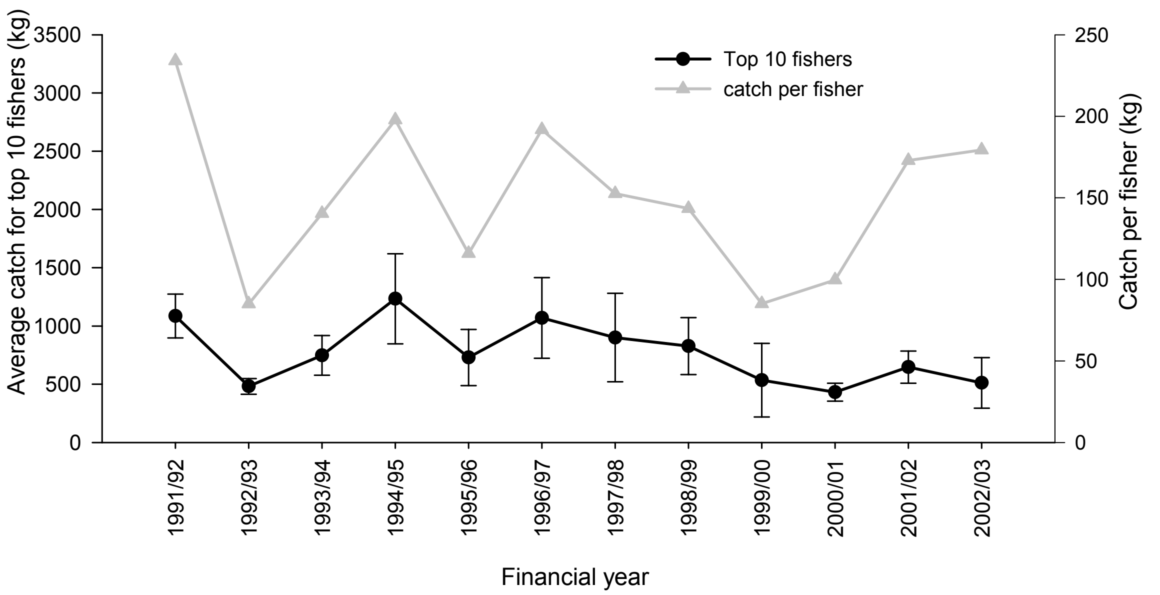


Figure 2.29. Average catch of snub-nosed garfish per fisher, and average catch (± S.E.) for the top 10 fishers each year 1991/92 to 2002/03.

The index of CPUE based on catch and days of effort using the method of bullringing since 1997/98 ranged between approximately 14 kg and 34 kg per day (Fig. 2.30). The yearly trend is similar to that shown by the average catch for the top 10 fishers each year (Fig. 2.29), except for between 1997/98 and 1998/99 when it showed a slight increase.

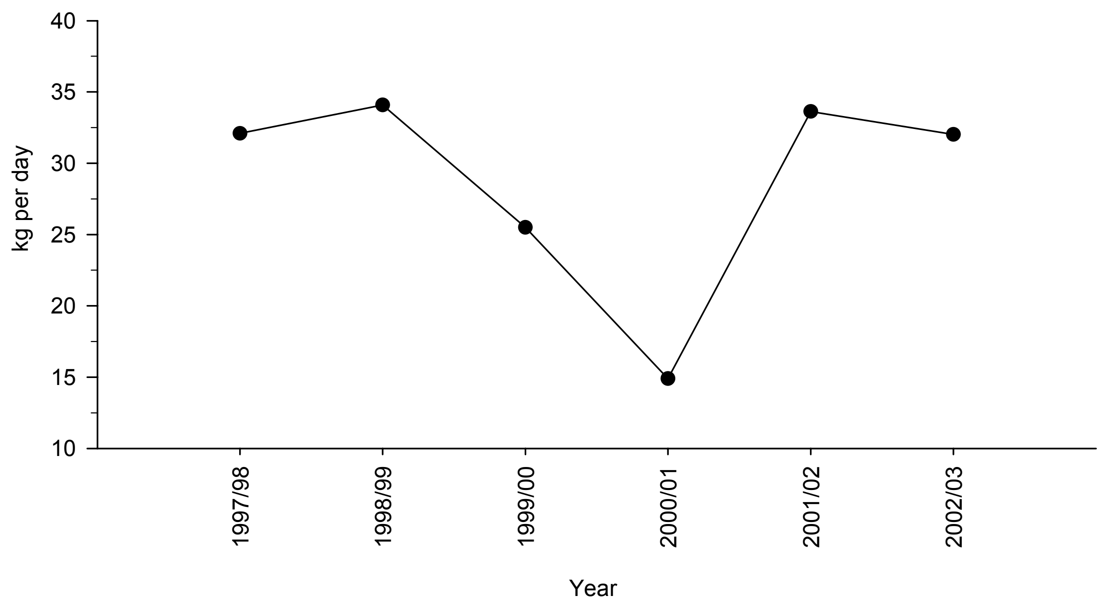


Figure 2.30. Reported landings (kg) per day of snub-nosed garfish (including those reported as river garfish from the Clarence River) using the method of bullringing since 1997/98.

2.3.9. Sizes in commercial landings

The sizes of snub-nosed garfish landed by commercial fishers from the Clarence River varied between years sampled (Fig. 2.31). Fish were, on average, larger in each consecutive year, however it should be noted that only 1 catch was sampled in 2003/04. These landings were all taken by the method of bullringing. Snub-nosed garfish caught as a by-catch when using running nets targeting prawns were significantly smaller than those caught using the method of bullringing (Fig. 2.32). Snub-nosed garfish caught as a by-catch when targeting prawns make a negligible contribution to the total catch of snub-nosed garfish in NSW. Fishers reported using nets of 1 1/4 inch and 1 1/2 inch mesh, however there was no difference in the sizes of snub-nosed garfish landed between different reported mesh sizes (Kolmogorov-Smirnov test, P = 0.05).

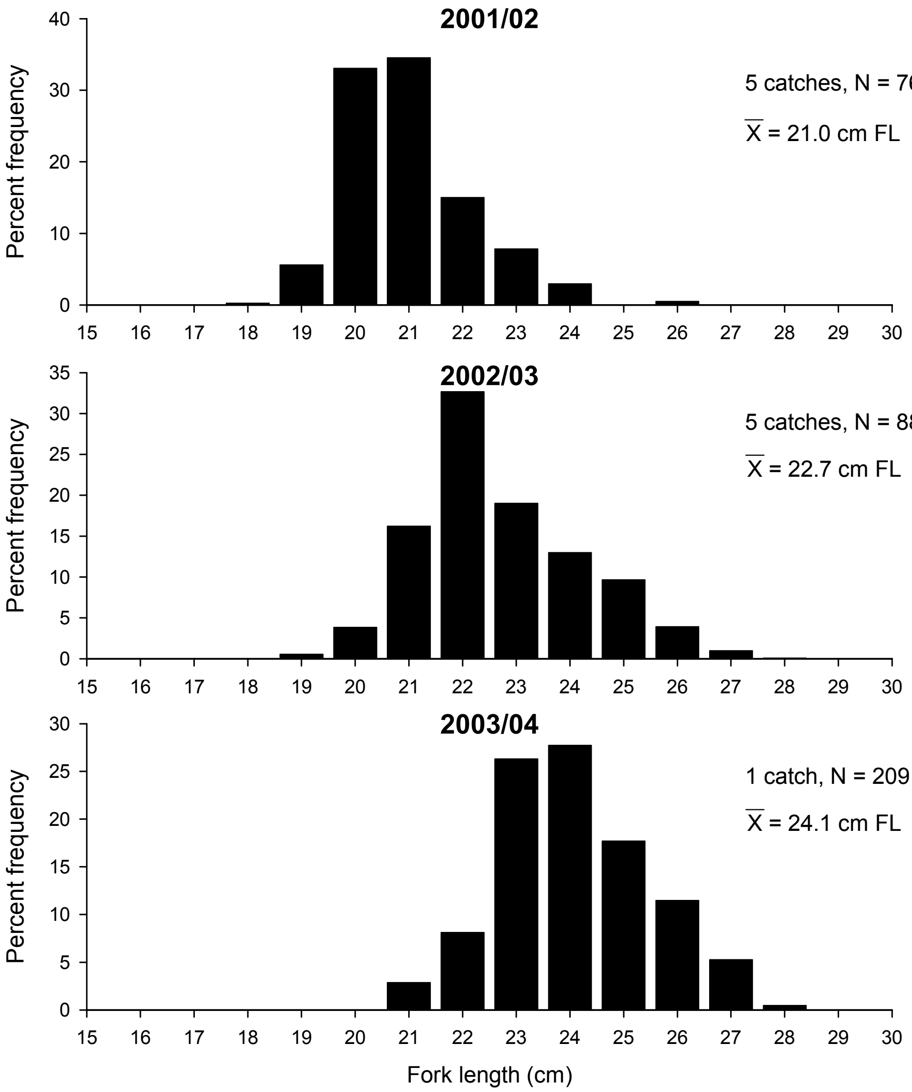


Figure 2.31. The sizes of snub-nosed garfish in commercial landings from the Clarence River between 2001/02 and 2003/04.

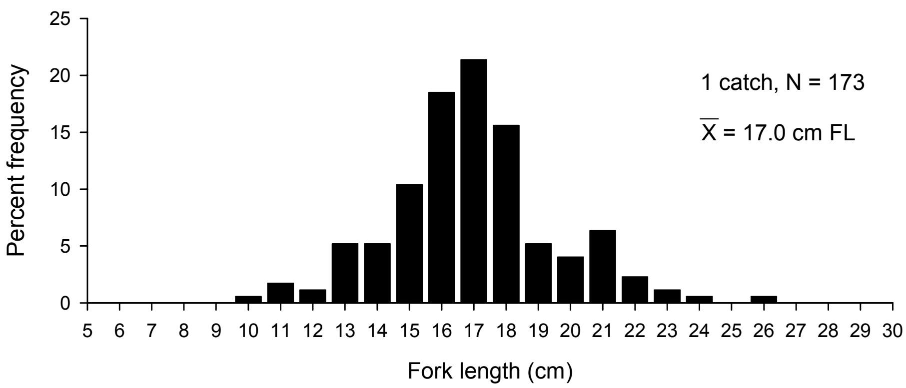


Figure 2.32. The sizes of snub-nosed garfish caught as by-catch when targeting prawns using running nets in the Clarence River.

2.3.10. Morphometric Relationships

The relationships between FL, TL, SL and LJFL for each species were linear with high R^2 values (Table 2.6). The relationships between FL and body weight (Wt) were described by power relationships for each species, with snub-nosed garfish being slightly heavier (on average) than river garfish, that were slightly heavier (on average) than sea garfish for any given length (Fig. 2.33).

Table 2.6. Relationships between different length measurements (mm), and between length and weight (Wt) in grams for sea, river and snub-nosed garfish. FL = fork length (from tip of upper jaw to the fork in the caudal fin), TL = total length (from the tip of the upper jaw to the extremity of the caudal fin), SL = standard length (from the tip of the upper jaw to the caudal base), LJFL = lower jaw to fork length (from the tip of the lower jaw to the fork in the caudal fin).

Species	Comparison	Relationship	R^2	n
Sea garfish	TL - FL	TL = 1.063 x FL - 0.897	0.9944	383
Sea garfish	SL - FL	SL = 0.961 x FL - 2.227	0.9983	384
Sea garfish	TL - SL	TL = 1.105 x SL +1.861	0.9938	383
Sea garfish	FL - LJFL	FL = 0.870 x LJFL - 12.317	0.9829	376
Sea garfish	Wt - FL	$Wt = 6 \times 10^{-7} \times FL^{3.379}$	0.9881	1329
River garfish	TL - FL	TL = 0.929 x FL + 1.040	0.9928	203
River garfish	SL - FL	SL = 0.943 x FL - 2.083	0.9920	181
River garfish	TL - SL	TL = 1.140 x FL = 2.665	0.9883	180
River garfish	FL - LJFL	FL = 0.881 x LJFL - 8.438	0.9892	218
River garfish	Wt - FL	$Wt = 2 \times 10^{-6} \times FL^{3.255}$	0.9701	1793
Snub-nosed garfish	TL - FL	TL = 1.081 x FL + 4.098	0.9871	40
Snub-nosed garfish	FL - LJFL	FL = 0.990 x LJFL - 4.214	0.9946	20
Snub-nosed garfish	Wt - FL	$Wt = 2 \times 10^{-6} \times FL^{3.251}$	0.9697	509

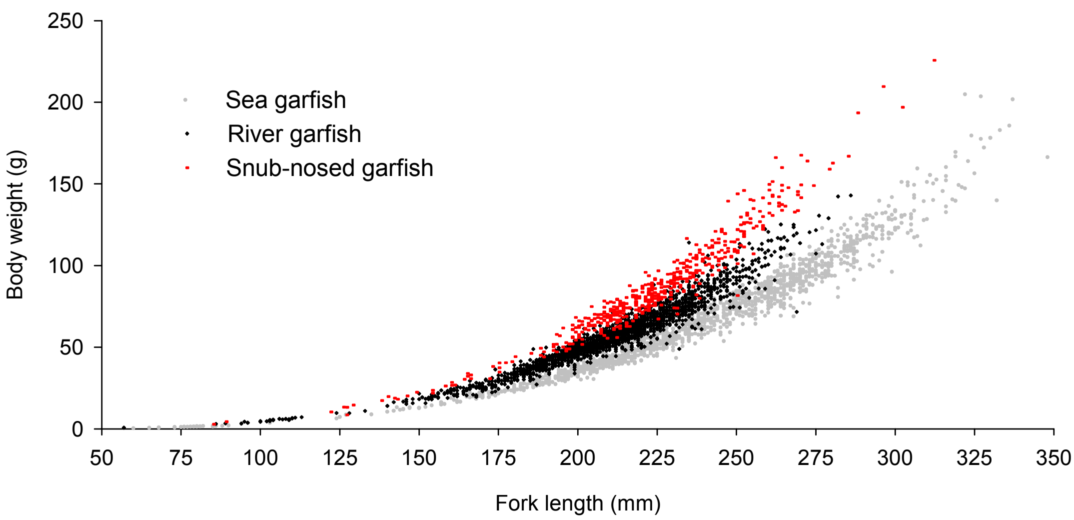


Figure 2.33. Relationships between fork length (mm) and body weight (g) for sea, river and snub-nosed garfish.

2.4. Discussion

Sea garfish

Analyses of the reported landings of sea garfish show that the fishery is distinctly seasonal and that this season varies with latitude (Figs. 2.6, 2.7 & 2.8). South of Sydney the garfish season usually starts in either December or January, depending on water conditions. The fish tend to increase in size as the season progresses (see Fig. 2.12) and catches have usually declined by around May. It should be noted that most fishers who target sea garfish also target the annual spawning run of sea mullet. When the mullet are running fishers stop targeting sea garfish. South of Sydney this usually occurs between March and April each year.

North of Sydney the sea garfish season tends to be later in the year with peak landings (since 1999/00), reported between April and June. The sea mullet run occurs during April and May in the major ports of Port Stephens and Wallis Lake each year, therefore providing a certain amount of protection from fishing for sea garfish during these months. Sea garfish landed north of Sydney tend to be smaller, on average, than those from south of Sydney (Fig. 2.13). This may be due to: (i) an abundance of small fish (from the previous years spawning) at this time, and; (ii) the use of garfish haul nets with small (25mm) mesh by most fishers in this area. The legal mesh size for use in garfish haul nets has recently been increased to 28mm and future monitoring of the size composition of landings should indicate whether this change has had the desired effect of preventing capture of these young fish.

Yearly variation in the sizes of sea garfish landed, particularly north of Sydney, may reflect: (i) changes in the relative abundance of older fish, or previous strong cohorts; (ii) variation in the growth rates of fish from the previous years age class, or; (iii) differences in the fishing operations of some fishers. For example, it was previously common for boat-based fishers from other regions to travel to the Wallis Lake area specifically to target extra large sea garfish, whereas local operators tended only to target them when readily available.

Yearly differences in the sizes of sea garfish landed may provide information on the health of the fishery. The observed annual pattern in sizes of sea garfish landed was reasonably well reflected by the relative quantities of fish of various size-gradings being sold through the Sydney Fish Markets (Fig. 2.16). This indicates that sea garfish that were sent to the Sydney Fish Markets during this study were reasonably representative of the sizes of fish that were landed (or at least the sizes of fish that we measured at their point of landing). This may not always be the case, as at times large fish are exported overseas and very small fish are sold as bait. However, when it is known that these alternative markets are either non-existent, or only small, then monitoring the quantities of sea garfish by size-grade being consigned to the Sydney Fish Markets may provide a cost-effective method for monitoring the fishery.

Recent large declines in landings of sea garfish have been attributable to a scarcity of fish from south of Sydney, and also from the far north coast of NSW (Table 2.2, Figs. 2.7 & 2.8). Fishers from these areas report a lack of fish as being the major reason for the small landings. Such evidence is plausible, as selling sea garfish can be lucrative and fishers are therefore likely to target sea garfish when they are available. There may be many reasons for the observed lack of sea garfish on the south and far north coasts of NSW. The stock may have been fished down significantly, and it is conceivable that their distribution may have contracted towards the centre of their range (i.e. the central coastal region of NSW – see Kailola et al., 1993). Landings from this central region (i.e. ocean zone 5) have been relatively stable (Figs. 2.7 & 2.8) whereas those from the extremity of the range of sea garfish have declined.

The catching of sea garfish at small sizes may not achieve the maximum biological or economic yield from the resource. The prices paid for different size-gradings at the Sydney Fish Markets (Table 2.3) show that 'large' and 'extra-large' sea garfish fetch average prices of up to 6 times those paid for 'small' fish. The significantly higher prices paid for large and extra-large sea garfish suggest that the value of the fishery is governed by the relative proportions of these sized fish in landings.

Analyses of the reported landings and effort in the sea garfish fishery suggest that the fishery is at a historically low level. Total landings (Fig. 2.5), the number of fishers active in the fishery (Table 2.1), and 3 indices of CPUE (catch per fisher, catch per fisher for the top 10 catchers each year, and catch per day of garfish hauling – Figs. 2.9 & 2.10) all show declines during recent years. Improved reporting through fishers monthly catch returns is a priority within the NSW DPI, and its importance in future monitoring of the sea garfish fishery in NSW cannot be overstated. While all 3 indices of CPUE showed similar patterns we suggest that, as garfish haul nets are used almost exclusively to target sea garfish, that the best index of effort may be days of effort using this net. A trial daily logbook to collect information on the catch and number of shots each day has begun to see whether a more refined index of CPUE can be developed. From a management perspective, the relative efficiency of beach versus boat-based fishers targeting sea garfish is important. Unfortunately the current catch return forms do not differentiate between beach and boat-based catches and the trial daily logbook will also collect this information.

It is important to note that while total catch and CPUE information may be useful indicators of the status of the sea garfish fishery, it is changes in the age-structure of the exploited population that will provide the most powerful tool to assess the status of the stock. Chapter 3 describes variation in size-at-age, longevity and the age-structures observed in the fishery each year.

River garfish

The historical reported landings of river garfish in NSW are difficult to interpret. Landings fluctuated between approximately 80 and 100 tonnes per year between the 1950's and the early 1970's. Following 2 years of very high landings (1973/74 & 1974/75) a large decline occurred during the next 3 years. Landings have been relatively stable since 1978/79 at around 37t per year (Fig. 2.17). The large decline in landings in the mid 1970's is likely to be an artefact of several management and reporting changes rather than a real indication of declining stock levels. Changes to the format of the monthly commercial fishers catch return forms during the early 1970's (Form 50) and then again in 1977 (Form 49) are the most likely explanation for the decline in reported landings of river garfish during this period. Several management changes such as the removal of a minimum legal length of 8.5 inches sometime during the late 1960's/early 1970's and a reduction in the temporal closure for taking garfish in estuaries from 5 months (Sept to Jan) to only 2 months (Dec & Jan) during the mid 1960's could have been expected to have resulted in significant increases in landings. No such increases were observed.

Lake Illawarra, Wallis Lake, Tuggerah Lakes and the Port Stephens estuary are the only commercially important estuaries for river garfish in NSW (Figs. 2.19 & 2.20). River garfish reported from the Clarence River appear to have been misreported (they are actually snub-nosed garfish), and St Georges Basin has been made a recreational fishing only estuary (since May 2002). By sampling commercial landings of river garfish from Lake Illawarra, Wallis Lake and Tuggerah Lakes we feel we have achieved a thorough understanding of the state-wide fishery for river garfish.

The fishery for river garfish is distinctly seasonal, peaking during winter/spring (Fig. 2.18). We suggest that the fishery peaks during these seasons for 2 main reasons: (i) river garfish aggregate over shallow weed beds at this time of year to reproduce (Chapter 4) and are therefore more easily caught, and; (ii) there are few other species to target in the estuaries during these months and fishers target river garfish by necessity in order to earn a living.

Reported commercial landings of river garfish have declined slightly each year since 1999/00 (Fig. 2.17), however this appears to be due to a reduction in the number of fishers catching river garfish (Table 2.4). We consider the index of CPUE of reported catch per day using the method of bullringing to be the best indicator because bullringing is used to specifically target garfish. This index of CPUE showed a slight increase after 1999/00 and has been stable since, suggesting that the relative abundance of river garfish has been constant since this time. The 2 other indices of CPUE (catch per fisher, and catch per fisher for the top 10 fishers each year) show declines since 1999/00 but are likely to be less informative as they do not account for actual fishing effort, but rather fisher participation.

The sizes of river garfish observed in commercial landings were consistent between years in the estuaries sampled (i.e. Fig 2.24). This is not surprising if the gears used to catch the fish were similar each year in each estuary. Bullringing nets are essentially used as mesh nets, the selectivity properties of which have been well described (Hamley, 1975). The size distribution of fish retained in such nets may not provide a representative sample of fish in the population. River garfish landed from Wallis Lake were generally smaller than those landed from Lake Illawarra (Fig. 2.25). There is some evidence that river garfish from Lake Illawarra grow faster and larger than those from Wallis Lake (Chapter 3), however the most likely reason for the observed size differences is a difference in gear design between the 2 estuaries.

Snub-nosed garfish

The commercial fishery for snub-nosed garfish in NSW is small when compared to the fisheries for sea and river garfish. Reported commercial landings of snub-nosed garfish have been less than 15 tonnes each year since the mid-1980's, and less than 10 t each year since 1997/98 (Fig. 2.26). The fishery is largely restricted to the Estuary General Fishery in the Clarence River . The fishery for snub-nosed garfish is seasonal, peaking during the winter months. There is a closure on taking this species in estuaries during December and January. There are few dedicated participants in the fishery for snub-nosed garfish with only 7 fishers reporting more than 90% of the total catch during 2002/03 (Table 2.5).

Two indices of CPUE (catch per fisher, and average catch per fisher for the top 10 catchers each year) are likely to be of little use because of the very small number of dedicated fishers and the relatively large number of fishers that report very small (<5kg) quantities of snub-nosed garfish each year. The index of CPUE based on reported catch per day using the method of bullringing is likely to be the best indicator of relative abundance for snub-nosed garfish. This index has ranged between approximately 14 and 34 kg per day since 1997/98 however there is no obvious trend during this time.

One issue that needs to be addressed for the fishery for snub-nosed garfish is the misreporting of the majority of the catch taken in the Clarence River as river garfish. This has occurred because the only garfish species listed on the Estuary General Fishery catch return form is river garfish. Fishers who want to report snub-nosed garfish landings must write the species name in themselves, and probably find it easier to record them under the listed garfish species on the form. This misreporting is easily addressed by inserting the species snub-nosed garfish in the species list, and should be done as soon as is possible to minimise the misreporting that has been occurring.

The sizes of snub-nosed garfish landed by fishers using bullringing nets varied between each year of the study (Fig. 2.31). This variation was likely due to different commercial fishers being active during different years of the study and each using slightly different nets. One fisher, who's catches was sampled regularly during 2001/02, retired after that year and the main fisher sampled during 2002/03 was not fishing during the previous year. While we found no significant differences in the length-composition of snub-nosed garfish caught in nets reported to consist of 1 1/4 and 1 1/2 inch mesh, we did not measure the mesh sizes and relied on fishers reported mesh-sizes only. It is likely that some fishers nets consisted of several mesh sizes and any differences in net design (i.e. hanging ratio of the mesh and twine material) will have changed the net selectivity and masked the effect of variations in mesh size.

3. AGE, GROWTH AND A PRELIMINARY STOCK ASSESSMENT

John Stewart & Julian Hughes

SUMMARY

A method to determine the age of sea, river and snub-nosed garfish was developed using sectioned sagittal otoliths. Sectioned otoliths of sea garfish showed inconsistent and confusing patterns of opaque and translucent zones that were difficult to interpret. A mean CV of 19% for sea garfish otoliths read twice reflected the relatively low precision in ageing this species. River and snub-nosed garfish however, showed distinct and easily counted opaque and translucent zones. Mean CV's of 3.2% and 8.8% respectively for otoliths read twice reflected the high precision in ageing these species. The periodicity of opaque zone formation was validated by: (i) marking captive, wild caught, sea and river garfish with vital stains (tetracycline and alizarin) and periodically examining their otolith growth; (ii) monthly otolith marginal increment analyses; (iii) examining changes in the otolith edge status through the year and; (iv) examining the otoliths from known young-of-the-year fish. The results showed that opaque zones in otoliths of all 3 species were formed during winter/spring but did not become visible on the otolith edge until summer. This information allowed the development of a model of otolith growth and protocols for converting counts of opaque zones into age classes.

Estimates of age showed maximum ages of 4 years for sea garfish and 7 years for river and snub-nosed garfish. Growth was modelled by fitting the von Bertalanffy growth curve to size-at-age data for each species. Growth was rapid in all 3 species with estimated sizes at age 1 year being 23 cm FL for sea garfish, 16 to 20 cm FL (depending on the estuary sampled) for river garfish and 17.5 cm FL for snub-nosed garfish. There were differences in growth rates between sexes with females growing faster and reaching larger sizes than males in all 3 species. There was no difference in growth rates between male and female sea garfish until after their first year. River garfish from Lake Illawarra grew faster and reached larger sizes than those from either Tuggerah Lakes or Wallis Lake. Sea garfish growth rates were also estimated using monthly measurements of fish in commercial landings. These data showed sea garfish recruiting to the fishery at around 20 cm FL between May and September and this cohort could be followed, growing at around 1 cm per month between May and July, until they left the fishery at around 3 years of age. Estimates of the von Bertalanffy growth curve parameters were made using the ELEFAN length-frequency program and were similar to our age-based estimates.

The age compositions of the 3 garfish species in commercial landings were determined by applying age-length keys to the length frequency data described in Chapter 1. The commercial fishery for sea garfish during 2001/02 and 2002/03 was based almost exclusively on fish in their second year (60%) and first year (nearly 40%) with a few fish in their 3rd year of life. The ages of river garfish in commercial landings between 2001/02 and 2003/04 from Lake Illawarra, Tuggerah Lakes and Wallis Lake were similar. River garfish in commercial landings ranged from less than 1 year to 7 years old with approximately 60-80% being in their 3rd and 4th years of life. Landings of snub-nosed garfish during 2001/02 and 2002/03 were dominated (75%) by fish in their 2nd and 3rd years of life. Landings of snub-nosed garfish during 2003/04 were characterised by a lack of 1 year old fish.

Total instantaneous mortality rates (Z) were estimated using catch curves based on the age composition in commercial landings for each species and year studied. Sea garfish were considered to be fully recruited to the fishery by age 1 and river and snub-nosed garfish by age 2. Natural mortality (M) was estimated using maximum ages (Hoenig, 1983) and the von Bertalanffy growth function parameters and water temperature (Pauly, 1980). Fishing mortality (F) was determined by subtracting M from Z. The results showed that Z for sea garfish is currently extremely high and that more than 95% of sea garfish die each year after being recruited to the fishery at age 1. Estimates for M of between 0.75 and 0.81 and F of between 2.19 and 2.65 indicate that sea garfish are likely to be seriously over-exploited. Total mortality estimates for river garfish were considerably lower than those for sea garfish and ranged between 0.77 and 1.09, corresponding to between 53 – 66% of river garfish 2 years and older dying each year. Estimates of F (0.34 – 0.86) were slightly greater than estimates of M (0.23 – 0.43) in each estuary, indicating that the fisheries are likely to be slightly over-exploited. Mortality rates for snub-nosed garfish were similar to those for river garfish and Z ranged between 0.75 – 1.29.

We used estimates of growth and mortality rates with information on the reproductive biology of each species (Chapter 4) to generate preliminary stock assessments based on per recruit analyses. Yield per recruit (YPR), egg per recruit (EPR) and spawner biomass per recruit (SBPR) analyses were done based on the method of Beverton & Holt (1957). YPR models for each species showed indefinite increases for increasing F. These models do not account for reductions in reproductive outputs and the potential for stock collapse and should be discounted. Sea garfish EPR and SBPR models indicated present levels of between 10 – 25% of the unexploited stock. These low levels, combined with high levels of fishing pressure and the life-history of this species (short-lived with recruitment likely to be variable and dependant upon environmental conditions) suggest that the stock of sea garfish is in danger of recruitment failure. Recent attempts to reduce fishing pressure (commercial only) need to be carefully monitored and, if no improvements in stock levels are seen then further measures to protect the stock will be required. The recreational catch of sea garfish should also be restricted. Stocks of river and snub-nosed garfish are also heavily exploited with EPR and SBPR levels predicted to be at around 40% of unexploited levels. The fisheries for these 2 species appear sustainable at current levels of exploitation but require careful monitoring.

3.1. Introduction

Information on the age of fish is fundamental to understanding their life-histories and exploitation status. Estimates of size-at-age and age composition can be used to model growth and mortality rates, which can be used to predict how a stock will respond to exploitation and management changes. The technique of estimating fish age by counting annual marks within calcified structures (i.e. otoliths, scales, vertebrae and spines) has been well documented (Beamish & McFarlane, 1983; Beckman & Wilson, 1995). Of these, otoliths are the most frequently used structure to estimate age (Secor et al., 1995). Several previous studies on species of the family Hemiramphidae have used scales (Berkeley & Houde, 1978; Sokolovsky & Sokolovskaya, 1999), whole otoliths (Ling, 1958), sectioned otoliths (McBride & Thurman, 2003; Jones et al., 2002; and Jordan et al, 1998), and whole otoliths broken and burnt (Jones, 1990) to estimate age. Scales are easily shed when eastern sea garfish are handled and previous studies appear to have under-estimated the age of garfish using scales (e.g. Berkeley & Houde 1978 – *Hemiramphus brasiliensis* and *He. balao*). Scales were therefore not considered as a useful structure for age estimation. The most recent and comprehensive studies (McBride & Thurman, 2003 and Jones et al., 2002) used sectioned otoliths and consequently we also used sectioned otoliths to estimate age in each species studied.

Validating the ageing technique used is paramount in any study and should include: (i) verifying that there are periodic marks formed within the structure studied; (ii) that these marks can be reliably identified, and; (iii) that counts of these marks can be accurately converted into age classes

(Campana, 1992; Francis et al., 1992). In this chapter we validate the periodicity and identification of opaque zones within garfish otoliths by: (i) marking fish with a vital stain and keeping them in aquaria; (ii) marginal increment analyses; (iii) examining the periodic pattern in otolith edge status – (opaque or translucent), and; (iv) examining the size and structure of otoliths from young-of-the-year fish.

Prior to this study there were no published studies that have estimated the age of any species of garfish in NSW. This is likely to have been a result of: (i) the relatively low value of the commercial and recreational fisheries for garfish in NSW, and; (ii) the difficulty in interpreting opaque zones in their otoliths. We could only find references to age estimation for 4 species from the genera *Hyporhamphus* and *Hemiramphus* (*Hy. sajori, Hy. melanochir, He. brasiliensis* and *He. balao,)* despite these genera comprising a total of 33 species. Species previously studied have been characterised by having relatively fast growth rates and being short to moderately long-lived. Maximum ages of *He. brasiliensis* and *He. balao* in Florida USA, have been reported as 4 and 2 years respectively (McBride & Thurman, 2003) and the maximum age of *Hy. sajori* in Japan as 2 years (Sokolovsky & Sokolovskaya 1999). The southern sea garfish (*Hy. melanochir*) has been reported up to 10 years old in southern Australia (Jones, 1990; Jones et al., 2002).

In this chapter we present estimates of ages based on counts of opaque zones in otoliths of sea, river and snub-nosed garfish. These estimates of size-at-age are used to model and compare growth rates between species, sexes and locations, and to generate estimates of the age structures present in commercial landings. These age structures are then used to estimate total mortality rates. Preliminary assessments of the stocks of sea, river and snub-nosed garfish are made in terms of yield, egg and spawner biomass per recruit analyses.

3.2. Materials & methods

3.2.1. Age estimation

We used sagittal otoliths to estimate age for all three species of garfish studied and the following methodology was applied. Otoliths were accessed ventrally by removing the gills, scoring the thickened region of the vertebrae with a scalpel blade and snapping the head back. The otoliths were removed using forceps, cleaned and stored in small envelopes containing information on the sample. The sex of the fish was determined from a macroscopic examination of the gonads (see Chapter 4).

Estimates of ages were made from sections of otoliths. One of each pair of sagittal otoliths was embedded in resin, sectioned transversely through its centre and the section mounted on a glass slide. The slide was then viewed under a compound microscope using reflected light against a black background. Opaque zones were evident in sections of otoliths viewed this way and were scored as annual marks. Measurements were made from the core of the sectioned otolith to the centre of each successive opaque zone and to the otolith edge. All measurements were made along the ventral edge of the sulcus using a microscope mounted video camera interfaced with a computer running 'Image Pro Plus' image analysis software.

3.2.2. Validation of ageing method

3.2.2.1. Marking otoliths with a vital stain

To examine otolith growth and the timing of opaque zone formation and appearance in the otoliths of sea and river garfish, we used a vital stain to mark the otoliths of wild-caught captive fish.

Experiment 1 – tetracycline marking

Sea garfish

A commercial fisher using a garfish haul net captured 360 live sea garfish for us on the 12th April, 2002. These fish were placed in a 300 litre (l) aerated tank and transported by boat to the aquaria facilities at the Cronulla Fisheries Centre. They were placed in 4500 l round tanks and given a mild antibiotic bath (oxytetracycline solution at 100 grams per 1000 l) to reduce the risk of infection from being captured. Unfortunately, the process of capture and handling caused severe scale loss and 358 fish died within a few days of capture. Subsequently, sea garfish were captured at night using a spot-light and dipnet from a fisheries research vessel at the mouth of Port Hacking between 15th April and 7th May 2002. After being transported to the aquaria facilities at the Cronulla Fisheries Centre, the fish were treated with formaldehyde (150 mg/l for 1 hour) to remove parasites and given a mild antibiotic bath (oxytetracycline solution at 100 grams per 1000 l) to reduce the risk of infection from being captured.

Sea garfish were injected with tetracycline on the 27th May, 2002. Tanks were lowered to volumes of 1000 l and the fish lightly sedated with 50 ml of benzocaine solution (Ethyl-p-amino benzoate dissolved in 100% ethanol at 1 g/10ml). Individual fish were anaesthetised in a saltwater benzocaine bath (50mg/l of benzocaine), weighed to the nearest gram, measured (as fork length to the nearest mm) and given an intraperitoneal injection of tetracycline (Engemycin 100 - oxytetracycline hydrochloride at 100mg/ml) at a dose of 75 - 100mg/kg body weight. The solution was administered using a 1 ml syringe and 29 gauge needle. Fish were then placed in an 80 l aerated tank to recover from the anaesthetic. They were then moved to another 4500 l tank with aeration and flowing seawater at ambient temperatures and salinities.

River garfish

River garfish were captured at night using a spot-light and dipnet from a fisheries research vessel in Port Hacking between 26th February and 15th May 2002. They were transported to the Cronulla Fisheries Centre and treated in a similar manner to the sea garfish. River garfish were injected with tetracycline on 21st May, 2002. The fish were sedated, anaesthetised and handled in the same way as for sea garfish. Tetracycline in the form of Engemycin 100 (oxytetracycline hydrochloride at 100mg/ml) was diluted in saline solution to 2 different concentrations (5mg/ml and 2mg/ml). The appropriate dilution was determined based on the weight of the fish being injected and the volume of tetracycline required.

Experiment 2 – Alizarin complexone marking

Due to a pump malfunction that caused the death of most of the fish treated with tetracycline in early October 2002 a second marking experiment was done. The process of handling and injecting garfish with tetracycline caused significant mortality and relatively low levels of successful otolith marking (see Results). Therefore we investigated the technique of immersion in alizarin complexone solution to stain otoliths. A series of experiments were done to determine the optimum dose rate and immersion time for marking garfish with alizarin complexone. The following procedure was used:

Sea garfish

Sea garfish were caught at night using a spot-light and dipnet from a fisheries research vessel at the mouth of Port Hacking during January 2003. The fish were treated and acclimated in 4500 l tanks as in the previous experiments. On the 3rd February these sea garfish were immersed in an alizarin bath at a concentration of 30 mg/l to stain their otoliths. After 5 hours a lot of fish were showing signs of stress, apparently from a lack of oxygen, and the bath was diluted to around 15mg/l by adding fresh seawater. Additional oxygen was put into the bath and the fish left for a further 19 hours. Thirty-eight sea garfish died during the immersion bath. Surviving fish were sampled monthly to examine their otolith growth subsequent to the alizarin mark.

The otoliths from all fish were examined after the experiment was terminated. Otoliths were sectioned as described in 3.2.1 and viewed under a dissecting microscope using reflected light against a black background. The alizarin marks were visible under this light and the distances from the otolith core to the alizarin mark, to any identified opaque zones and to the otolith edge were measured.

River garfish

River garfish were captured at night using a spot-light and dipnet from a fisheries research vessel in Port Hacking during December 2002 and January 2003. These fish were treated in a similar manner to the sea garfish but were placed in a separate 4000 l tank. On the 23rd January 2003 these fish were given a 24 hour bath in alizarin at a concentration of 30 mg per l to stain their otoliths. Three small river garfish died during the immersion. Fish were sampled monthly to examine their otolith growth subsequent to the alizarin mark and were analysed in the same manner as for sea garfish.

3.2.2.2. Marginal increment analyses

Marginal increment analyses were used to examine the periodicity of opaque zone appearance in the otoliths of garfish. The marginal increment was defined as follows: for fish with no opaque zones as the distance (in mm) from the core to the otolith edge along the ventral edge of the sulcus; for fish with 1 opaque zone as the distance from the first opaque zone to the otolith edge as a proportion of the first complete annulus, and; for fish with 2 or more opaque zones as the distance from the most recently completed opaque zone to the otolith edge as a proportion of the last completed increment. These measurements were made for all garfish collected for age determination. The sizes of these marginal increments through time were used to describe the periodicity of annulus formation and also in converting counts of opaque zones into ages.

3.2.2.3. Otolith edge status

The otolith margin from each fish was assigned as being either opaque or translucent when its section was examined for age determination. This edge status was subjective, often difficult to determine and was assigned as being translucent when uncertain. The timing of appearance of opaque otolith edges was used to examine annual periodicity in otolith growth.

3.2.2.4. First increment formation

The timing of the first increment formation was assessed using the staining experiments described above (where young-of-the-year fish were used) and by sampling very small young-of-the-year fish from commercial catches. It is common for some very small sea garfish to be caught in catches of large sea garfish when brought onboard and these were donated by commercial fishers. These otoliths were sectioned as described above and their sizes and internal structure used to support our interpretations of what constituted the first annual increment.

3.2.3. Otolith size and weight versus estimated age and fish length

For a structure to be of use in estimating age, it must grow throughout the life of the fish. To determine whether sagittal otoliths grow throughout the lives of garfish, otolith radii and weights were plotted against fork length and age for each species. Otolith radius was measured as the distance from the core to the edge along the ventral edge of the sulcus in sectioned otoliths. Otolith weight for each fish sampled was the average of the weights of the left and right otoliths.

3.2.4. Development of ageing protocol

Sectioned otoliths were examined using a dissecting microscope with reflected light against a black background. The microscope and image analysis software was as described above. Measurements from the core to each opaque zone and to the otolith edge were taken and pasted into excel spreadsheets, along with information on the edge status (opaque or translucent) and the readability of the section.

An ageing protocol was developed for each species based on a universal birth date (set at the middle of the spawning season – see Chapter 4), the number of opaque zones counted, the state of the otolith edge (either wide or opaque as defined below) and the month of capture.

Two hundred otoliths from each species were re-read at least 3 weeks after their first read to examine the precision of our estimates of counts of opaque zones. The coefficient of variation (CV) for the two readings for each otolith was calculated and an average across all otoliths for each species obtained after the method described in Kimura and Lyons (1991), and Campana (2001).

3.2.5. Growth rate determination

3.2.5.1. Age-based growth

The size-at-age data for the 3 species were fitted to the von Bertalanffy growth function:

$$L_t = L_\infty [1 - e^{-k(t - t_o)}]$$

Where L_t is the length at age t, L_∞ is the asymptotic length, k is the rate at which the curve approaches the L_∞, and t_0 is the hypothetical age of the fish at zero length.

Growth curves were compared using the technique of Kimura (1980) where 95% confidence ellipses were generated around the parameter estimates of k and L_∞. Confidence ellipses that did not overlap indicated differences in growth parameters. The mean sizes of fish for any given year class were compared using t-tests.

3.2.5.2. Length-based growth

Sea garfish

In addition to our age-based estimates of growth we examined the sizes of sea garfish landed by commercial fishers during the project. Lengths measured between December 2001 and May 2004 were pooled by month. We did not sample sea garfish in August, October or November in any of the years because the fishery was not active during these months. We used data for these months from a previous study done by NSW Fisheries in 2000/01 where sea garfish were measured at the Sydney Fish Markets.

The ELEFAN length-frequency analysis module built into the FiSAT computer program (Gayanilo et al., 1997) was used to estimate the von Bertalanffy growth function parameters k and L_∞ for the sea garfish monthly length data.

We did not have suitable length data for river and snub-nosed garfish to estimate their growth rates.

3.2.6. Estimation of age structures in landings

Estimates of the age compositions in commercial landings of the 3 garfish species studied were made using the size compositions determined in Chapter 1 and age-length keys. The age-length keys were determined after the methods of Kimura (1977) and Lai (1993) and were constructed using the estimates of size-at-age determined in this chapter.

3.2.7. Estimation of mortality rates

Estimates of total mortality (Z) were made from the slope of the descending limb of the catch curve (i.e. by regressing the natural logarithm of the abundance of fish at age against that age for all fully recruited age classes). Sea garfish were considered to be fully recruited to the fishery by age 1 year and river garfish and snub-nosed garfish by age 2 years.

Two independent empirical estimates of mortality were also made based on maximum age and water temperature. An estimate of natural mortality (M) was made after the method of Hoenig (1983) for exploited populations where:

$$M = -\ln(0.05)/T_{max}$$

T_{max} was set at the maximum age observed during the present study and was 4 years for sea garfish and 7 years for river and snub-nosed garfish.

A second estimate of M was made using the equation derived by Pauly (1980) that is based on the von Bertalanffy growth function parameters and water temperature. Water temperature was set at 20°C for each species. This estimate of M was adjusted by multiplying by 0.6 to adjust for schooling fish (Pauly, 1980; Jones, 1990).

Estimates of fishing mortality (F) were made by subtracting the estimates of M from Z.

3.2.8. Preliminary Stock Assessment

Yield per recruit (YPR), egg per recruit (EPR) and spawner-biomass per recruit (SBPR) analyses were done for a range of M and F. The method used was based on that of Beverton & Holt (1957). Assumptions were that: (i) M is constant for all ages after recruitment; (ii) F is constant after the age at first capture; (iii) recruitment is constant, and; (iv) the fish are a closed population. Mean weight-at-age was calculated from the growth functions described above and the length/weight relationships in Chapter 1.

Sea garfish size-selectivity in standard 28 mm mesh was used (see Appendix 4) and converted to age using the von Bertalanffy growth function parameters. Estimates of egg-production were based on the fecundity-FL relationship (Chapter 4) and maturity was assumed to be knife-edged at 20.1 cm FL or 8 months (Chapter 4). The biological reference point $F_{0.1}$ was taken as the point where the slope of the yield curve was 10% of the value of the original slope.

YPR, EPR and SBPR analyses were done separately for river garfish from each estuary sampled and for snub-nosed garfish. The same protocols were used as for sea garfish, however selectivity was chosen to be knife-edged at an age corresponding to the smallest fish in commercial landings i.e. 18 and 19 cm FL for river and snub-nosed garfish respectively. Estimates of maturity, fecundity and length/weight relationships were taken from Chapters 2 and 4.

3.3. Results

3.3.1. General description of garfish otoliths

Whole and sectioned otoliths were initially examined to determine the best method of age estimation. Whole otoliths were thick and discrete zones or structures were not readily visible. We therefore used sectioned otoliths to estimate age.

Sea garfish

Sectioned otoliths of sea garfish were difficult to interpret. Otoliths from some very large fish had no obvious opaque zones while others displayed numerous fine opaque zones of varying widths. After examining the otoliths from the fish with alizarin marked otoliths and some very small obviously young-of-the-year sea garfish, the structure seen in otolith sections was more easily interpreted. The core of the otolith was always densely opaque and the size of this area was extremely variable. This dense opaque core was followed by a thin translucent area and a broad diffuse opaque zone that was scored as the first annulus (Fig. 3.1). Subsequent opaque zones were also broad and diffuse and could generally be seen on either side of the sulcus.

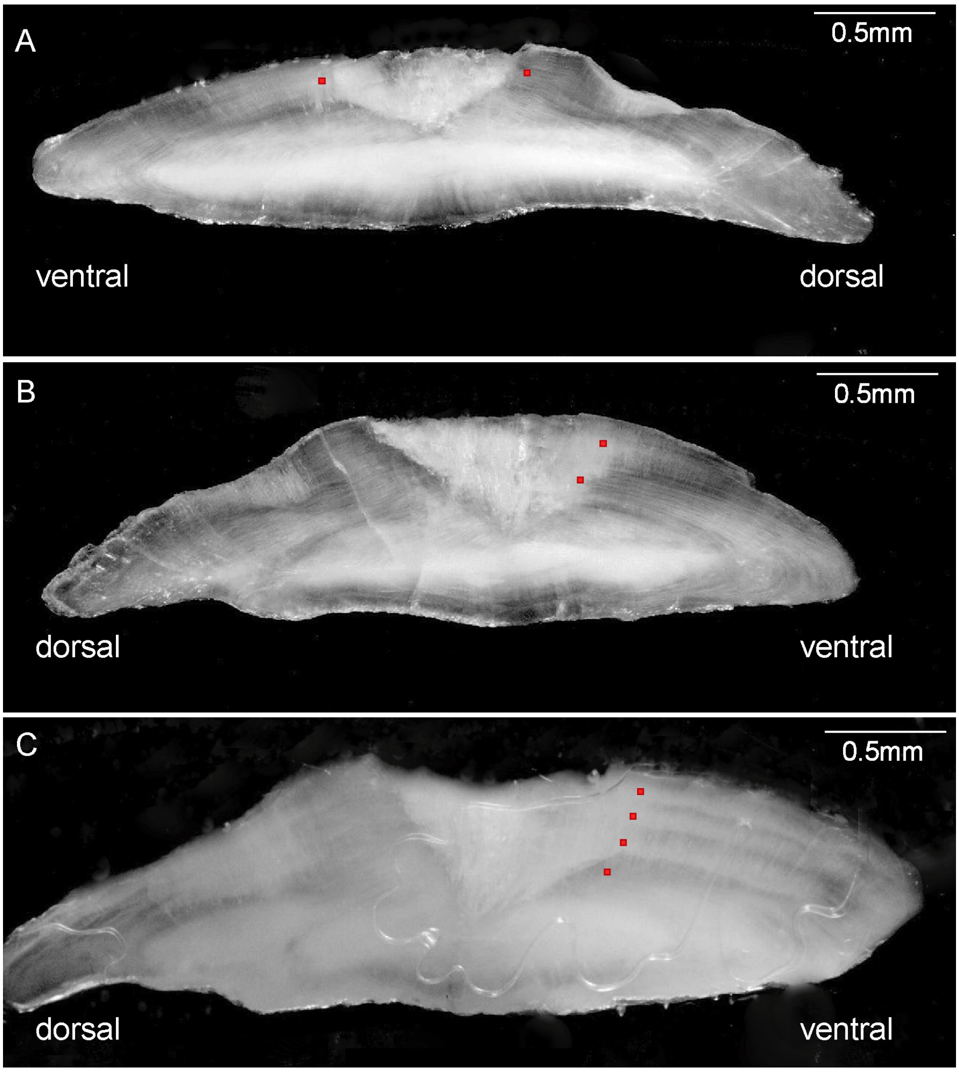


Figure 3.1. Sections of sea garfish otoliths viewed under reflected light against a black background. A) aged 1+ years and 307 mm FL, B) aged 2+ years and 274 mm FL, c) aged 4+ years and 335 mm FL.

<u>River and Snub-nosed garfish</u>

Sections of river and snub-nosed garfish otoliths were similar to each other in appearance but differed from those from sea garfish. They were relatively easy to interpret and opaque zones easily counted. The core was always densely opaque and was followed by a thin translucent area, then a broad lightly diffuse zone and a definite thin opaque band. This thin opaque band was scored as the first annulus (Fig. 3.2). Whole otoliths were thick and distinct zones could not be counted.

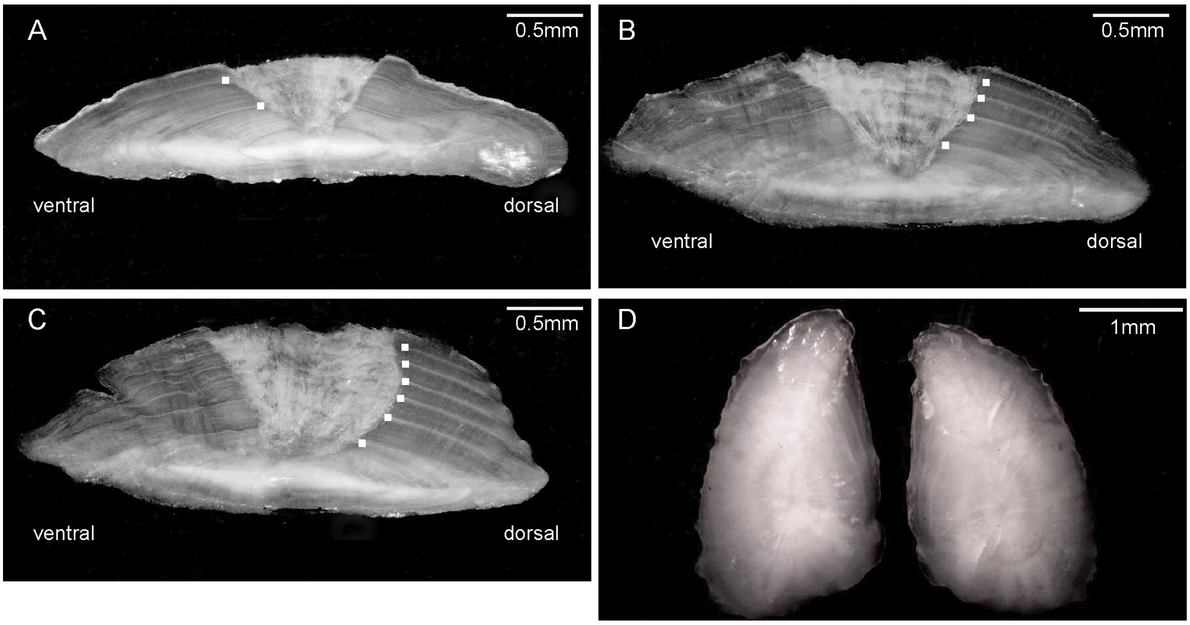


Figure 3.2. River garfish otoliths viewed under reflected light against a black background. A) aged 2+ years and 240 mm FL; B) aged 4+ years and 239 mm FL; C) aged 6+ years and 215 mm FL; D) whole otoliths from a fish aged 3+ years and 231 mm FL.

3.3.2. Validation of ageing method

Sea garfish

3.3.2.1. Marking otoliths with a vital stain

(a) Tetracycline marking

Forty-three sea garfish, ranging between 15 and 31 cm FL (Fig. 3.3) were injected with tetracycline on the 27th May 2002. Unfortunately, mainly due to a pump malfunction, all had died by October 2002. Some fish were sent to a laboratory for analyses on cause of death and the remaining 38 fish had their otoliths sectioned and analysed.

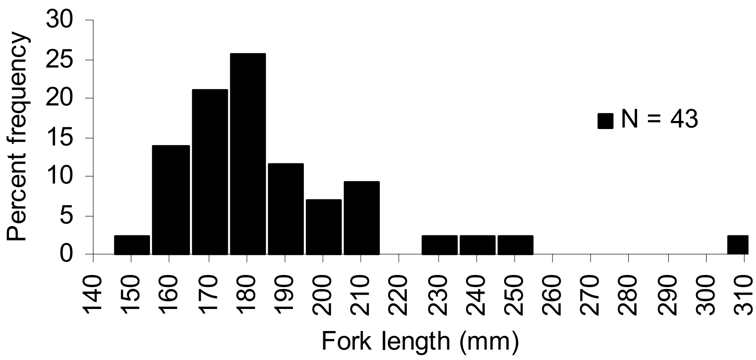


Figure 3.3. The sizes of sea garfish injected with tetracycline in May 2002.

Eighteen of the 38 sea garfish examined (47%) had visible tetracycline marks on their otoliths when viewed under ultra-violet light. All of these fish were 0+ years old and had translucent edges. One fish was estimated as being 1+ years old when it died in July 2002 but did not have a tetracycline mark on its otolith. Otolith growth from the OTC mark to the otolith edge was variable but increased with time (Fig. 3.4)

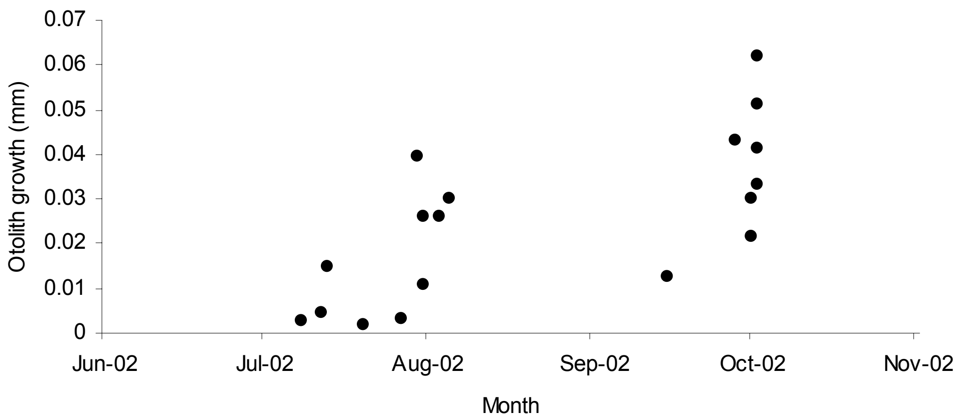


Figure 3.4. Sea garfish otolith growth after tetracycline was administered in May 2002.

(b) Alizarin marking

Forty-six sea garfish treated with alizarin in February 2003 had died within a few days of treatment. Those fish that died were generally representative of the sizes of the survivors (Fig. 3.5).

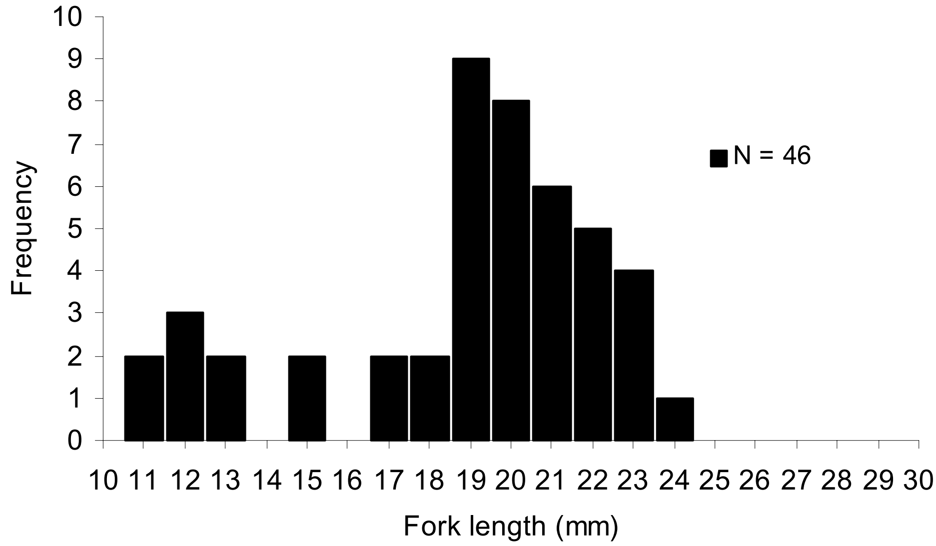


Figure 3.5. Sizes of sea garfish that died during and within 2 days of being treated with alizarin complexone on 3rd February 2003.

Samples of the surviving sea garfish were taken each month to examine their otolith growth subsequent to the alizarin mark. The alizarin mark was easily identified as a thin red band under normal reflected light (Fig. 3.6).

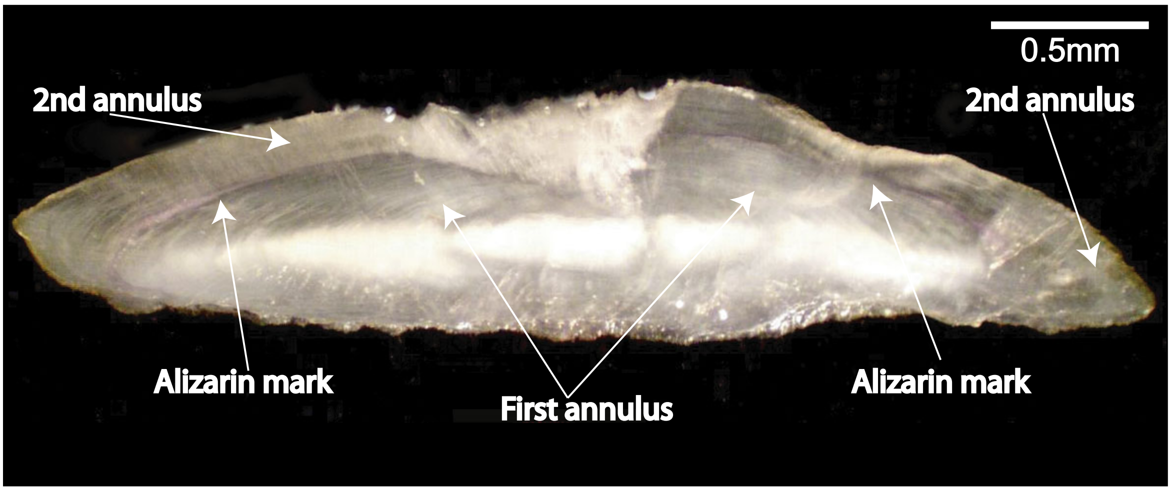


Figure 3.6. Sectioned otolith from fish number HaA25. The fish was treated with alizarin complexone on 3rd February 2003 and killed on the 14th January 2004. It was a male, was estimated as being 1+ years old when stained and 253 mm FL when sampled.

Only one fish (HaA2) did not have an alizarin mark on its otolith. Four fish had no opaque zones when stained and 28 had 1 complete opaque zone (Fig. 3.7). Opaque bands subsequent to the alizarin mark first became visible in January. In fish that already had 1 opaque zone when stained the position of the alizarin mark was just outside the broad opaque first annulus (see Fig. 3.6.), however the position of the first annulus was marked as the centre of the opaque zone. This suggests that the first opaque zone was formed sometime earlier than the beginning of February (when the fish were treated), probably during winter/spring.

Sea garfish with 1 opaque zone when stained were, on average, 20.5 cm FL in February 2003 (Fig. 3.5). The average size of sea garfish sampled between January and July 2004 was 28.5 cm FL and the largest, sampled in May 2004, was 32.0 cm FL. This growth rate will be discussed later.

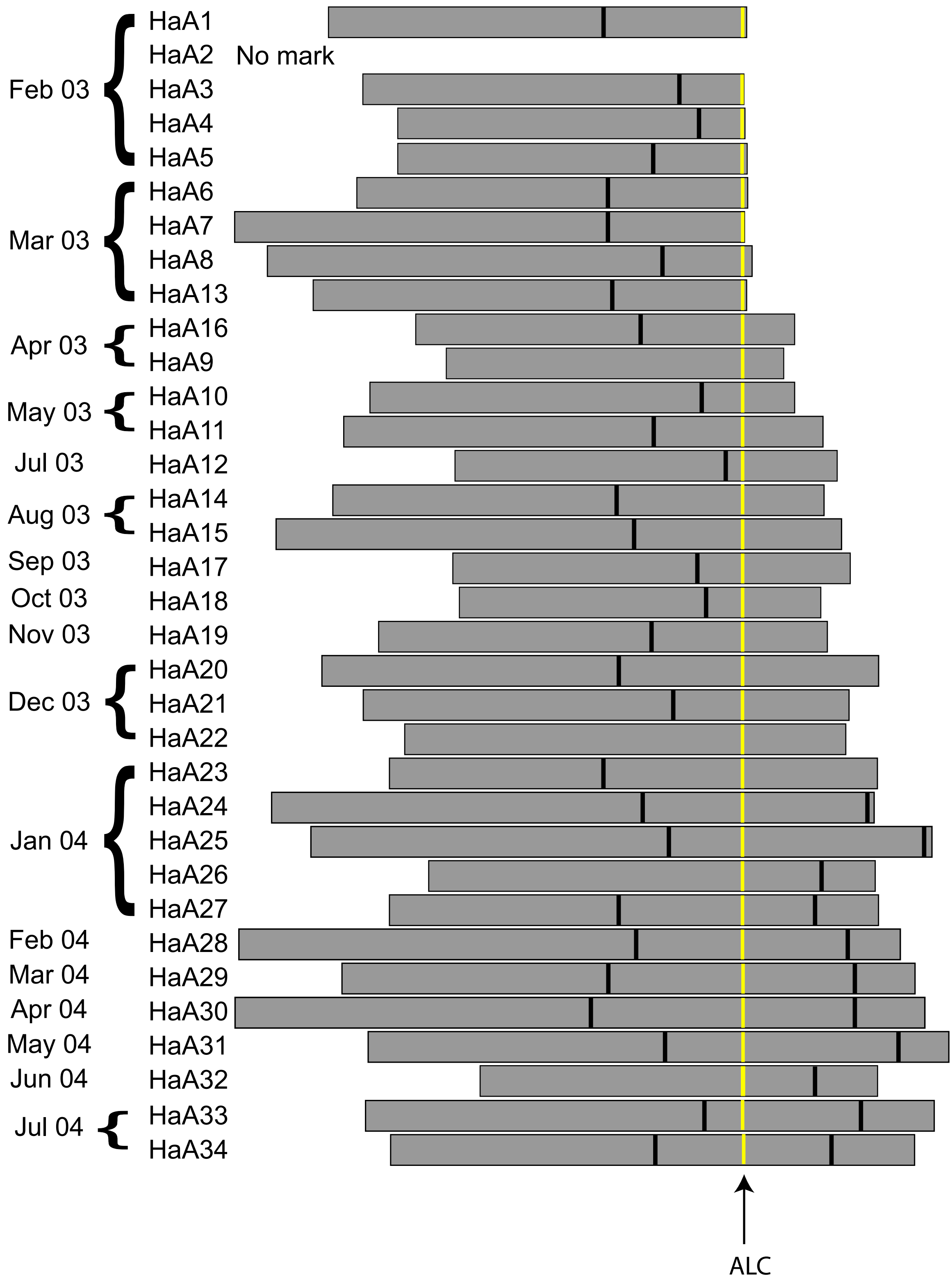


Figure 3.7. Relative distances from the otolith core to the alizarin mark (ALC) and opaque zones (black bars) taken along the ventral edge of the sulcus in sectioned otoliths. Marking with alizarin complexone occurred in February 2003.

3.3.2.2. Marginal increment analyses

The monthly marginal increments for sea garfish with 1 opaque zone showed considerable individual variation, but with a repeated seasonal pattern from a low in December steadily increasing to around June before decreasing again (Fig. 3.8). This pattern shows that opaque zones become visible during spring and summer.

There were only 32 sea garfish that had 2 or more opaque zones in their otoliths. This small number was insufficient to show any seasonal pattern in marginal increment.

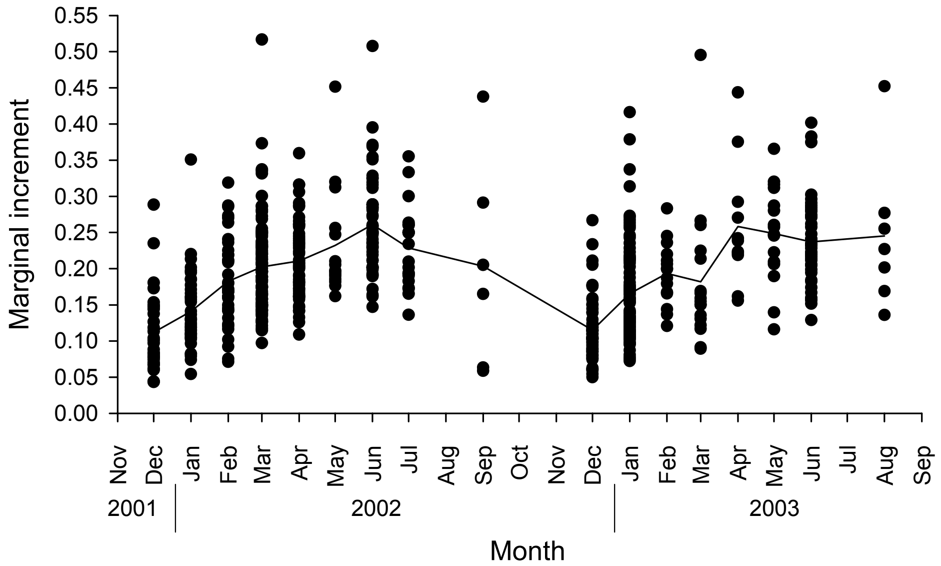


Figure 3.8. Marginal increment plot for sea garfish with 1 opaque zone. The line indicates the monthly means.

3.3.2.3. Otolith edge status

The proportion of sea garfish otoliths with opaque edges each month supports the marginal increment analyses and is consistent with annual periodicity of opaque zone formation. The highest proportion of otoliths having opaque edges occurred during December each year, while the lowest proportions were seen during autumn (Fig. 3.9).

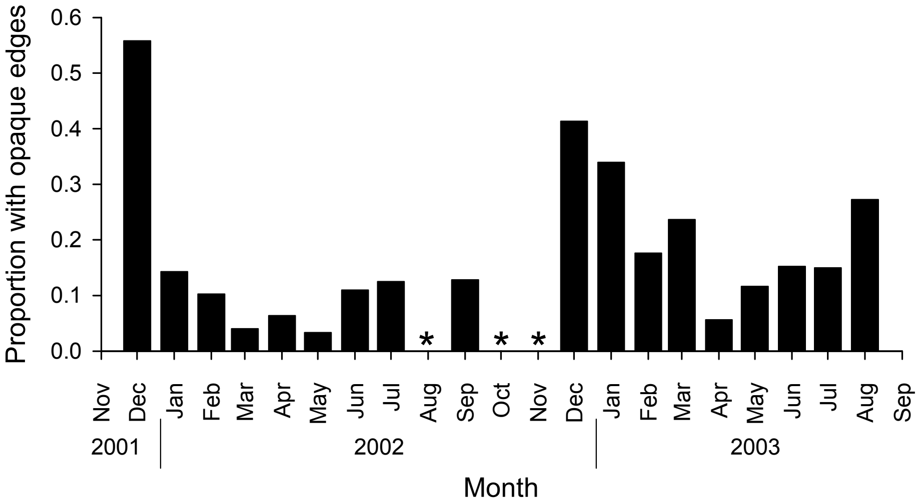


Figure 3.9. Monthly proportion of sea garfish otoliths determined as having opaque edges. Note that no fish were sampled in those months marked with an asterix.

3.3.2.4. *First increment formation*

The mean distance (± S.E.) from the core to the middle of the 1st opaque zone for all sea garfish with 1 or more opaque zones was 0.526 (0.003) mm. We sampled 6 very small (<10 cm FL and <3.4 g) fish in December 2001 that were assumed to be from the most recent spawning event (July to December) and sectioned their otoliths. Their otoliths were entirely opaque and had a mean distance from core to edge of 0.17 mm and a section width of 0.977 mm. Slightly larger (12 to 18 cm FL) sea garfish sampled in March showed 14% with totally opaque otoliths (1 of 7 fish) and 100% sampled in April had translucent edges (8 fish) (Fig. 3.10).

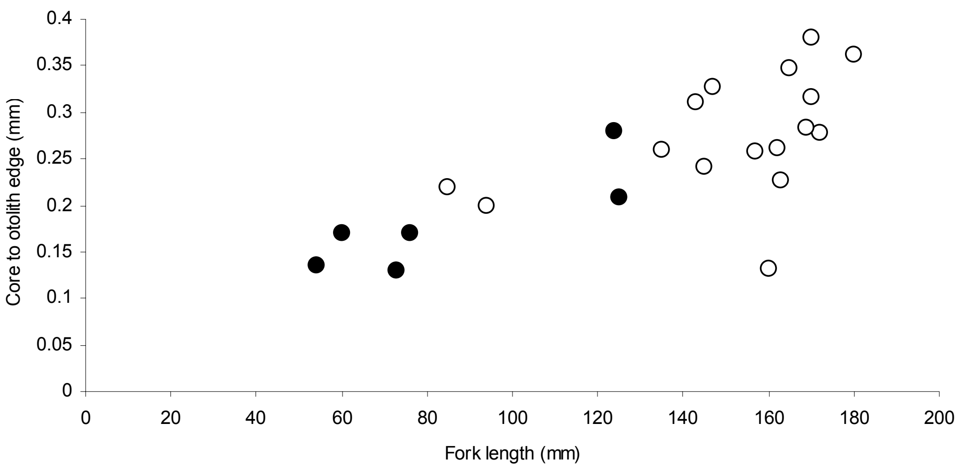


Figure 3.10. Plot of the distances from the core to edge in sectioned otoliths of small sea garfish described above. Black circles denote opaque otoliths and white circles denote otoliths with translucent edges.

3.3.2.5. Otolith size and weight versus estimated age and fish length

There was a power relationship between fish length and mean otolith weight (Fig. 3.11), showing that the otoliths continue to grow throughout the life of the fish and are therefore useful tools for estimating age.

There was a significant linear relationship between age (in days determined below) and mean otolith weight (Fig. 3.12). However, there was significant variation and otolith weight is therefore not considered a useful proxy for estimating age in sea garfish.

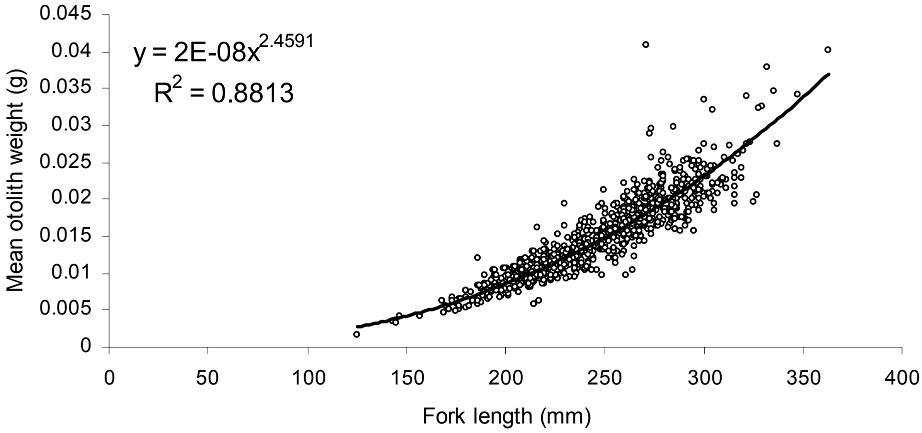


Figure 3.11. Relationship between sea garfish length and mean otolith weight.

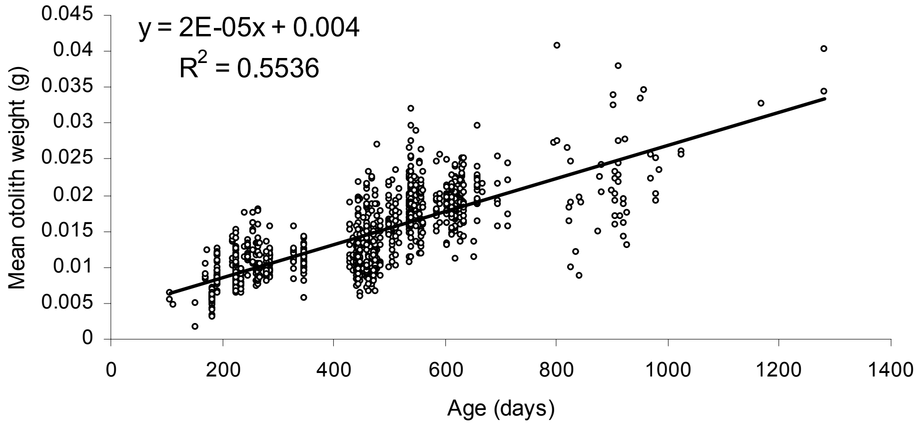


Figure 3.12. Relationship between sea garfish age and mean otolith weight.

River garfish

3.3.3. Validation of ageing method

3.3.3.1. Marking otoliths with a vital stain

(a) Tetracycline marking

One hundred and fifty eight river garfish were injected with tetracycline on the 21st May 2002 (Fig. 3.13). Unfortunately all but 7 fish had died by October 2002, mainly due to a pump malfunction. Five of these died during the next 21 months and the two fish that survived were killed on the 15th July, 2004.

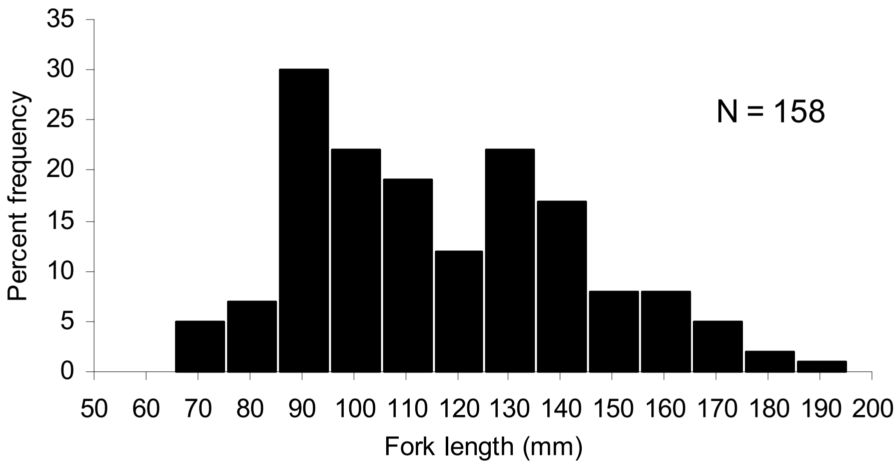


Figure 3.13. The sizes of river garfish injected with tetracycline in May 2002.

In total we sectioned and analysed the otoliths from 41 river garfish that were injected with tetracycline. Only 3 fish (7.3%) had identifiable tetracycline marks in their otoliths. Two of these died in August 2002 and had no opaque zones, while the 3rd was killed on the 15th July 2004 and had 2 opaque zones (Fig. 3.14). The one fish that had formed opaque zones subsequent to the tetracycline mark had the first opaque zone form close to the tetracycline mark administered in May 2002. Sample HrT40 otolith growth was consistent with the model of 1 opaque zone forming each year.

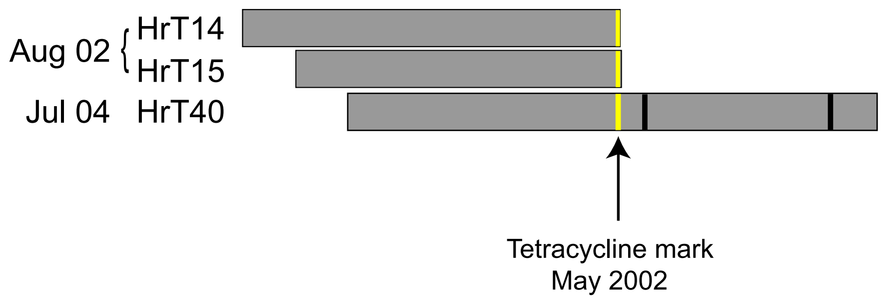


Figure 3.14. Relative distances from the otolith core to the tetracycline mark and annual zones (black bars) taken along the ventral edge of the sulcus in sectioned river garfish otoliths.

(b) Alizarin marking

Sixty-one river garfish treated with alizarin on the 23rd January 2003 died during either the treatment or within the 1st month afterwards. These fish were generally representative of the sizes of the survivors (Fig. 3.15).

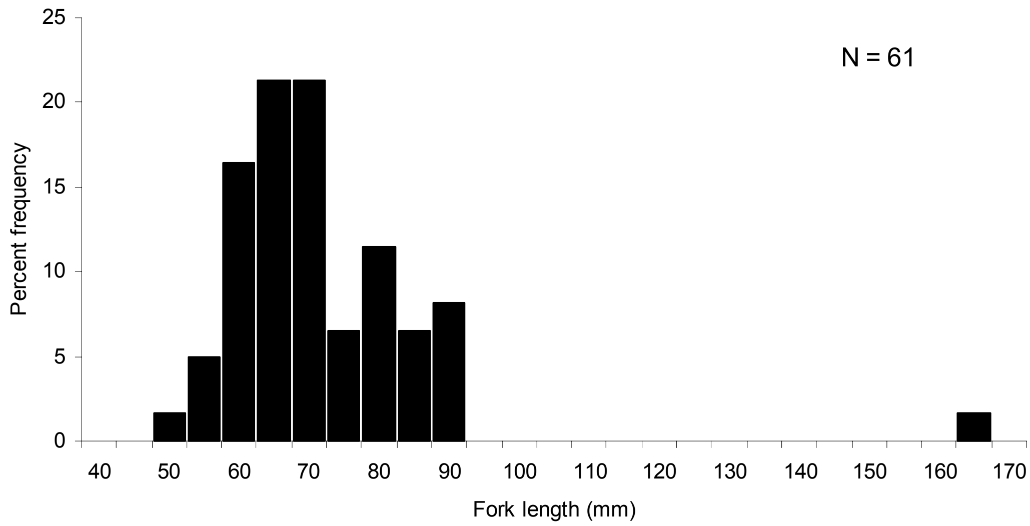


Figure 3.15. Sizes of river garfish that died within 1 month of being treated with alizarin complexone on 23rd January 2003.

Samples of the surviving river garfish were taken each month until July 2004 to examine their otolith growth subsequent to the alizarin mark. The alizarin mark was easily identified as a thin red band under normal reflected light (Fig. 3.16).

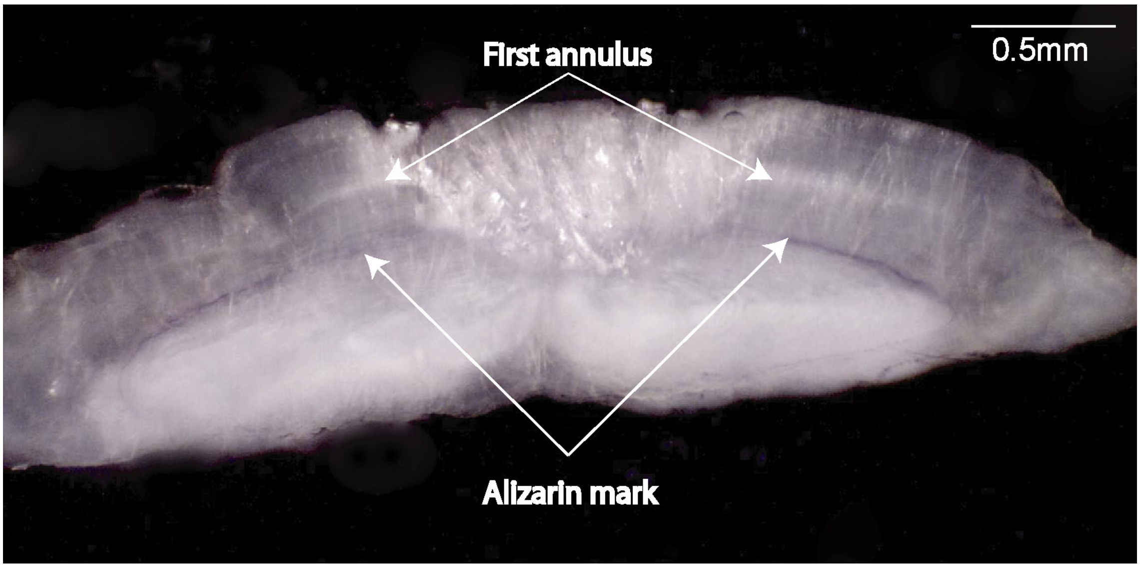


Figure 3.16. Sectioned otolith from fish number HrA116. The fish was treated with alizarin complexone on 23rd January 2003 and killed on the 15th June 2004. It was a female, had no opaque zones when stained and measured 141 mm FL when sampled.

A total of 80 river garfish were examined and of these, 79 had alizarin marks in their otoliths. One fish had 1 opaque zone when stained, the other 78 had no opaque zones at the start of the experiment (Fig. 3.17). Opaque zones were scored on the edge of otoliths of some fish in January and in all fish sampled by March. Otolith growth slowed during winter (June to November) and increased during summer (Fig. 3.17).

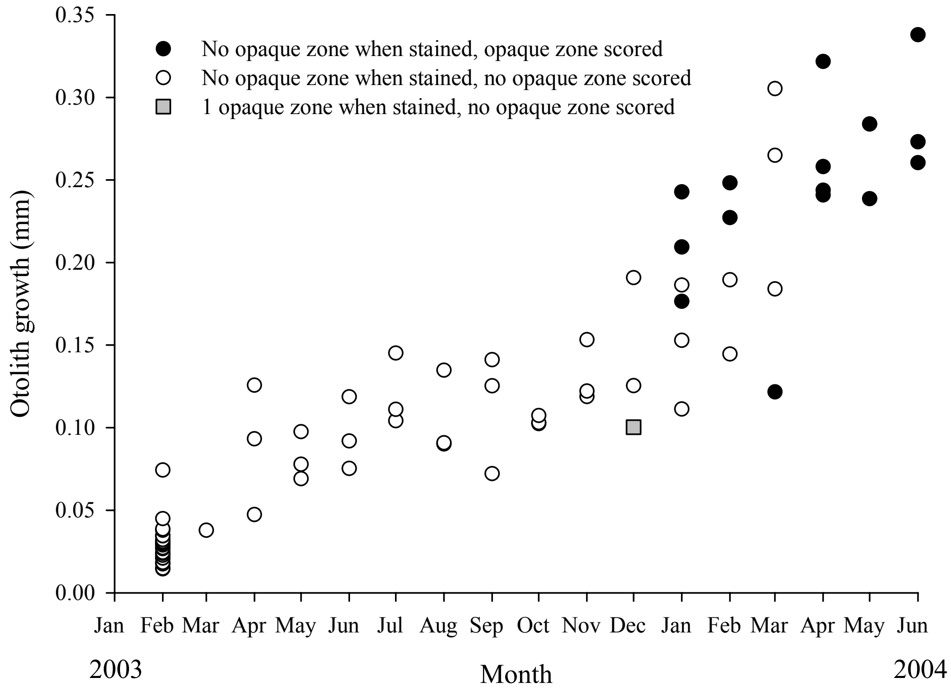
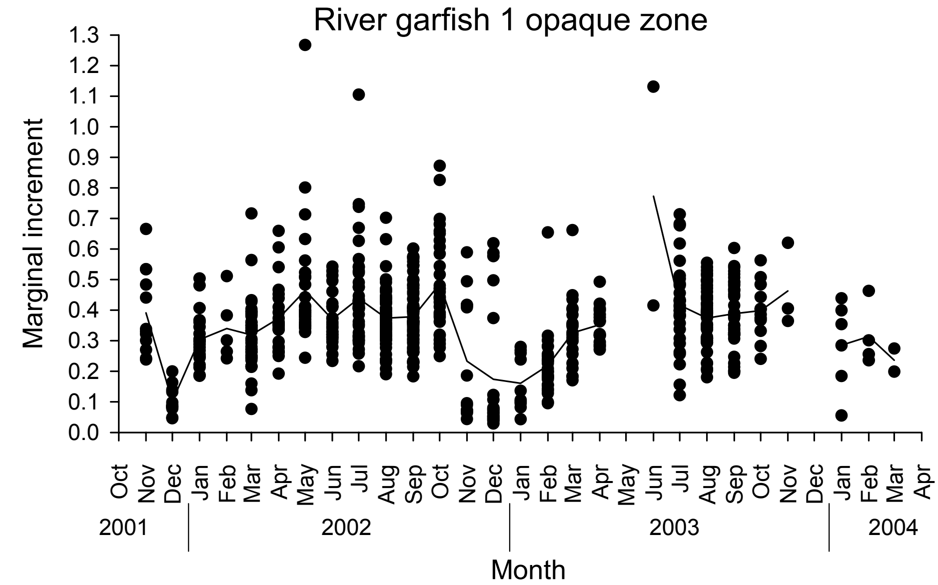


Figure 3.17. Distances from the alizarin mark to the otolith edge for river garfish stained in January 2003 and kept in captivity. Open circles represent fish that had no opaque zones when stained and had not formed an opaque zone when sampled. Black circles represent fish that had no opaque zones when stained that had an identified opaque zone subsequent to the alizarin mark when sampled. The grey square represents the single fish that had 1 opaque zone when stained and it had not formed an additional opaque zone when sampled.

3.3.3.2. Marginal increment analyses

The monthly marginal increments for river garfish showed considerable variation but with a repeated seasonal pattern with low values in summer (November to January) (Fig. 3.18). This pattern shows that opaque zones become visible during spring and early summer. November to March were the months where some fish had identifiable opaque zones near their otolith edges and others did not.



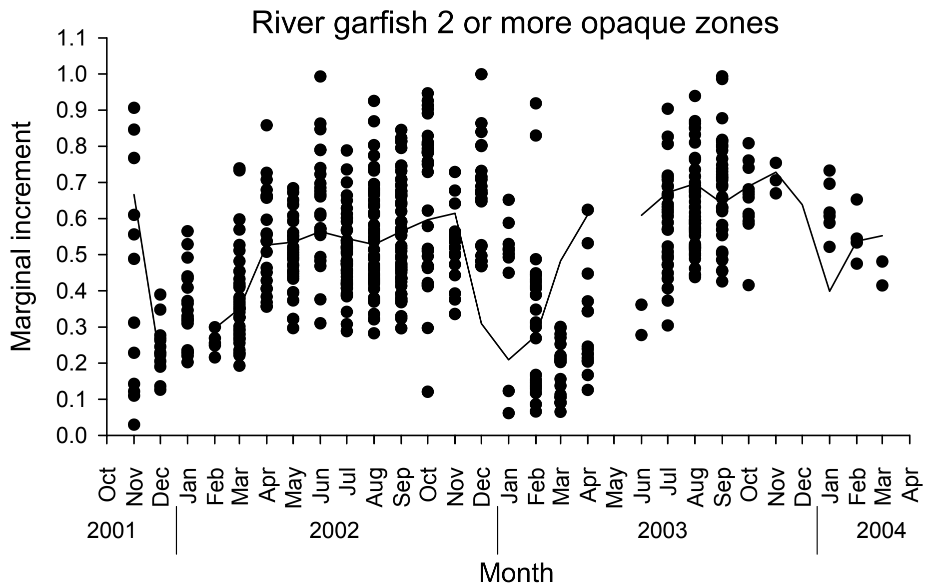


Figure 3.18. Marginal increment plots for river garfish with 1 opaque zone and 2 or more opaque zones. The line indicates the monthly means.

3.3.3.3. Otolith edge status

The proportion of river garfish otoliths with opaque edges each month supports the marginal increment analyses and shows that late spring and early summer had the highest proportion of otoliths with opaque edges each year (Fig. 3.19). This result is consistent with annual periodicity of opaque zone formation.

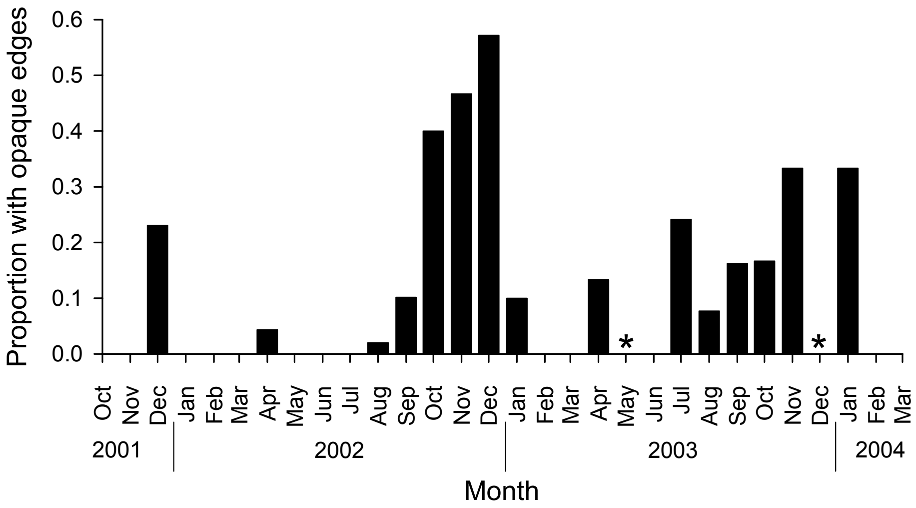


Figure 3.19. Monthly proportion of river garfish otoliths determined as having opaque edges. Note that no fish were sampled in those months marked with an asterix.

3.3.3.4. First increment formation

The mean distance (± S.E.) from the core to the middle of the 1st opaque zone for all river garfish with 1 or more opaque zones was 0.517 (0.002) mm. Fifteen small river garfish (<110 mm FL and <6.8 g), assumed to be from the previous years spawning, were sampled between March and July 2003. The mean distance from the otolith core to the otolith edge in these fish was 0.393 (0.019) mm (Fig. 3.20). These fish were estimated to be between 6 and 9 months old and had translucent otolith edges.

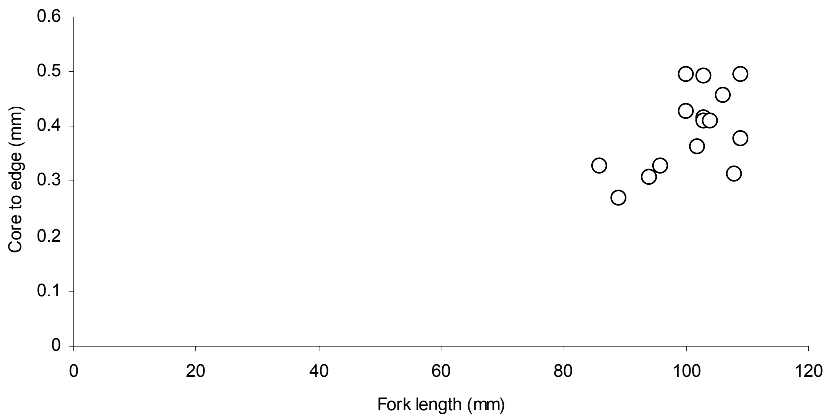


Figure 3.20. Plot of the distances from the core to edge in sectioned otoliths of small river garfish described above.

3.3.3.5. Otolith size and weight versus estimated age and fish length

There was a power relationship between fish length and mean otolith weight (Fig. 3.21), showing that the otoliths continue to grow throughout the life of the fish and are therefore useful tools for estimating age.

There was a significant linear relationship between age and mean otolith weight (Fig. 22). There was large variation in otolith weight for any given age and it is therefore not considered to be a useful proxy for estimating age in river garfish.

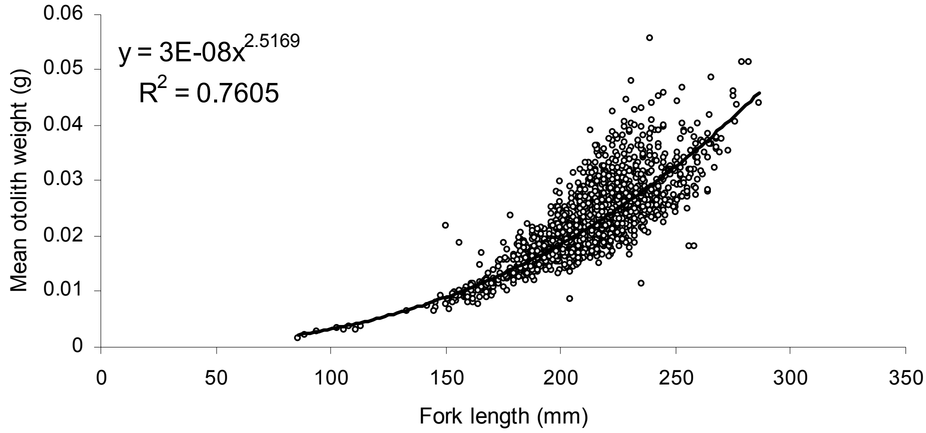


Figure 3.21. Relationship between river garfish length and mean otolith weight.

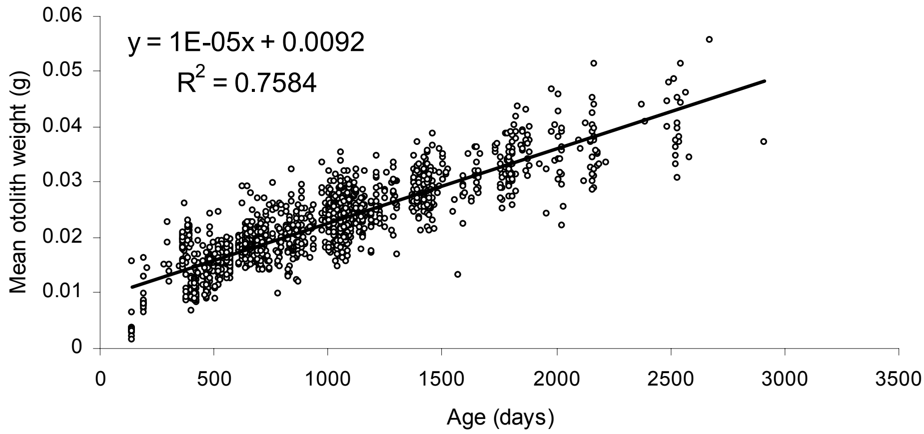


Figure 3.22. Relationship between river garfish age and mean otolith weight.

Snub-nosed garfish

3.3.4. Validation of ageing method

3.3.4.1. Marginal increment analyses

The monthly marginal increments for snub-nosed garfish showed considerable variation but with a repeated seasonal pattern of opaque zones appearing in spring/summer (October to January) (Fig. 3.23). October and November were the months when some fish had identifiable opaque zones near their otolith edges and others did not.

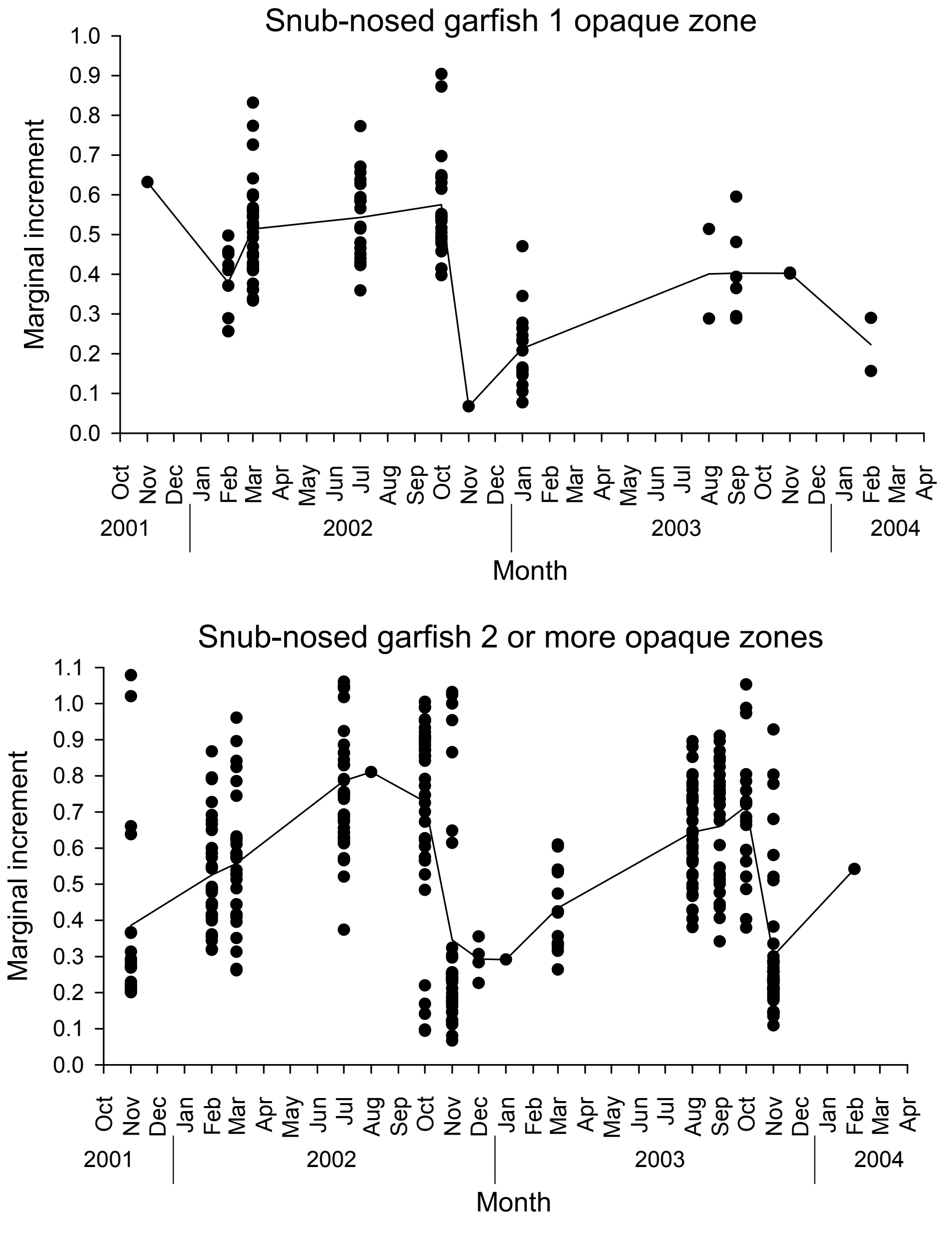


Figure 3.23. Marginal increment plots for snub-nosed garfish with 1 opaque zone and 2 or more opaque zones. The line indicates the monthly means.

3.3.4.2. Otolith edge status

The proportion of river garfish otoliths with opaque edges each month supports the marginal increment analyses and shows that October and November generally had the highest proportion of otoliths with opaque edges each year (Fig. 3.24).

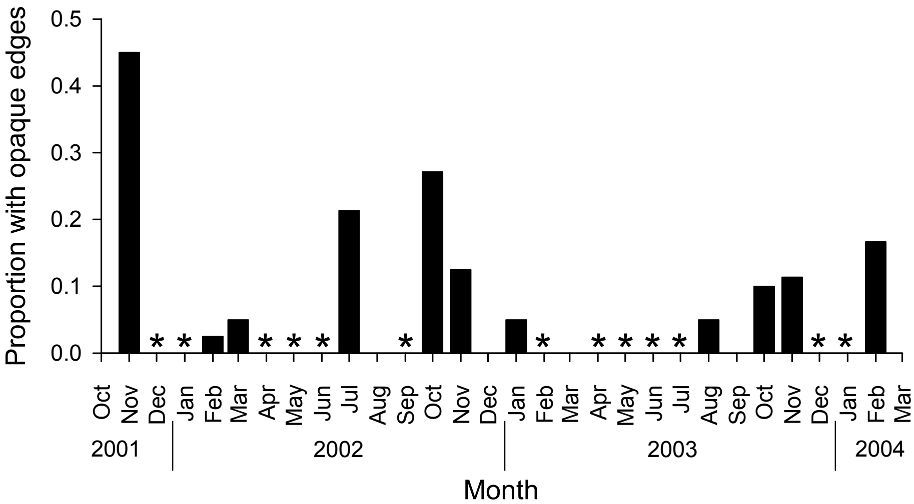


Figure 3.24. Monthly proportion of snub-nosed garfish otoliths determined as having opaque edges. Note that no fish were sampled in those months marked with an asterix.

3.3.4.3. First increment formation

We did not sample any very small snub-nosed garfish, however their otoliths were very similar to those from river garfish and we believe that they should be interpreted in a similar manner. The mean distance (± S.E.) from the core to the middle of the 1st opaque zone for all snub-nosed garfish with 1 or more opaque zones was 0.47 (± 0.003) mm. This is very similar to the mean distance in river garfish otoliths of 0.517 (± 0.002) mm.

3.3.4.4. Otolith size and weight versus estimated age and fish length

There was a power relationship between fish length and mean otolith weight (Fig. 3.25), showing that the otoliths continue to grow throughout the life of the fish and are therefore useful tools for estimating age.

There was a significant linear relationship between age and mean otolith weight (Fig. 3.26). There was large variation in otolith weight for any given age and it is therefore not considered to be a useful proxy for estimating age in snub-nosed garfish.

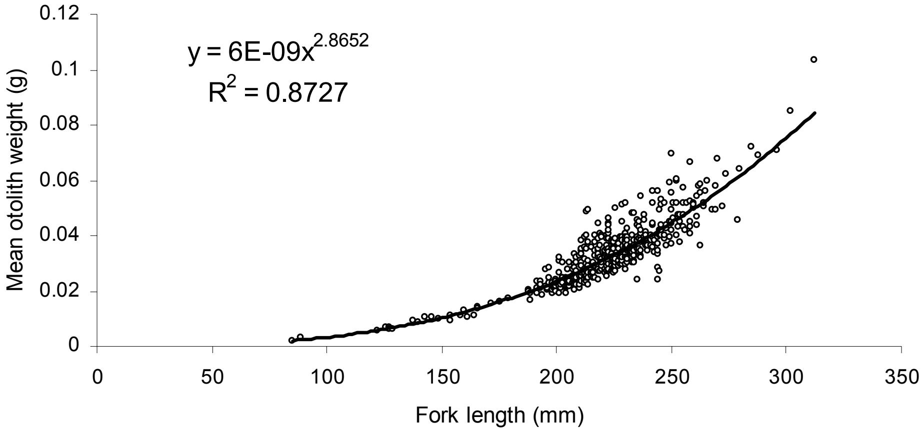


Figure 3.25. Relationship between snub-nosed garfish length and mean otolith weight.

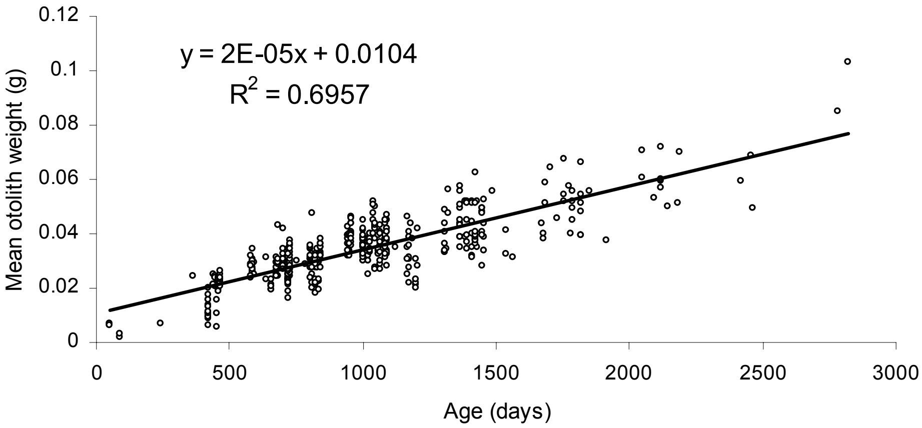


Figure 3.26. Relationship between snub-nosed garfish age and mean otolith weight.

3.3.5. Development of ageing protocol

Sea garfish

Protocol for converting counts of opaque zones to age

Otoliths were assigned as having either wide, medium or narrow edges and this classification varied depending on how many opaque zones were present (Table 3.1). The marginal increments were measured as described in the methods and varied depending on whether the fish were aged 0+, 1+ or 2+ years and older.

Table 3.1. Classification of sea garfish otolith edges. MI is marginal increment as defined above.

No. opaque zones	Edge status		
	Wide	Medium	Narrow
0	≥0.6mm	<0.6mm	N/A
1	MI ≥ 0.3	0.1 < MI < 0.3	MI ≤ 0.1
>1	MI ≥ 0.7	0.1 < MI < 0.7	MI ≤ 0.1

After examining the distribution of marginal increments each month (Fig. 3.8) and identifying those in which some fish had opaque zones near to the otolith edge while other fish did not, a model was developed to convert counts of opaque zones to age classes. This model was based on the month of capture and width of the otolith edge (Fig. 3.27).

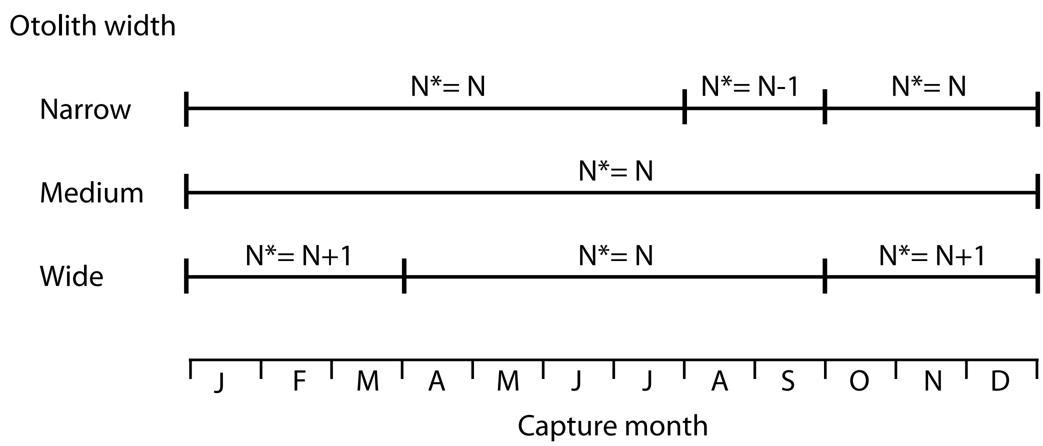


Figure 3.27. Model to determine the age class (N*) of sea garfish based on the month of capture and the width of the otolith edge.

A universal birth date of 1st October was assigned to sea garfish (based on the middle of the spawning season – Chapter 4). Based on the above determinations the following algorithm was applied to convert counts of opaque zones into ages.

$Age_D = N^* \times 365 + D_c$

Where:

Age_D = Age in months
N* = Number of opaque zones modified by edge width and capture month
D_c = Days from nominated birthday to capture

River garfish

Protocol for converting counts of opaque zones to age

Otoliths were assigned as having either wide, medium or narrow edges and this classification varied depending on how many opaque zones were present (Table 2). The marginal increments were measured as described in the methods and varied depending on whether the fish were aged 0+, 1+ or 2+ years and older.

Table 3.2. Classification of river garfish otolith edges. MI is marginal increment as defined in section 3.2.2.2.

No. opaque zones	Edge status		
	Wide	Medium	Narrow
0	≥0.45mm	<0.45mm	N/A
1	MI ≥ 0.6	0.2 < MI < 0.6	MI ≤ 0.2
>1	MI ≥ 0.4	0.2 < MI < 0.4	MI ≤ 0.2

A model was developed to convert counts of opaque zones to age classes as described for sea garfish. River garfish from Lake Illawarra and Tuggerah Lakes were assigned a universal birthday of 1st October (the middle of the spawning season – Chapter 4) and the model to assign them to correct age classes is presented in Fig. 3.28.

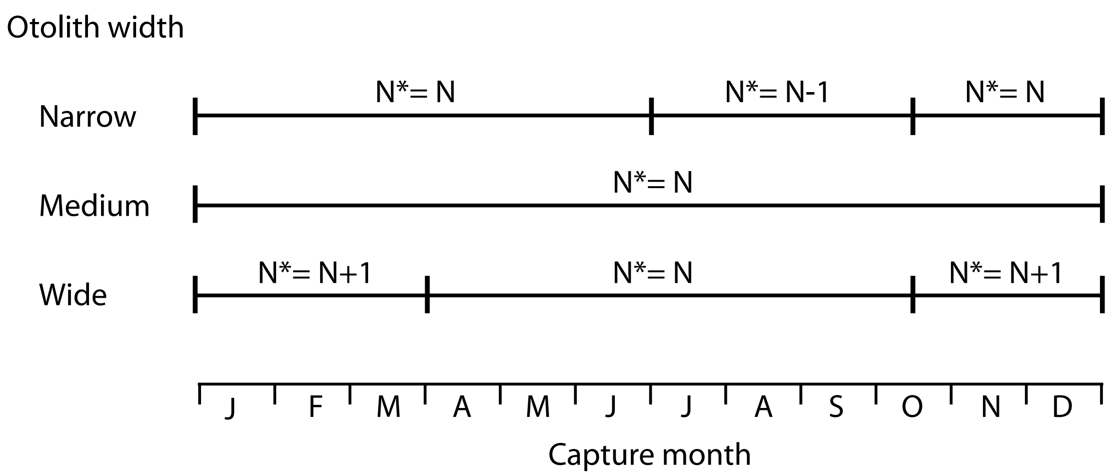


Figure 3.28. Model to determine the age class (N*) of river garfish from Lake Illawarra and Tuggerah lakes based on the month of capture and the width of the otolith edge.

River garfish from Wallis Lake were assigned a universal birthday of 15th September (the middle of the spawning season – Chapter 4) and the model to assign age classes adjusted accordingly (Fig. 3.29).

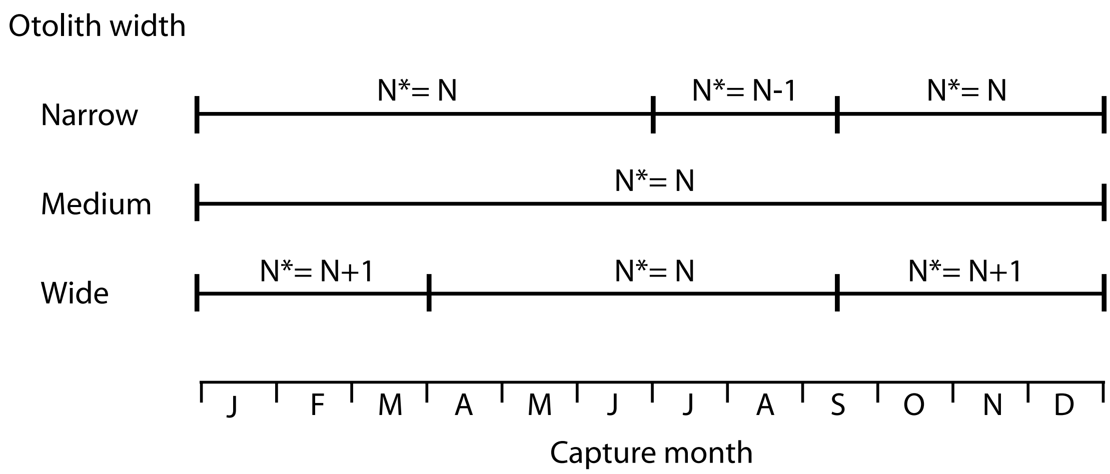


Figure 3.29. Model to determine the age class (N*) of river garfish from Wallis Lake based on the month of capture and the width of the otolith edge.

The same algorithm used to convert counts of opaque zones to ages for sea garfish was used for river garfish.

Snub-nosed garfish

Otoliths were assigned as having either wide, medium or narrow edges and this classification varied depending on how many opaque zones were present (Table 3.3). The marginal increments were measured as described in the methods and varied depending on whether the fish were aged 0+, 1+ or 2+ years and older.

Table 3.3. Classification of snub-nosed garfish otolith edges. MI is marginal increment as defined above.

No. opaque zones	Edge status		
	Wide	Medium	Narrow
0	≥0.45mm	<0.45mm	N/A
1	MI ≥ 0.6	0.2 < MI < 0.6	MI ≤ 0.2
>1	MI ≥ 0.65	0.4< MI< 0.65	MI ≤ 0.4

Snub-nosed garfish were assigned a universal birthday of 1st December (the middle of the spawning season – Chapter 4). The model use to convert counts of opaque zones to age class was based on the month of capture and the width of the otolith edge as given in Fig. 3.30. The same algorithm to convert counts of opaque zones to ages for sea and river garfish was also used for snub-nosed garfish.

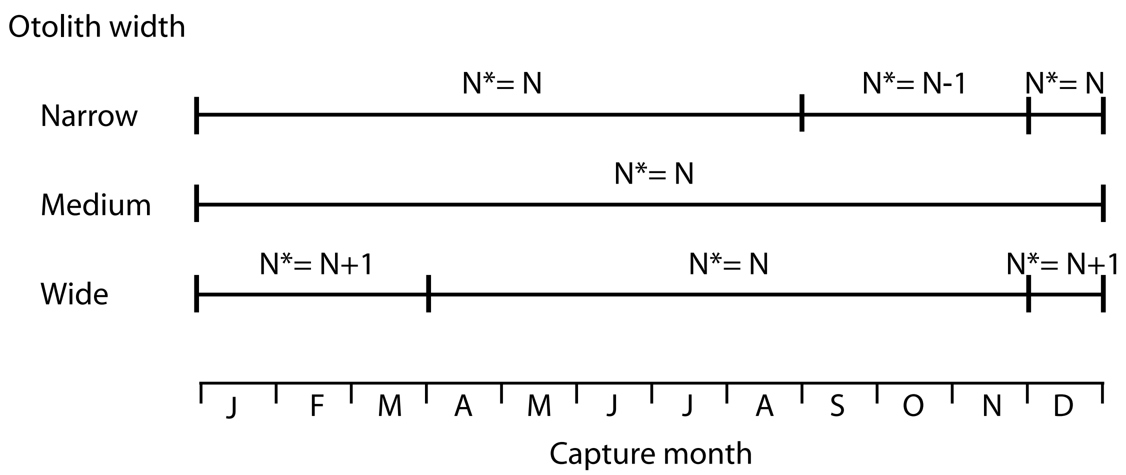


Figure 3.30. Model to determine the age class (N*) of snub-nosed garfish based on the month of capture and the width of the otolith edge.

3.3.6. Growth rates

Sea garfish

3.3.6.1. Age-base growth

There was no evidence of variation in growth rates between years, with the mean size-at-age of fish estimated as aged 0+, 1+ and 2+ years and older being not significantly different (t-tests, $P > 1.6$ in each case; Table 3.4).

The 95% confidence interval ellipses generated around the von Bertalanffy growth function parameters L_{∞} and k for male and female sea garfish did not overlap (Fig. 3.31), confirming differences in growth between sexes. The data were therefore kept separate (Fig. 3.32, Table 3.4). There was no difference in the mean size of female or male sea garfish aged 0+ years ($t = 0.25$, $P = 0.4$), but significant differences between those aged 1+ years ($t = 9.2$, $P < 0.001$) and 2+ years ($t = 7.0$, $P < 0.001$). Data from sexes and years were combined to provide overall growth curve parameter estimates for sea garfish to be used in per recruit calculations.

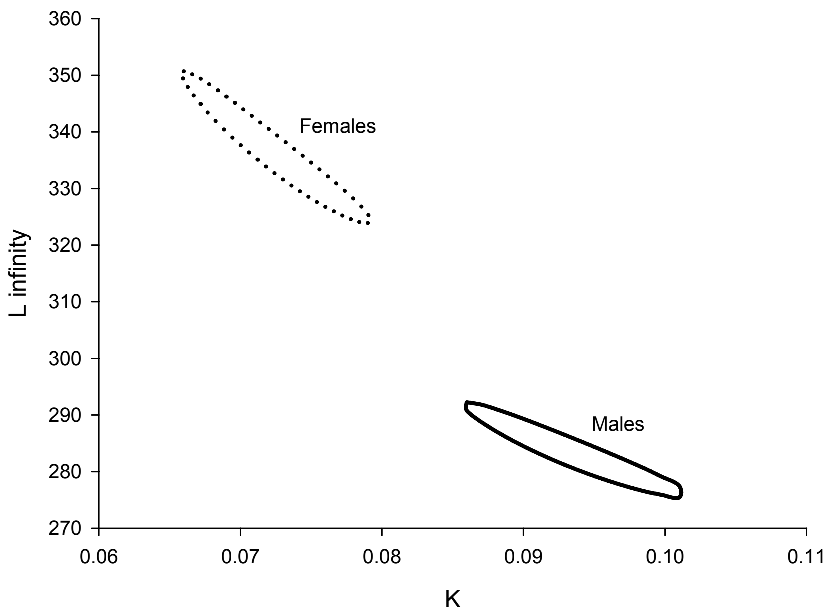


Figure 3.31. Ninety-five percent confidence ellipses for the von Bertalanffy growth parameters k and L_{∞} for male and female sea garfish.

Males and females grew at a similar rate until aged 1+, after which male growth was slower than female growth. We only estimated 3 fish to be greater than 3 years old and these were all females. One fish, sampled during the early pilot phase of this study, was estimated to be 4+ years old and was measured as 335 mm FL (Fig 3.1).

The von Bertalanffy growth function parameters (Table 3.5) provided good estimates of the asymptotic size for females and males, the largest recorded during the study being 363 mm FL for females and 306 mm FL for males.

Table 3.4. Mean size-at-age of sea garfish (sexes combined) each year and for each sex (years combined).

	Age (years)	0+	1+	2+	3+
2001/02	Mean FL (mm)	207.9	262.7	283.9	-
	St Dev	17.9	23.5	29.5	-
	N	84	274	21	-
2002/03	Mean FL (mm)	206.3	252.1	288.1	355.5
	St Dev	24.5	31.2	35.7	112.5
	N	206	353	29	2
Females	Mean FL (mm)	207.7	268.0	306.9	347.0
	St Dev	22.1	28.2	20.9	16.5
	N	129	281	28	3
Males	Mean FL (mm)	208.4	248.3	260.2	-
	St Dev	21.3	25.6	26.4	-
	N	192	355	22	-

Table 3.5. Von Bertalanffy growth function parameters (with standard errors) for sea garfish.

	Females	Males	Combined sexes
$L\infty$ (mm)	337.2 (10.03)	283.4 (6.78)	318.1 (8.14)
k (monthly)	0.071 (0.01)	0.093 (0.01)	0.076 (0.01)
T0 (months)	-5.11 (0.93)	-5.35 (1.19)	-6.44 (0.93)

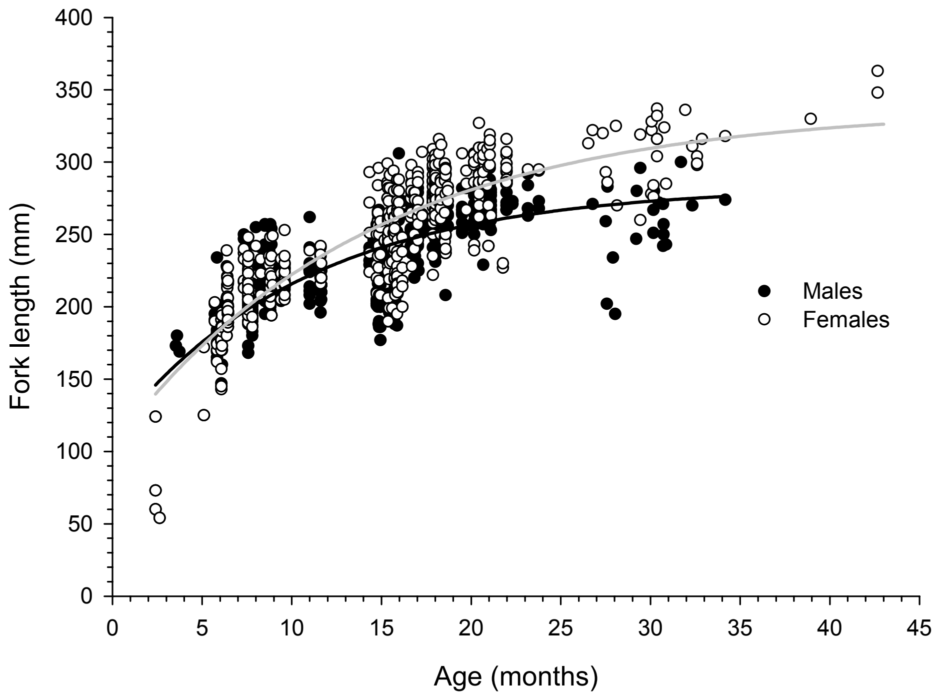


Figure 3.32. Size-at-age data for sea garfish with fitted von Bertalanffy growth curves.

3.3.6.2. Length-based growth

Sea garfish recruit to the fishery in May with a modal peak at around 20 cm FL (Fig. 3.33). These fish can be followed until July and grow at around 1cm a month during this time. Samples during August to October were difficult to obtain because the fishery is generally inactive during these months, nevertheless the samples showed a predominance of very small fish. As fish continue to grow they can be followed from November through to the time when they exit the fishery at around 3 years of age.

The ELEFAN length-frequency analysis module (FiSAT - Gayanilo et al., 1997), using the 'automatic search routine' with a starting month of May and a starting length of 20.5 cm FL, produced estimates of $k = 0.56$ and L_∞ of 34.13 cm FL.

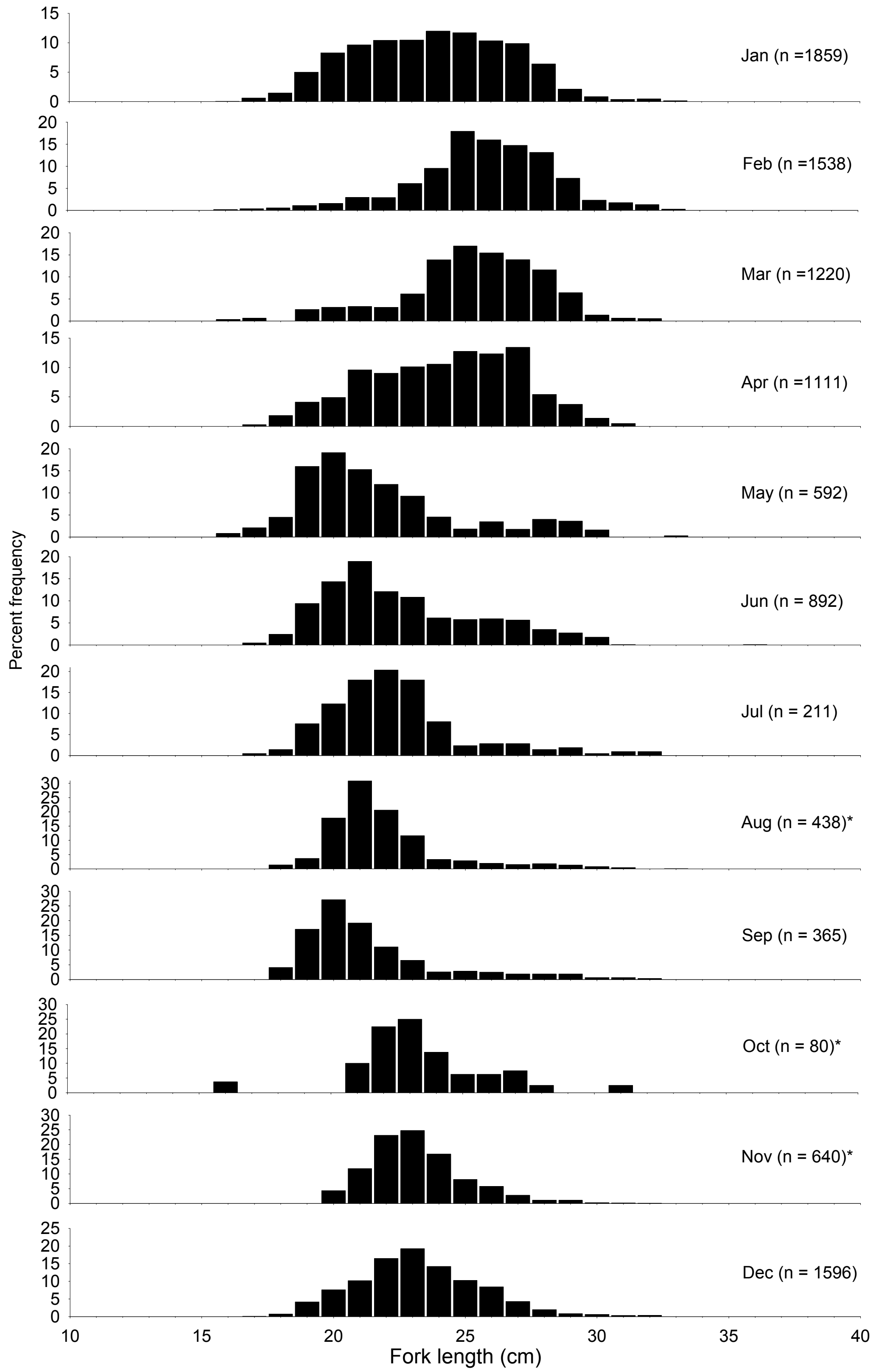


Figure 3.33. The sizes of sea garfish measured during the study (December 2001 to May 2004) combined from all areas. *Samples from August, October and November were measured at the Sydney Fish Markets in 2001.

River garfish

The size-at-age data for female and male river garfish were compared between sexes and estuaries (Table 3.6).

Table 3.6. Mean size-at-age (with standard errors) of female and male river garfish. FL = fork length in mm. Age is in years. Lengths without standard errors had N = 1. Dashes denote no fish of that age class were observed.

	Lake Illawarra		Tuggerah Lakes		Wallis Lake	
	Females	Males	Females	Males	Females	Males
Age	FL	FL	FL	FL	FL	FL
0+	182.0 (7.6)	157.6 (4.5)	128.4 (12.0)	133.6 (20.3)	-	-
1+	203.8 (1.3)	191.4 (1.3)	194.8 (2.1)	184.5 (1.5)	205.4 (1.6)	188.8 (1.5)
2+	232.2 (1.1)	214.2 (1.3)	204.7 (2.1)	196.4 (1.4)	216.1 (1.0)	202.7 (1.1)
3+	243.9 (1.3)	224.9 (1.6)	224.6 (2.1)	212.3 (2.8)	221.9 (0.9)	209.3 (1.4)
4+	251.4 (3.9)	236.3 (4.1)	225.7 (2.9)	216.1 (5.2)	231.5 (1.7)	215.6 (1.1)
5+	267.9 (1.9)	230.0	237.9 (4.3)	221.0 (6.0)	238.4 (1.8)	221.5 (2.3)
6+	270.3 (8.4)	-	254.0 (1.0)	-	238.6 (4.7)	225.1 (2.3
7+	275.0	-	243.0 (2.0)	-	239.0	220.0

The data were fitted to the von Bertalanffy growth function and the parameters compared (Table 3.7). The 95% confidence interval ellipses generated around the parameter estimates of L_∞ and k did not overlap (Fig. 3.34), confirming differences in growth between sexes at each location and also between locations.

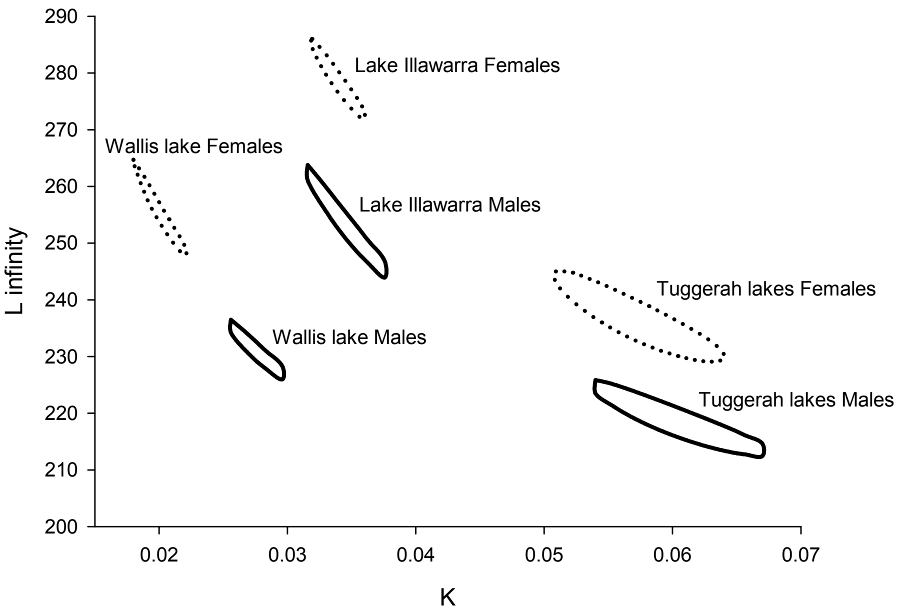


Figure 3.34. Ninety-five percent confidence ellipses for the von Bertalanffy growth parameters k and L_∞ for male and female river garfish from Lake Illawarra, Tuggerah Lakes and Wallis Lake.

Females grew faster than males and were, on average, larger than males at any given size (Figs. 3.35, 3.36 & 3.37 and Table 3.6). Both females and males had estimated maximum ages of 7+ years. River garfish from Lake Illawarra were larger than those from the other 2 estuaries at any given age (Table 3.6) and reached larger sizes (Fig. 3.34 and Table 3.6). Data from sexes and years were combined from each estuary to provide overall growth curve parameter estimates to be used in per recruit calculations.

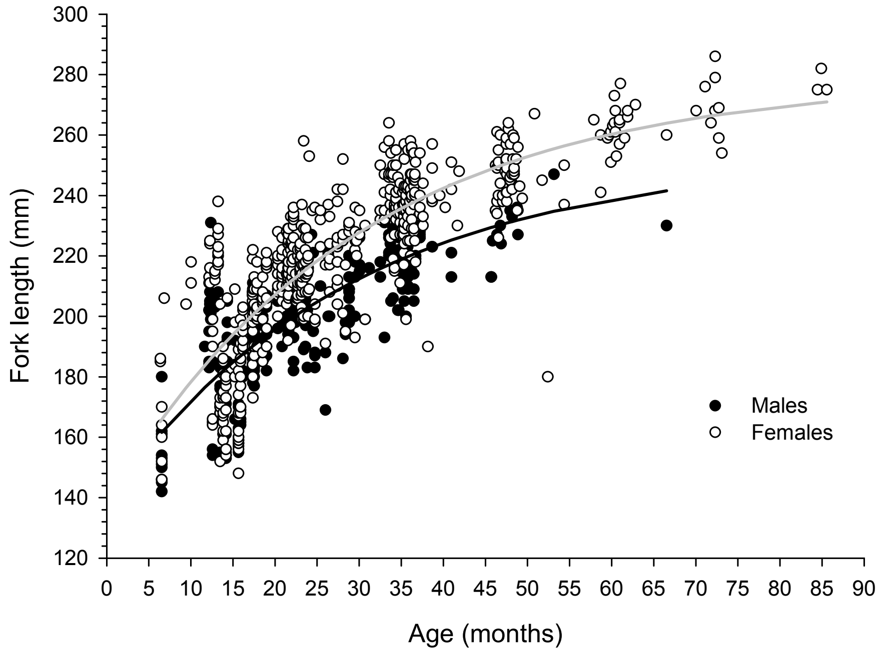


Figure 3.35. Size-at-age data for river garfish from Lake Illawarra with fitted von Bertalanffy growth curves.

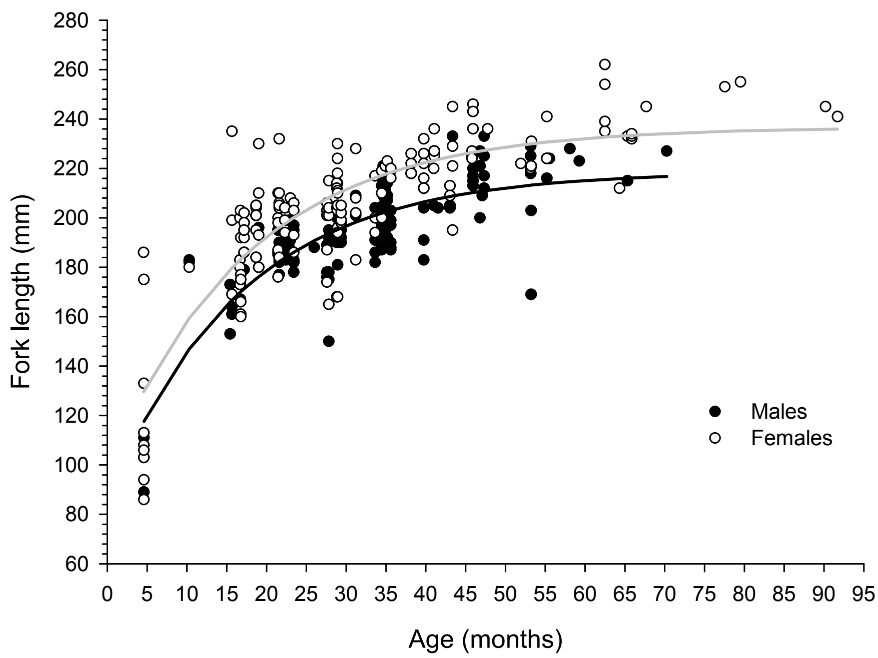


Figure 3.36 Size-at-age data for river garfish from Tuggerah Lakes with fitted von Bertalanffy growth curves.

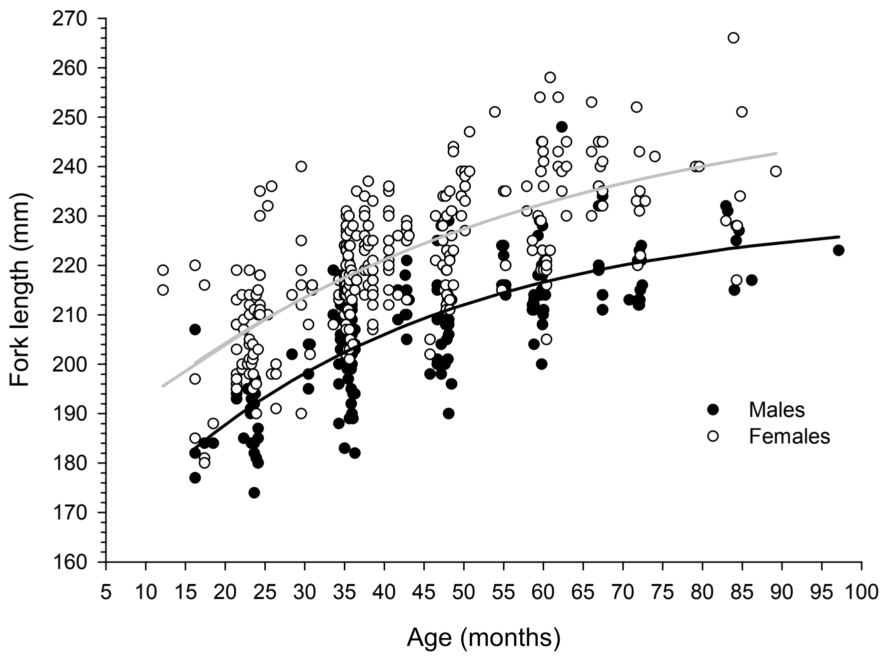


Figure 3.37. Size-at-age data for river garfish from Wallis Lake with fitted von Bertalanffy growth curves.

Table 3.7. Von Bertalanffy growth function parameters (with standard errors) for river garfish.

	Lake Illawarra			Tuggerah Lakes			Wallis Lake		
	Female	Male	All	Female	Male	All	Female	Male	All
L_∞ (mm)	278.7 (5.6)	253.0 (11.7)	283.7 (7.5)	236.7 (4.1)	218.7 (3.7)	230.0 (3.6)	255.4 (10.8)	230.89 (5.6)	239.7 (6.0)
K (monthly)	0.034 (0.004)	0.035 (0.008)	0.028 (0.003)	0.06 (0.006)	0.06 (0.007)	0.052 (0.005)	0.02 (0.007)	0.03 (0.007)	0.03 (0.007)
T_0 (months)	-20.15 (2.8)	-22.89 (5.5)	-24.71 (3.0)	-9.39 (1.9)	-8.26 (2.1)	-11.26 (1.9)	-60.3 (19.5)	-40.8 (12.8)	-48.5 (14.6)

<u>Snub-nosed garfish</u>

The size-at-age data for female and male snub-nosed garfish were compared between sexes (Table 3.8). The data were fitted to the von Bertalanffy growth function and the parameters (Table 3.9) compared. The 95% confidence interval ellipses generated around the parameter estimates L_∞ and K did not overlap (Fig. 3.38), confirming differences in growth between sexes. Females grew faster than males and were, on average, larger than males at any given size (Fig. 3.39 and Table 3.8). Females were estimated up to 7+ years and males 6+ years. Data from sexes and years were combined to provide overall growth curve parameter estimates to be used in per recruit calculations.

Table 3.8. Mean size-at-age (with standard errors) of female and male snub-nosed garfish. FL = fork length in mm. Lengths without standard errors had N = 1. Dashes denote no fish of that age class were observed.

	Females	Males
Age	FL	FL
0+	128 (29.5)	107.5 (11.8)
1+	210.2 (1.8)	178.9 (9.0)
2+	231.4 (1.4)	216.9 (1.5)
3+	238.4 (3.4)	224.5 (1.8)
4+	254 (5.6)	228.7 (3.8)
5+	267.8 (10.2)	239.1 (5.6)
6+	269.0 (19)	252.0
7+	307.0 (5)	-

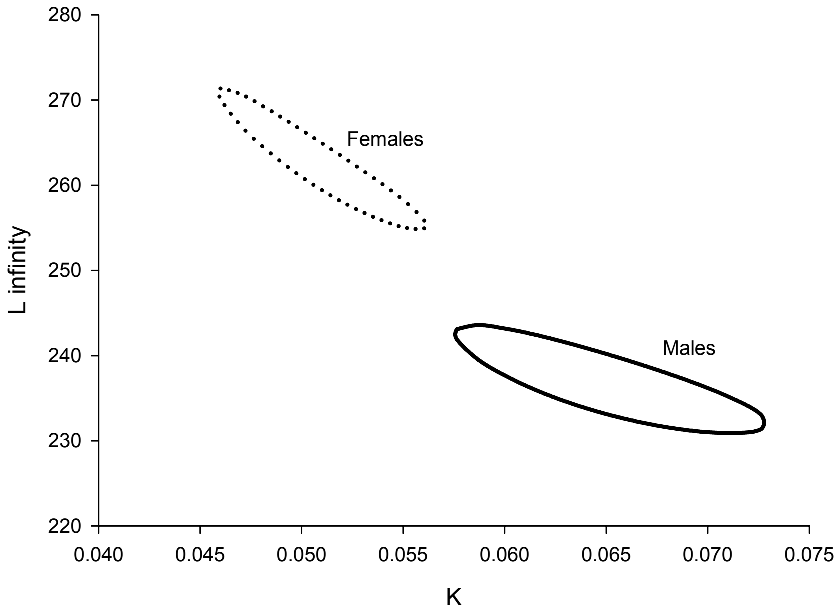


Figure 3.38. Ninety-five percent confidence ellipses for the von Bertalanffy growth parameters k and L_∞ for male and female snub-nosed garfish.

Table 3.9. Von Bertalanffy growth function parameters (with standard errors) for snub-nosed garfish.

	Females	Males	All
L_∞ (mm)	262.7 (4.8)	236.9 (3.1)	244.6 (2.2)
K (monthly)	0.05 (0.006)	0.06 (0.006)	0.08 (0.005)
T_0 (months)	-10.8 (2.4)	-5.0 (1.2)	-4.7 (1.0)

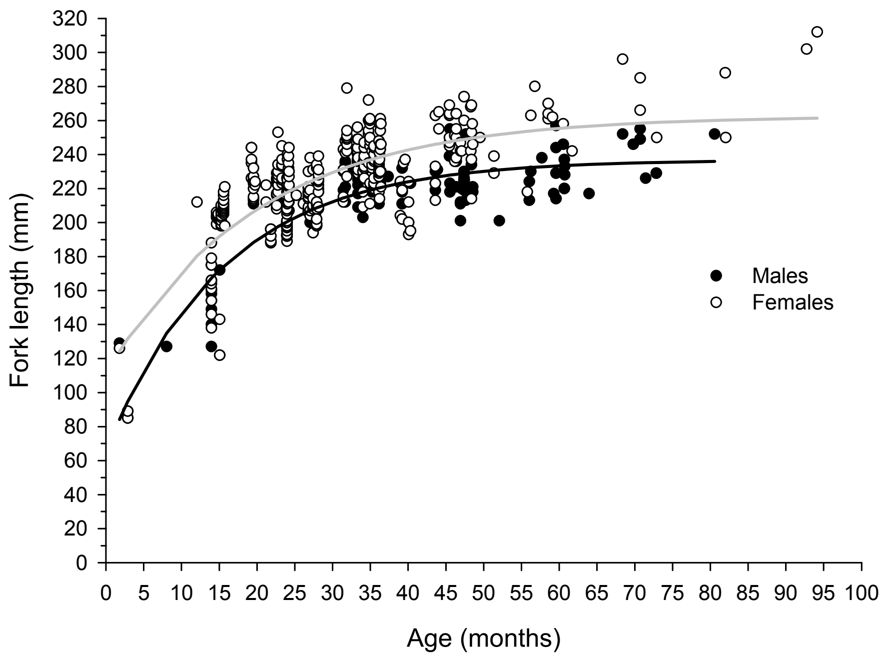


Figure 3.39. Size-at-age data for snub-nosed garfish with fitted von Bertalanffy growth curves.

3.3.7. Precision

Sea garfish

Ages were assigned to all otoliths examined and two-hundred comparative readings showed total agreement for 84.5% of otoliths, agreement to ± 1 year for 15% and agreement ± 2 years for 0.5% (1 fish). The coefficient of variation (CV), averaged across all ages, was 0.190.

River garfish

Precision in assigning counts of opaque zones to river garfish otoliths was high. Ages were assigned to all otoliths examined. Two-hundred comparative readings showed total agreement for 94% of otoliths examined and agreement to ± 1 year for the remaining 6%. The coefficient of variation (CV), averaged across all ages, was 0.032.

Snub-nosed garfish

Ages were assigned to all otoliths examined and two-hundred comparative readings showed total agreement for 79% of otoliths examined and agreement to ± 1 year for the remaining 21%. The coefficient of variation (CV), averaged across all ages, was 0.088, slightly higher than that for river garfish.

3.3.8. Estimation of age structures in landings

Sea garfish

The age-length keys for sea garfish sampled during 2001/02 and 2002/03 were similar (Tables 3.10 & 3.11) and were applied to the size-composition estimates (Chapter 2) to obtain estimates of age-compositions in commercial landings for these years.

Table 3.10. Age-length key for sea garfish sampled during 2001/02.

	Age (years)				
Length class (mm)	0	1	2	3	Total
150-159					0
160-169	2				2
170-179	2				2
180-189	5	1			6
190-199	25	3			28
200-209	27	5			32
210-219	26	2			28
220-229	17	15			32
230-239	13	23			36
240-249	9	30	2		41
250-259	4	33	3		40
260-269		72	1		73
270-279		57	6		63
280-289		39	2		41
290-299		32			32
300-309		12	1		13
310-319		4	2		6
320-329			4		4
330-339			1	1	2
340-349					0
350-359					0
360-369					0
N	130	328	22	1	481

Table 3.11. Age-length key for sea garfish sampled during 2002/03.

	Age (years)				
Length class (mm)	0	1	2	3	Total
150-159	1				1
160-169	5				5
170-179	15	1			16
180-189	25	4			29
190-199	23	9	1		33
200-209	20	31	1		52
210-219	28	15			43
220-229	21	30			51
230-239	12	28	1		41
240-249	3	30	1		34
250-259	3	33	1		37
260-269		41	1		42
270-279		29	2		31
280-289		21	5		26
290-299		12	4		16
300-309		10	2		12
310-319		4	5		9
320-329		1	2		3
330-339			2		2
340-349				1	1
350-359					0
360-369				1	1
N	156	299	28	2	485

The estimated age compositions of commercial landings were almost identical during 2001/02 and 2002/03, with 60% of the catch consisting of fish in their 2nd year of life during both years (Figs. 3.40 & 3.41). Approximately 40% of the catch consisted of fish in their first year during both years studied.

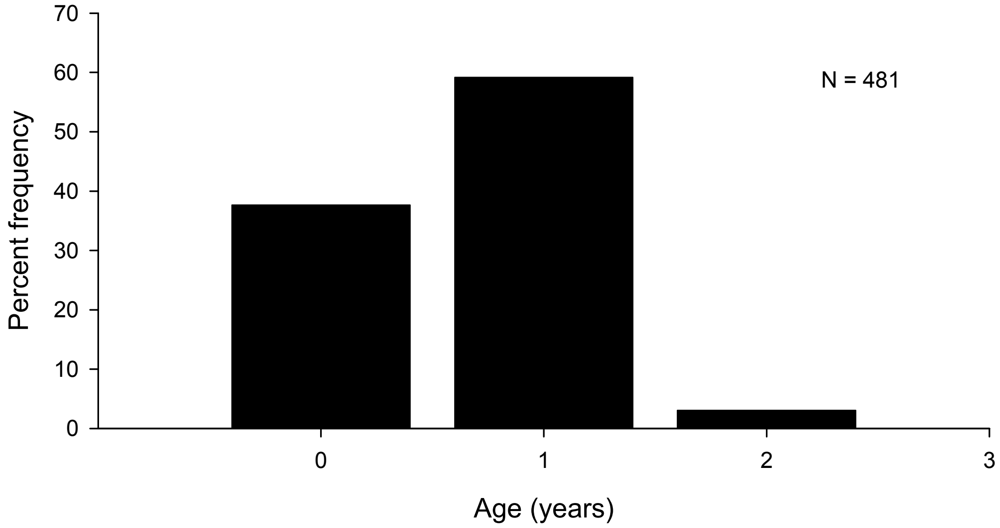


Figure 3.40. The age composition of sea garfish in commercial landings during 2001/02.

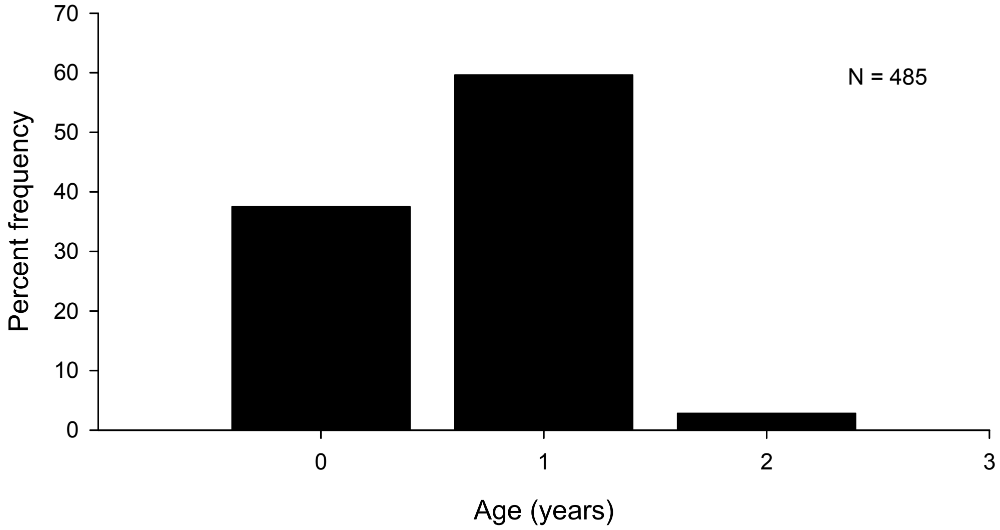


Figure 3.41. The age composition of sea garfish in commercial landings during 2002/03.

<u>River garfish</u>

The age-length keys for river garfish from Lake Illawarra for the years 2001/02, 2002/03 and 2003/04 (Tables 3.12, 3.13 & 3.14) were combined with the size composition data (Chapter 2) and used to estimate age compositions in commercial landings for those years.

The age composition of landings was very similar between years with approximately 75 to 80% of the catch being aged 2 and 3+ (Fig. 3.42). The majority of the rest of landings consisted of fish aged 3, 4 and 5+ years.

Table 3.12. Age-length key for river garfish from Lake Illawarra sampled during 2001/02.

	Age (years)								
Length class (mm)	0	1	2	3	4	5	6	7	Total
140-149	4	1							5
150-159	5	14							19
160-169	4	10							14
170-179	1	10							11
180-189	1	18							19
190-199		20	3						23
200-209	1	22	6						29
210-219		16	9	1					26
220-229		9	12	1					22
230-239		1	10	2	1	1			15
240-249				3	1				4
250-259			1	1	1				3
260-269						3			3
270-279						1			1
280-289									0
290-299									0
N	16	121	41	8	3	5	0	0	194

Table 3.13. Age-length key for river garfish from Lake Illawarra sampled during 2002/03.

	Age (years)								
Length class (mm)	0	1	2	3	4	5	6	7	Total
140-149									0
150-159		5							5
160-169		18	1						19
170-179		13							13
180-189	2	30	5		1				38
190-199		34	15	1					50
200-209		55	14						69
210-219		65	28	4					97
220-229		26	38	13	1				78
230-239		7	34	18	4				63
240-249			28	16	2				46
250-259		1	12	8	3	2	1		27
260-269			1	5	7	3			16
270-279						3	1	1	5
280-289						1			1
290-299									0
N	2	254	176	65	18	9	2	1	527

Table 3.14. Age-length key for river garfish from Lake Illawarra sampled during 2003/04.

	Age (years)								
Length class (mm)	0	1	2	3	4	5	6	7	Total
140-149									0
150-159									0
160-169									0
170-179									0
180-189		6							6
190-199	1	5							6
200-209	1	14	1	2					18
210-219	2	12	9	1					24
220-229		9	10	4					23
230-239		2	15	3					20
240-249			5	13	1				19
250-259		1	3	8	2	1			15
260-269					2	3			5
270-279					1				1
280-289							1		1
290-299									0
N	4	49	43	31	6	4	1	0	138

Unlike Lake Illawarra, many catches of river garfish from Tuggerah Lakes were obtained from fishers who caught them as a by-catch in hauling and prawn nets. We pooled all size-at-age data from Tuggerah Lakes between 2001/02 and 2003/04 to provide an age-length key for this estuary (Table 3.15).

The age structure of samples of river garfish from Tuggerah Lakes was not estimated by applying the age-length key to the size composition data presented in Chapter 2 because we only sampled 1 catch for lengths. In this instance, our sampling for age estimation was assumed to be representative of what was caught during the study and the age structure is presented in Fig. 3.43. This age composition had a slightly lower proportion of 1+ fish but was otherwise similar to that observed each year from Lake Illawarra (Fig. 3.42).

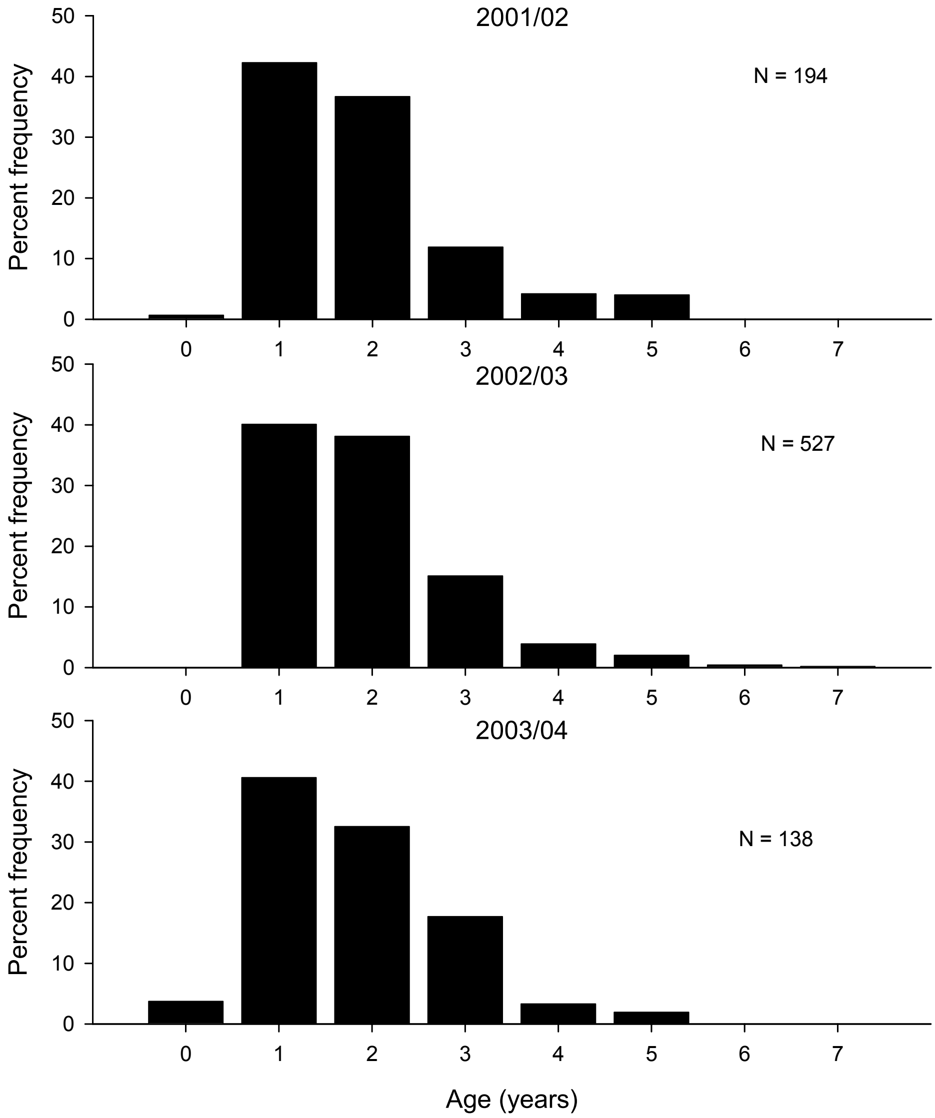


Figure 3.42. Age compositions of river garfish in commercial landings from Lake Illawarra between 2001/02 and 2003/04.

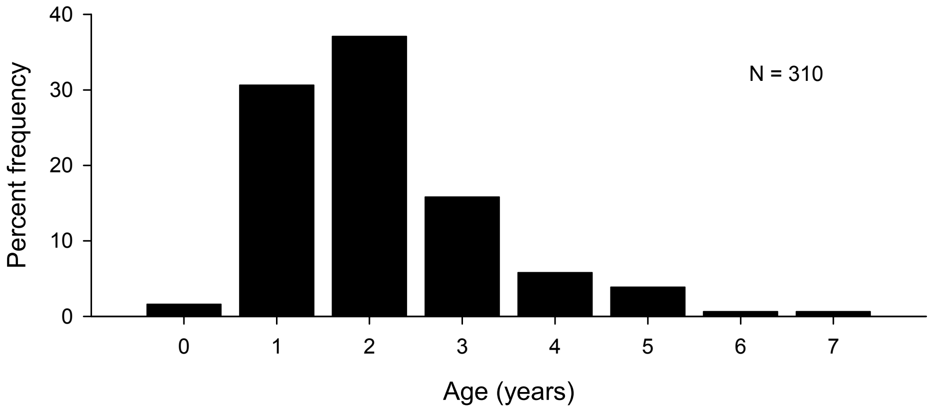


Figure 3.43. Age composition of river garfish sampled from Tuggerah Lakes between 2001/02 and 2003/04.

Table 3.15. Age-length key for river garfish from Tuggerah Lakes sampled between 2001/02 and 2003/04.

	Age (years)								
Length class (mm)	0	1	2	3	4	5	6	7	Total
80-89	2								2
90-99	1								1
100-109	4								4
110-119	2								2
120-129	1								1
130-139		1	1						2
140-149		7	3		1				11
150-159	1	9	5						15
160-169	4	30	11	1					46
170-179		26	36	2					64
180-189		17	34	8	1				60
190-199		3	19	11	3	2			38
200-209			6	18	11	1			36
210-219		3	1	6	1	6			17
220-229				3	1	1		2	7
230-239						1	2		3
240-249						1			1
N	15	96	116	49	18	12	2	2	310

We sampled 20 river garfish for age estimation from Wallis Lake during 2001/02, 74 during 2002/03 and 374 during 2003/04. There was little difference in the size composition of river garfish sampled from Wallis Lake (Chapter 2) and we therefore pooled all size-at-age data into a general age-length key for Wallis Lake (Table 3.16).

Table 3.16. Age-length key for river garfish from Wallis Lake sampled between 2001/02 and 2003/04.

	Age (years)								
Length class (mm)	0	1	2	3	4	5	6	7	Total
170-179		2							2
180-189		15	5						20
190-199		22	16	4					42
200-209		17	43	19	4				83
210-219		14	53	42	26	10	3	1	149
220-229		1	17	34	18	8	6	1	85
230-239			7	16	15	15	3	1	57
240-249			1		7	11	3		22
250-259					2	4	1		7
260-269							1		1
N	0	71	142	115	72	48	17	3	468

The age composition of commercial landings from Wallis Lake showed a smaller proportion of fish aged 1+ years than in either Tuggerah Lakes or Lake Illawarra (Fig. 3.44). The bulk of the catch (80%) consisted of fish aged 1+, 2+ and 3+ years old, however fish up to 7 years old were also caught.

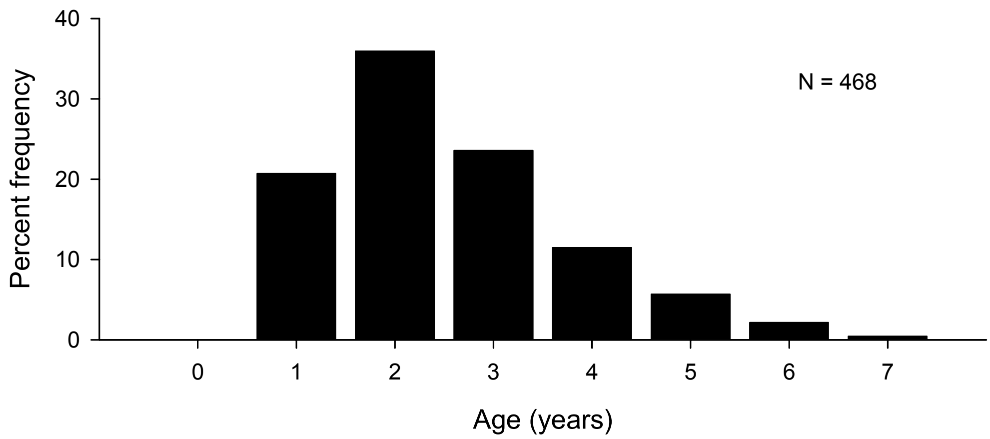


Figure 3.44. Age composition of river garfish in commercial landings from Wallis Lake between 2001/02 and 2003/04.

Snub-nosed garfish

The age-length keys for snub-nosed garfish for the years 2001/02, 2002/03 and 2003/04 (Tables 3.17, 3.18 & 3.19) were combined with the size composition data (Chapter 2) and used to estimate age compositions in commercial landings for those years.

Table 3.17. Age-length key for snub-nosed garfish sampled during 2001/02.

	Age (years)								
Length class (mm)	0	1	2	3	4	5	6	7	Total
190-199		4	5	1					10
200-209		21	13	4	1				39
210-219		10	21	5		1			37
220-229		6	2	6	1				15
230-239		1	6	4	1				12
240-249		1	1		1				3
250-259			1	1	1				3
260-269				1					1
N	0	43	49	22	5	1	0	0	120

Table 3.18. Age-length key for snub-nosed garfish sampled during 2002/03.

	Age (years)								
Length class (mm)	0	1	2	3	4	5	6	7	Total
120-129	3	1							4
130-139		1							1
140-149		3							3
150-159		3							3
160-169		5							5
170-179		3							3
180-189		1							1
190-199				1					1
200-209		3	2	1					6
210-219	1	13	9	6	3				32
220-229		23	18	6	3	2			52
230-239		15	14	3	3				35
240-249		4	14	4		1			23
250-259		1	9	3	1	2	1		17
260-269			4	2	2				8
270-279			2						2
280-289					1				1
290-299						1			1
300-309								1	1
N	4	76	72	26	13	6	1	1	199

Table 3.19. Age-length key for snub-nosed garfish sampled during 2003/04.

	Age (years)								
Length class (mm)	0	1	2	3	4	5	6	7	Total
80-89	2								2
90-99									0
100-109									0
110-119									0
120-129		1							1
130-139		1							1
140-149									0
150-159									0
160-169									0
170-179		1							1
180-189		3							3
190-199		14							14
200-209		9	3						12
210-219		8	5	2	1				16
220-229		3	9	9	1				22
230-239			27	6	1				34
240-249			9	3	1	2			15
250-259			1	5	1	1	1		9
260-269				6	2	1			9
270-279				1	1				2
280-289						1	1		2
290-299									0
300-309									0
310-319								1	1
N	2	40	54	32	8	5	2	1	144

The ages in commercial landings were similar during 2001/02 and 2002/03 with approximately 75% of the catch consisting of fish aged 1+ and 2+ years old (Fig. 3.45). Landings during 2003/04 were characterised by a lack of 1+ year olds and a greater proportion of 3+ year olds.

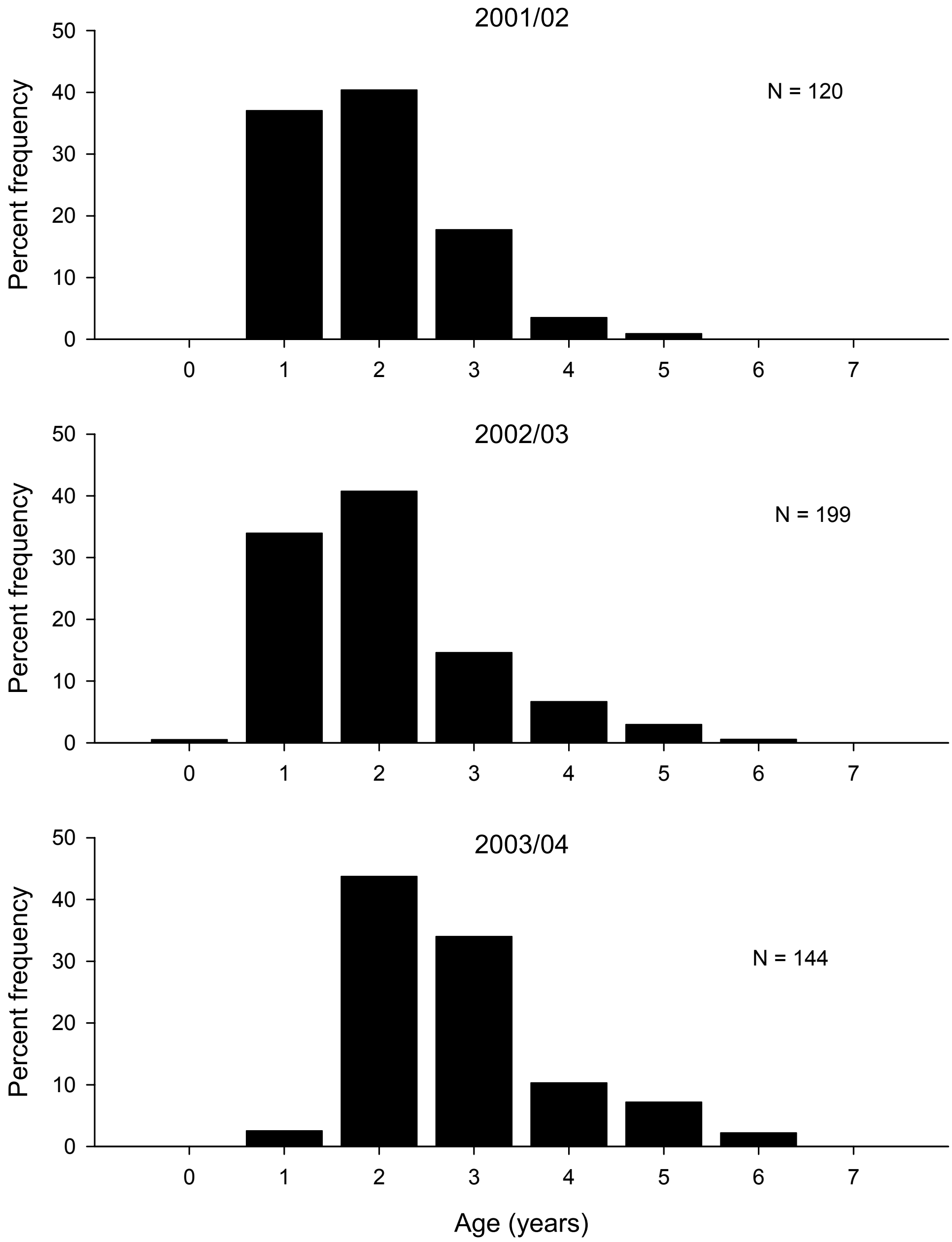


Figure 3.45. Age compositions of snub-nosed garfish in commercial landings between 2001/02 and 2003/04.

3.3.9. *Estimation of mortality rates*

Sea garfish

Estimates of total mortality (Z) made from the catch curves for sea garfish were 3.4 for 2001/02 and 3.0 for 2002/03 (Table 3.20). Independent estimates of natural mortality (M) based on the methods of Hoenig (1983) using a maximum age of 4 years, and Pauly (1980) using the von Bertalanffy parameters for combined sexes of sea garfish (Table 3.5) and a water temperature of 20°C ranged between 0.75 and 0.81 (Table 3.20). Therefore estimates of fishing mortality (F), made by subtracting M from Z, ranged between 2.19 and 2.65. These mortality estimates suggest that up to 96% of sea garfish die each year after being recruited to the fishery at age 1.

Table 3.20. Estimates of annual mortality rates for sea garfish.

Estimation source	Instantaneous mortality estimates		
	Total (Z)	Natural (M)	Fishing (F = Z - M)
Catch curve 2001/02	3.4		
Catch curve 2002/03	3.0		
Hoenig (1983)		0.75	
Pauly (1980)		0.81	
Range of estimates	3.0 – 3.4	0.75 – 0.81	2.19 – 2.65

River garfish

Estimates of Z made from the catch curves for river garfish are presented in Table 3.21. Total mortality rate estimates were considerably less than those for sea garfish, ranging from 0.77 to 1.09. These mortality rates correspond to between 53 and 66% of the population aged 2 years and older dying each year. Estimates of M based on the method of Pauly (1980) were made separately for each estuary because of significantly different growth rates at each location (Fig. 3.34). Estimates of F, made by subtracting the estimates of M from Z, ranged between 0.34 and 0.86 for all three estuaries.

Table 3.21. Estimates of annual mortality rates for river garfish. LI = Lake Illawarra, TL = Tuggerah Lakes, WL = Wallis Lake.

Estimation source	Instantaneous mortality estimates		
	Total (Z)	Natural (M)	Fishing (F=Z - M)
LI catch curve 2001/02	0.77		
LI catch curve 2002/03	1.09		
LI catch curve 2003/04	1.02		
TL catch curve (pooled years)	1.04		
WL catch curve (pooled years)	0.85		
Hoenig (1983)		0.43	
LI (Pauly, 1980)		0.23	0.34 – 0.86
TL (Pauly, 1980)		0.36	0.61 – 0.68
WL (Pauly, 1980)		0.23	0.42 – 0.62
Range of estimates	0.77 – 1.09	0.23 – 0.43	0.34 – 0.86

Snub-nosed garfish

Estimates of Z made from the catch curves for snub-nosed garfish were similar to those for river garfish but declined slightly from year to year (Table 3.22). Estimates of M ranged between 0.43 and 0.46 and, when subtracted from Z, resulted in estimates of F between 0.29 and 0.86. These mortality estimates correspond to between 50 and 80% of snub-nosed garfish dying each year after the age of 2 years.

Table 3.22. Estimates of annual mortality rates for snub-nosed garfish.

Estimation source	Instantaneous mortality estimates		
	Total (Z)	Natural (M)	Fishing (F = Z - M)
Catch curve 2001/02	1.29		
Catch curve 2002/03	1.0		
Catch curve 2003/04	0.75		
Hoenig (1983)		0.43	
Pauly (1980)		0.46	
Range of estimates	0.75 – 1.29	0.43 – 0.46	0.29 – 0.86

3.3.10. Preliminary stock assessment

Sea garfish

Yield per recruit (YPR) analyses over a range of plausible estimates of M and F showed indefinite increases with increasing F (Fig. 3.46). Changes in estimated YPR were relatively constant at any given F over a range of M. The reference point $F_{0.1}$ ranged between 0.09 and 0.37 for M's of 0.5 and 0.9 respectively. Spawner-biomass per recruit (SBPR) and egg per recruit (EPR) analyses showed that at present levels of exploitation (F between 2.2 and 2.7) for a plausible range of M (0.5 to 0.9) that these levels may represent between approximately 10 and 25% respectively of the unexploited stock.

River garfish

Lake Illawarra

YPR analyses, over a range of plausible estimates of M and F, showed similar trends to those for sea garfish and increased indefinitely with increasing F (Fig. 3.47). Values of the reference point $F_{0.1}$ ranged between 0.3 and 0.4 for M's of 0.2 and 0.3 and is within the range of values for F estimated in Table 3.21. SBPR and EPR analyses showed that, at present levels of exploitation (F between 0.25 and 0.85) and for a plausible range of M (0.1 to 0.6), that they represent between approximately 20 and 70% of the unexploited stock. Based on an M of 0.4 (using Hoenig's 1983 method) and an F of 0.6 (based on the catch curves from 2002/03 and 2003/04) these levels are likely to be around 40% of unexploited levels.

Tuggerah Lakes & Wallis Lake

The YPR analyses for Tuggerah Lakes and Wallis Lake were very similar to those for Lake Illawarra, increasing indefinitely with increasing F and estimates of $F_{0.1}$ being 0.3 to 0.4. SBPR and EPR analyses for both estuaries showed that at present levels of exploitation (F between 0.4 and 0.7) and M between 0.1 and 0.6 that these levels represent between 25 and 70% of unexploited levels. For an M of 0.4 (using Hoenig's 1983 method) and an F of 0.6 SBPR and EPR levels are estimated to be around 40% of unexploited levels.

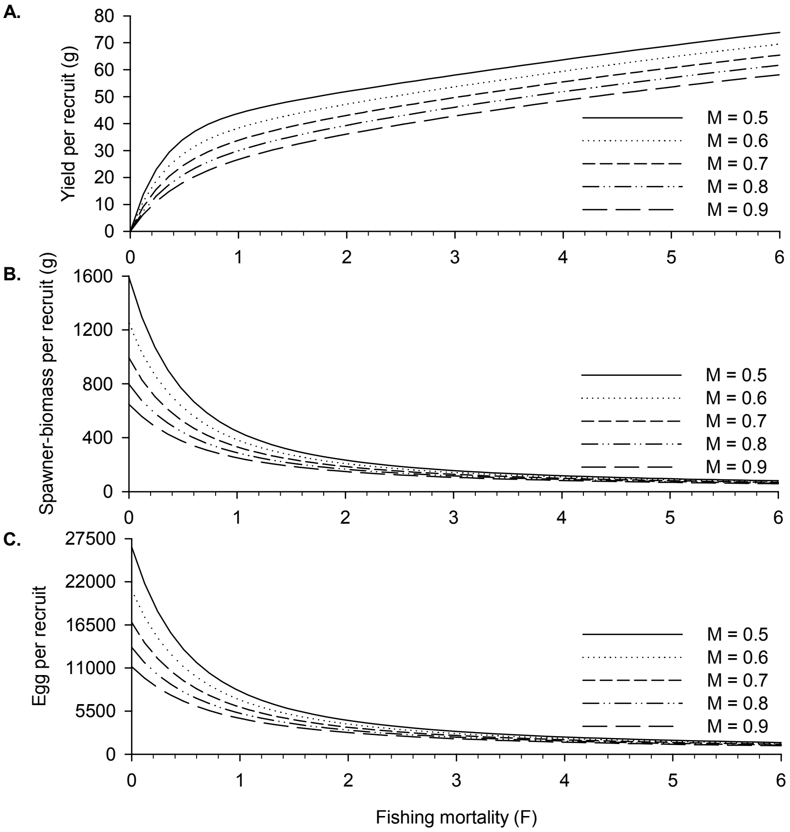


Figure 3.46. A. Yield per recruit; B. Spawner-biomass per recruit; and C. Egg per recruit analyses as functions of increasing fishing mortality (F) for a plausible range of natural mortality (M) estimates for sea garfish.

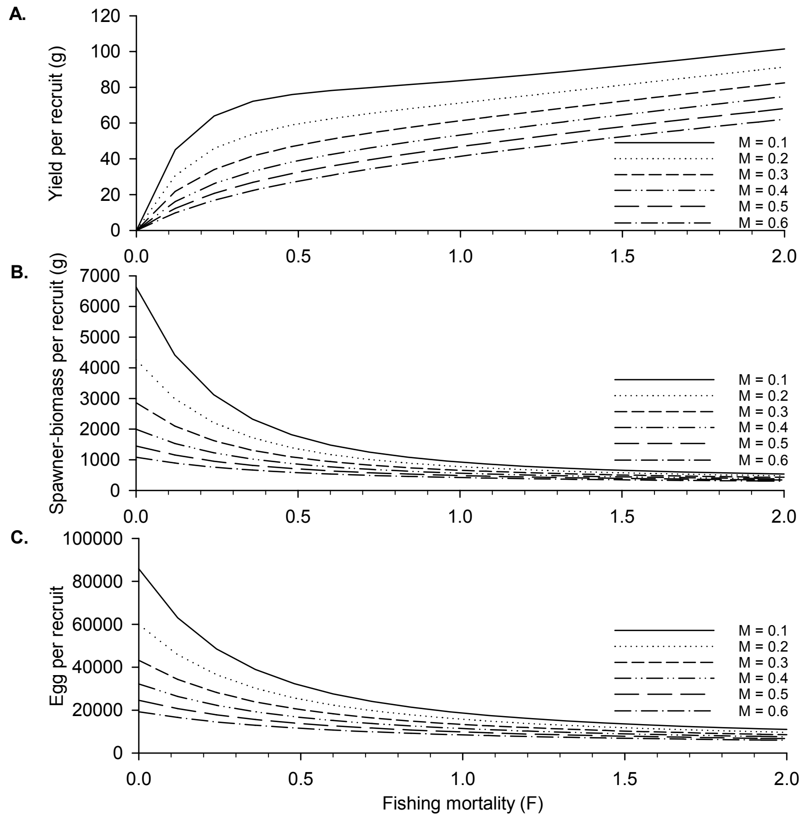


Figure 3.47. A. Yield per recruit; B. Spawner-biomass per recruit; and C. Egg per recruit analyses as functions of increasing fishing mortality (F) for a plausible range of natural mortality (M) estimates for river garfish from Lake Illawarra.

Snub-nosed garfish

YPR analyses, over a range of plausible estimates of M and F, showed similar trends to those for sea and river garfish and increased indefinitely with increasing F (Fig. 3.48). SBPR and EPR analyses were similar to those for river garfish and showed that at present levels of exploitation (F between 0.2 and 0.9) and for a plausible range of M (0.2 to 0.6) that these levels represent between approximately 20 and 70% of the unexploited stock. Based on an estimate of M of 0.4 (using Hoenig's 1983 method) and an F of 0.6 (based on the catch curves from 2002/03 and 2003/04) these levels are likely to be around 35% of unexploited levels.

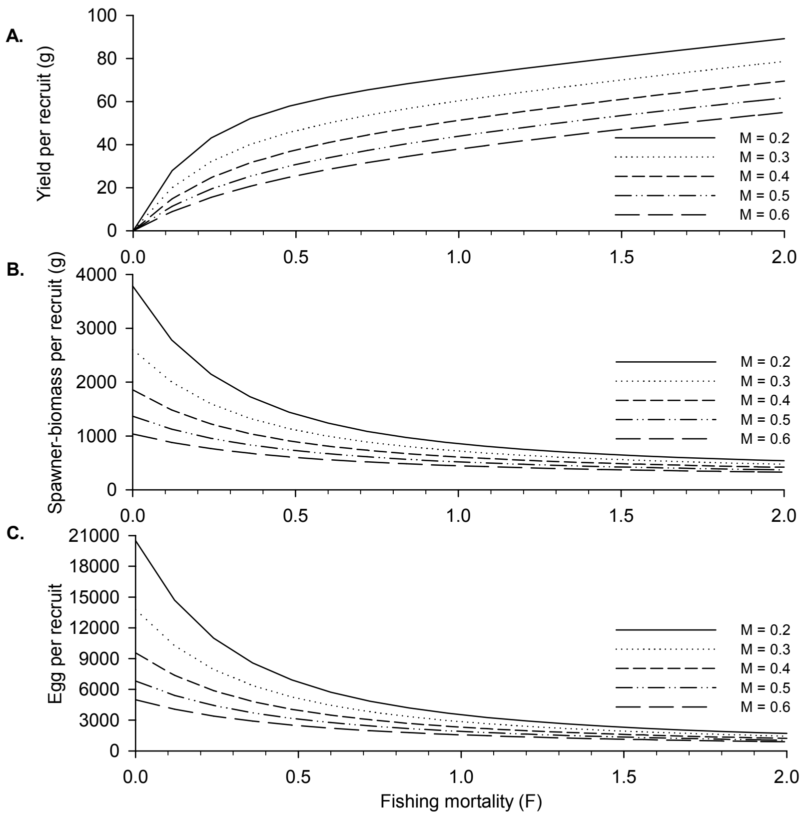


Figure 3.48. A. Yield per recruit; B. Spawner-biomass per recruit; and C. Egg per recruit analyses as functions of increasing fishing mortality (F) for a plausible range of natural mortality (M) estimates for snub-nosed garfish.

3.4. Discussion

Otoliths from all 3 species studied increased with fish size and age (Figs. 3.11, 3.12, 3.21, 3.22, 3.25 & 3.26) suggesting that they grow throughout the lives of the fish and are therefore useful structures for age estimation. The linear relationships between otolith weight and fish age are similar to that reported for the southern sea garfish (Jones et al., 2003) showing that otolith material is deposited at a fairly constant rate throughout the life of the fish.

Whole otoliths of garfish sampled from NSW were similar in shape to those reported for other hemiramphids (i.e. *Hyporhamphus melanochir* – Ling, 1958; Jordan et al., 1998; Jones et al., 2002). It has been reported however, that the otoliths from eastern sea garfish are much longer (relative to height) than those from *H. melanochir* (Collette, 1973). Sectioned otoliths showed large variation in internal structure between the 3 species studied and also with that reported for other hemiramphids. Sectioned otoliths of river and snub-nosed garfish were similar in appearance to each other and displayed very clear alternating translucent and opaque zones (Fig. 3.2). The opaque zones were thinner and more definite than those reported for *H. melanochir* (Jones et al., 2002) and *Hemiramphus* spp. (McBride & Thurman, 2003) and also for sea garfish (*H. australis*) in the present study. Sectioned otoliths of sea garfish, on the other hand, were very difficult to interpret. Patterns of alternating translucent and opaque zones were unclear and inconsistent. It was only after examining sea garfish that were stained with alizarin and kept in captivity that it became possible to confidently interpret their otoliths. Opaque zones in sea garfish are wider than the intervening translucent zones and are quite diffuse (Figs. 3.1 & 3.6).

The inconsistent and confusing appearance of sea garfish otoliths meant that our precision re-reading them was relatively low (average CV of 0.19). An average CV of 0.19 is at the higher end of the generally reported range (Campana, 2001). We had total agreement for 169 of 200 otoliths that were re-read (84.5%), however precision was considered poor because of the small number of age classes in the fishery. Discrepancies between first and second reads were always due to identification of the 1st opaque zone. Jones et al. (2002) reported average CV's of less than 0.03 for southern sea garfish which reflects the differences in appearance of the opaque zones between these species. Sectioned otoliths of river and snub-nosed garfish were more easily interpreted and this was reflected by the high degree of precision estimated for them (94% agreement with an average CV of 0.032 for river garfish and 79% agreement with an average CV of 0.088 for snub-nosed garfish). These values are well within the range of CV's reported for many other species (Campana, 2001).

Immersion in alizarin complexone was a far more effective method of staining the otoliths of garfish than the more traditional method of injecting tetracycline into the peritoneal cavity. Only 47% of sea garfish and 7.5% of river garfish injected with tetracycline in the present study had otoliths with visible tetracycline marks. These values are much lower than those generally reported using similar methodology (Beamish & McFarlane, 1987). Jones et al. (2002) using a similar technique with southern sea garfish, reported high initial mortality rates (>50%) but did not report on the proportion that were successfully stained. The small volumes of tetracycline administered during our study (because of the small weights of the fish) meant that any spillage may have resulted in a lower dose rate than intended. In addition, the damage and stress caused by handling during the injection of tetracycline may have prevented uptake of the tetracycline and caused high mortality rates. In contrast, immersion in alizarin complexone solution limited the handling of delicate fish and resulted in the successful staining of 97 and 99% of sea garfish and river garfish respectively. One important difference is that alizarin marks may be viewed under normal light, whereas tetracycline is only visible under UV light. This means that reading otoliths stained with alizarin is easier, but because the reader can immediately see the position of the alizarin mark in relation to opaque zones some bias in where to assign opaque zones is difficult to prevent. As such this method should not be used to estimate ageing error, but is an excellent tool for demonstrating periodicity in opaque zone formation.

The variation in appearance of translucent and opaque zones in sectioned otoliths of the 3 species studied may be a result of differences in latitude, water temperature and physiology. The process of otolith formation and factors affecting variation in their internal structure are as yet not fully understood. It is thought that annuli form as a result of variation in somatic growth and physiological responses to environmental variation throughout the year (Fowler, 1995). The thin but distinct opaque zones in the otoliths of river and snub-nosed garfish are likely due to these species being restricted to their estuaries and experiencing low water temperatures during winter. These fish also spawn in winter/spring (Chapter 4) and available energy during this time is likely to be used for reproduction rather than for growth. Sea garfish, however, are a wide-ranging oceanic species that associate with temperate waters of a relatively consistent temperature. Studies have reported that the otoliths of fish that live in areas where seasonal influences are reduced often do not display distinct annuli (Fowler, 1995; Smith & Deguara, 2003). The sea garfish stained with alizarin in the present study were kept in tanks with flow-through water of ambient temperature that varied from around 23ºC in summer to around 15ºC during winter, yet their otoliths displayed indistinct zones similar to wild fish. This suggests that the differences in appearance of opaque zones between the species studied are largely influenced by physiology. Otoliths of faster growing fish have been shown to exhibit less distinct zones (Esteves & Burnett, 1993) and the inconsistent patterns observed in the otoliths of sea garfish may be a result of their extremely fast growth rate.

The annual periodicity of opaque zone formation in the otoliths of the sea, river and snub-nosed garfish has been validated. Marking with tetracycline and alizarin showed that opaque zones are formed during winter/spring in sea and river garfish but do not become visible on the edge of the otolith until summer (Figs. 3.7 & 3.17). Marginal increment analyses and the proportion of otoliths with opaque margins showed repeated seasonal patterns for each species, consistent with the annual formation of opaque zones in their otoliths (Figs. 3.8, 3.9, 3.18, 3.19, 3.23 & 3.24). These results support the model developed from the alizarin study that opaque zones become visible on the otolith edge in spring/summer.

The most complete marginal increment data set was collected for river garfish and provided evidence that opaque zones become visible on the edge of otoliths from fish aged 1+ years old slightly earlier than those aged 2+ years and older (i.e. Nov, Dec 2002 in Fig. 3.18). The fastest growing individuals in other species (*Trachurus novaezelandiae* & *Scomber australasicus*) found in NSW also have opaque zones becoming visible earlier in the year (Stewart et al., 1999), and this may have important implications when converting counts of opaque zones into age classes. The protocols developed for converting counts of opaque zones to age classes based on the marginal increment, number of opaque zones and month of capture were designed to minimise errors caused by variation in the timing of opaque zone appearance (Figs. 3.27, 3.28, 3.29 & 3.30).

Information on the timing of spawning from Chapter 4, the validation studies above and observation of the otoliths from very young sea and river garfish (Figs. 3.10, 3.17, 3.20) allow development of a model to describe early otolith growth in garfish. Sea and river garfish are born in late winter/spring and have entirely opaque otoliths. Translucent material is deposited outside of this opaque core area during the following summer/autumn and the 1st annulus is formed during the following winter. This 1st annulus does not become visible on the otolith edge until spring/summer when the fish is aged between 12 and 18 months old. The distance of the 1st annulus from the core was variable (e.g. ranging between 0.31 and 0.81mm for sea garfish) and may reflect the relative time during the spawning season that the fish was born (i.e. fish with wide 1st increments were born early - July - while fish with narrow 1st increments were born late - December). A similar observation was made for the southern sea garfish *Hyporhamphus melanochir* (Jones et al., 2002). Unfortunately, the very small measurement distances involved and the errors associated with sectioning (i.e. sectioning at slightly oblique angles or not through the core of the otolith) meant that is was not possible to refine estimates of age further based on the distance from the core to the 1st annulus. The very fast growth rates determined here, particularly for sea garfish, mean that an error of 6 months in age estimation can be significant and this is reflected in the wide range of sizes for any estimated age (Fig. 3.32).

The maximum sizes observed during this study (36.3 cm FL for sea garfish, 28.6 cm FL for river garfish and 31.2 cm FL for snub-nosed garfish) were close to the maximum reported for these species (39.8 cm, 28.0 cm and 27.7 cm standard length respectively; Collette, 1974). The measurement of fork length is slightly larger than that of standard length, however the 31.2 cm FL snub-nosed garfish sampled was still larger than any previously reported. The method of bullringing used to catch river and snub-nosed garfish is essentially a gill-net, for which the selectivity properties have been well documented (Hamley, 1975). Such nets often do not retain the largest fish and it is highly likely, therefore, that river and snub-nosed garfish reach larger sizes than those reported in our study. It is suggested that future sampling of the catches of recreational fishers should be done to better estimate maximum sizes (and ages) for these species. The selectivity of garfish hauling nets, used to catch sea garfish, has been well studied (Appendix 4) and these nets retain the largest fish encountered.

Estimates of age showed maximum ages of 4 years for sea garfish and 7 years for river and snub-nosed garfish. Given that we sampled fish close to the maximum sizes recorded, our maximum ages are likely to be close to maximum ages for these species. The maximum age of 4+ years for sea garfish is considerably younger than that of the closely related and morphologically similar southern sea garfish of 10 years (Jones, 1990; Jordan et al., 1998). This raises the question of whether eastern sea garfish can achieve similar ages and whether the stock has been depleted to such a level that no old fish remain? Given that the sizes of sea garfish in landings do not appear to have changed dramatically since the 1950's, (based on the measurements from 7 catches during 1955 - Chapter 2) this is unlikely to be the case. In addition, recent work on similar species in Florida (USA) reported maximum ages of 4 years for *Hemiramphus brasiliensis* and 2 years for *Hemiramphus balao* (McBride & Thurman, 2003). We only sampled 1 eastern sea garfish that was estimated to be 4+ years old (see Fig. 3.1) and 3 that were estimated to be 3+ years old. This suggests that despite eastern sea garfish having the capacity to reach 3 to 4 years of age that very few actually attain this age. Given that the status of the stock is currently listed as overfished, it is a logical assumption that very few fish reach their potential maximum age because they are caught beforehand. Large changes in management designed to reduce fishing pressure have recently been implemented (Appendix 3) and future age-based monitoring may detect whether such changes have had the desired effect.

Ours is the first study to estimate the growth rate of eastern sea garfish. Age-based growth curves showed that early growth is extremely rapid and males and females reach around 23.0 cm FL after 1 year (Fig. 3.32). After this age females grow significantly faster and reach larger sizes than males. Jones et al. (2002) reported differences in growth between female and male southern sea garfish, with females tending to reach larger sizes than males, however the differences in mean size-at-age found by these authors do not appear to be as large as we observed for eastern sea garfish. McBride & Thurman (2003) and Berkeley & Houde (1978) also reported females to have a larger average size-at-age for *Hemiramphus brasiliensis* and *Hemiramphus balao*.

The estimated size at age 1 of around 23.0 cm FL for eastern sea garfish is considerably larger than that reported for the southern sea garfish. Using estimates of the von Bertalanffy growth function parameters provided for the southern sea garfish (Jones et al., 2002), they reached around 16 to 18 cm FL at 1 year of age depending on the sampling location. McBride & Thurman (2003) reported the average size of both *Hemiramphus brasiliensis* and *Hemiramphus balao* aged 1+ to be between 22.5 and 25 cm FL, while our estimates for all sea garfish aged 1+ years old were between 24.8 and

26.8 cm FL (Table 3.4). It appears as though eastern sea garfish are more similar in growth rate and maximum age to *Hemiramphus* spp. than the southern sea garfish. This may be due to differences in habitat and distribution. Sea garfish are more similar to the hemiramphids reported by McBride & Thurman (2003) in being largely oceanic, whereas southern sea garfish are more of an inshore species (Ling, 1958; Jones, 1990; Jordan & Lyle, 2000).

The combined monthly commercial length frequency data (Fig. 3.33) provides strong evidence that growth after recruitment to the fishery at around 20 cm FL continues to be rapid (in the order of 1 cm per month between May and July). The fact that small fish were observed recruiting to the fishery through at least 5 months (May to September) reflects the prolonged spawning period for sea garfish (Chapter 4). Sea garfish can grow from around 20 to 27 cm (35 to 95 g – see length/weight relationship in Chapter 2) within 12 months of entering the fishery. This increase in modal size supports the model of extremely fast growth during their first 12 months. There have been no studies on larval growth of sea garfish, however Berkeley & Houde (1978) reported newly hatched *Hemiramphus brasiliensis* in captivity to grow at more than 1 mm per day for the first month and to reach around 5 cm standard length. They estimated *Hemiramphus brasiliensis* to recruit to the fishery at around 17 cm and at 5 months of age. The growth of sea garfish stained with alizarin and kept in captivity also supports the model of extremely rapid growth. The average size of fish assumed to be 1+ years old when stained in February 2003 was 20.5 cm FL (Fig. 3.5). The average size of fish sampled between January and July 2004 was 28.5 cm FL, an average increase of 8 cm in 11 to 17 months, similar to that observed in the monthly commercial length frequency data.

Similar to eastern sea garfish, female river and snub-nosed garfish also reached larger sizes than males and were, on average, larger at any given age (Figs. 3.35, 3.36, 3.37 & 3.39). All river garfish grew rapidly, however there were significant differences in growth rates between the 3 estuaries sampled. River garfish from Lake Illawarra tended to grow larger than those from either Tuggerah or Wallis Lakes and were, on average, larger at any given age. The size-at-age data for river garfish from Tuggerah and Wallis Lakes were similar (Figs. 3.36 & 3.37) and the differences in von Bertalanffy growth curves may have been an artefact of not sampling any 0+ year old fish from Wallis Lake.

The age composition of sea garfish in commercial landings was remarkably similar during 2001/02 and 2002/03 with approximately 90% of the catch consisting of fish less than 2 years old and 38% in their first year of life (Fig. 3.41). This constancy in age composition is surprising given the predominance of smaller fish in landings during 2002/03 (Chapter 2). There are fewer age classes in the fishery (currently 3 – 0, 1 & 2) compared to the fisheries for southern sea garfish in Victoria, South Australia and Western Australia (7 to 11 age classes; Jones et al., 2002). However, the age composition is very similar to the fishery for *Hemiramphus brasiliensis* in Florida, USA (McBride & Styer 2002, McBride & Thurman, 2003).

Estimates of Z for eastern sea garfish made from age-based catch curves were extremely high (3.0 to 3.4). These estimates suggest annual survival rates of between 3 and 5% for fish aged 1 year and older. Low annual survival rates have been reported for other heavily exploited garfishes such as *Hemiramphus brasiliensis* (14 to 14.9% - Berkeley & Houde, 1978; McBride & Thurman, 2003), *Hemiramphus balao* (7.5% - McBride & Thurman, 2003) and *Hyporhamphus melanochir* in South Australia (11 to 17% - Jones et al., 2002). Our estimates of M based on empirical relationships were similar, 0.75 using a maximum age of 4 years (Hoenig, 1983) and 0.81 based on the method of Pauly (1980). These estimates are within the range of M described for *Hemiramphus brasiliensis* and *Hemiramphus balao* of 0.75 to 1.15 (Mahmoudi & McBride, 2002), but greater than that for *Hyporhamphus melanochir* in South Australia of 0.55 (Jones, 1990). It appears that the longevity and mortality of eastern sea garfish are more similar to the hemiramphids of Florida than the southern sea garfish in Australia.

The estimates of F and M and the YPR, SBPR and EPR analyses all indicate that sea garfish are presently severely overfished and at a level that may be unsustainable. The estimates of F (2.19 to 2.65) are considerably greater than the estimates of M (0.75 to 0.81). The SBPR and EPR may be as low as 10% of the unexploited stock and as such there is a major risk of recruitment failure. Given that eastern sea garfish are a short-lived species that are likely to experience large fluctuations in recruitment due to environmental conditions, the risk of recruitment failure is further enhanced. The predicted increases in YPR at high levels of F should be interpreted with caution as it is a well known phenomena when dealing with data from short-lived species where the assumption of constant recruitment is likely to be violated (King, 1995). Any predicted increase in YPR is offset by the risk of recruitment failure as a consequence of low levels of spawning biomass. The NSW DPI has recognised the need to reduce fishing pressure on sea garfish and some severe restrictions have been placed on commercial fishers (see Appendix 3). The status of the sea garfish stock must be carefully monitored and, if no improvements identified, the fishery may need further restriction. Closure of the fishery is not recommended as the only cost-effective means of monitoring the stock is through monitoring the fishery. We note that there are currently no restrictions on the recreational take of sea garfish in NSW and this should be addressed as part of any attempt to promote the recovery of the sea garfish stock. The most recent estimate of the recreational catch of 'garfish' in NSW is around 22 tonnes per annum (Henry & Lyle, 2003) and there are currently no size or bag-limit restrictions.

The ages of river garfish in commercial landings from Lake Illawarra were similar each year between 2001/02 and 2003/04 (Fig. 3.42) which is not surprising given the constancy in size composition (Chapter 2). The age composition of commercially caught river garfish from Tuggerah Lakes was similar to that from Lake Illawarra but had a slightly smaller proportion of 1 year old fish (Fig. 3.43). The age composition of commercially caught river garfish from Wallis Lake had an even smaller proportion of 1 year old fish and no fish less than 1 year old (Fig. 3.44). These differences may be due to the differences in growth rates between estuaries, with river garfish from Lake Illawarra reaching a size that is susceptible to the method of bullringing earlier than those fish from either Tuggerah Lakes or Wallis Lake.

The estimates of Z made from age-based catch curves for river garfish were much lower than those for sea garfish and ranged between 0.77 and 1.09 (Table 3.19). Estimates of F were slightly greater than M for each estuary, suggesting that river garfish are being heavily exploited, but at more sustainable levels than sea garfish. The predicted increases in YPR for river garfish at high levels of F should be treated with caution as for sea garfish. Present levels of EPR and SBPR of between 20 and 70% of unexploited stocks but with a "best-guess" of around 40%, suggest that river garfish in all 3 estuaries sampled have been heavily exploited, but there is no evidence to suggest that this is being done at unsustainable levels. Recent small declines in CPUE (Chapter 2) indicate that the river garfish fishery should also be carefully monitored.

Estimates of total and natural mortality rates for snub-nosed garfish were similar to those estimated for river garfish (Table 3.20). The estimate of M made from the method of Pauly (1980) was 0.46, similar to that made based on a maximum age of 7 years of 0.43 (Hoenig, 1983). The range of estimates of Z resulted in a wide range of estimate for F (0.29 to 0.86) that incorporated the range of M (0.43 to 0.46). This, together with the SBPR and EPR analyses indicating levels of around 35% of the unexploited stock, suggest that snub-nosed garfish are currently fully exploited and also require careful monitoring.

4. REPRODUCTIVE BIOLOGY

Julian Hughes & John Stewart

SUMMARY

The reproductive biology of eastern sea garfish *Hyporhamphus australis*, river garfish *H. regularis*, and snub-nosed garfish *Arrhamphus sclerolepis* was examined and compared throughout their respective ranges in the coastal waters of NSW. Analyses consisted of determination of gonadosomatic indices (GSI's), macroscopic staging of gonads, mean maximum oocyte sizes, size at maturity, sex ratios, batch fecundities, and daily timing of spawning in river garfish.
All three species were shown to be multiple batch spawners with asynchronous oocyte development and protracted spawning seasons. Eastern sea garfish in NSW have a prolonged spawning season with significant reproductive activity occurring at least somewhere along the coastline over a seven-month period between June and December. Peaks in GSI, mean maximum oocyte size, and the presence of fish with stage 3 (ripe) and stage 4 (running ripe) gonads clearly indicated that spawning occurs in late spring and early summer (Nov-Dec) on the south coast, and in winter and early spring (Jun-Sep) on the north coast. River garfish also showed a protracted spawning season (Jul-Dec) in NSW. Peak activity suggested by GSI's, mean maximum oocyte size, and gonad staging indicated a winter-early summer spawning season of seven months length. The peak spawning period was marginally earlier in Wallis Lake (Jul-Nov), the most northern estuary sampled, compared with Tuggerah Lakes and Lake Illawarra (both Aug-Dec). The peak spawning period for snub-nosed garfish also occurred over a relatively long (4-month) period in late spring-early summer (Oct-Jan) in the Clarence River.

Sex ratios were biased toward male sea garfish for the north coast of NSW (1:0.81), but were not significantly different for the south coast (1:0.99). Ratios were significantly biased toward female river (Lake Illawarra- 1:1.8, Tuggerah Lakes- 1:1.3, Wallis Lake- 1:1.7), and snub-nosed garfish (1:3.2).

Batch fecundity (BF) was slightly higher for eastern sea garfish than for river garfish across the range of mature sizes examined. The BF for both sea and river garfish was higher than for snub-nosed garfish, possibly due to the analysis of too few samples (n=22) from which to gain a realistic and accurate representation of the BF pattern for snub-nosed garfish. BF also increased more rapidly with increasing fish size in sea garfish (R^2=0.52) than river garfish (R^2=0.41). With the exception of just two data points, BF for snub-nosed garfish showed a negligible increase with fish size (R^2=0.05).

For all three species of garfish, oocytes developed in a group-synchronous pattern. It was possible to follow the development of single spawning batch size classes of eggs from maturation through to ovulation. Mature female fish of all three species had distributions of oocyte diameters consisting of three or four modes, which strongly suggests a multiple spawning strategy during the spawning season. For hydrated spawning-sized fresh eggs (2.76, 2.72, and 2.40mm maximum diameter for sea, river, and snub-nosed garfish respectively), the chorion was smooth and unpigmented and covered by approximately 85-100 chorionic filaments, which were approximately 5-10mm long.

The estimated size (fork length) at 50% sexual maturity for female eastern sea garfish (20.9 ± 0.2cm) was slightly (but statistically significant) larger than for males (19.5 ± 0.3cm). Eastern sea garfish reached 50% maturity at a larger size (average for both sexes: 20.1 ± 0.2cm) than snub-nosed (17.6 ± 0.4cm), or river (16.1 ± 0.3cm) garfish. All three species appeared capable of

spawning in the spawning season immediately after the one in which they were born. There is currently no minimum legal length for any of these garfish species in NSW waters, but the lengths of all 3 species observed in commercial catches indicate that the major fishing techniques and gear selectivity targets almost entirely mature fish.

Evidence for spawning at or after dusk (between 6pm and 12am) in river garfish was provided by data from macroscopically staged ovaries where most stage 4 (running ripe) fish occurred at 6pm, and 50% of ovaries were spent (stage 5) by 12am. The gradual increase in GSI values from a minimum (6.19 ± 2.41) at 6am to a maximum (8.85 ± 3.20) at 6pm also suggests spawning between 6pm and 12am. However, the presence at all sample times of some females with stage 3 (ripe) or 4 (running ripe) ovaries, hydrated spawning-sized oocytes, and large GSI values implies that some female river garfish may be capable of spawning at any time of the diel cycle.

4.1. Introduction

The eastern sea garfish (*Hyporhamphus australis*), eastern river garfish (*H. regularis*), and snub-nosed garfish (*Arrhamphus sclerolepis*) are members of the family Hemiramphidae (halfbeaks, garfishes). Hemiramphids are one of five families in the order Beloniformes. Other members of this order are the Exocoetidae (flyingfishes), Scomberosocidae (sauries), Belonidae (needlefishes, longtoms), and Adrianichthyidae (ricefishes). The family is defined by one derived character; the third pair of pharyngeal bones fused into a plate (www.fishbase.org). Hemiramphids are surface dwelling fishes of marine, estuarine, and freshwaters of the Atlantic, Indian, and Pacific Oceans They are elongate and (usually) compressed, with posterior dorsal and anal fins, emarginate or forked caudal fin with elongate lower lobe, and with the lower jaw generally much longer than the upper (Watson, 1996; Trnski et al., 2000). Worldwide, the family comprises 101 species from 12 genera, of which 17 species from 6 genera occur in Australian waters. More than one third of hemiramphid species belong to the genus *Hyporhamphus*.

In Australia, eastern sea garfish *H. australis* occur in sheltered bays, clear coastal waters, and occasionally in the lower reaches of estuaries from Moreton Bay in Queensland, to Eden in New South Wales, including Lord Howe and Norfolk Islands (Kailola et al., 1993). The eastern river garfish *H. regularis* occur in coastal lakes and estuaries and sometimes freshwaters between Gladstone in Queensland and the Gippsland Lakes in Victoria (Collette, 1974). Snub-nosed garfish *A. sclerolepis* occur in tropical Australian estuaries and freshwater rivers and impoundments from Western Australia to northern New South Wales (Collette, 1974). In New South Wales, *H. australis*, *H. regularis*, and *A. sclerolepis* are important commercial and recreational species and are considered valuable food and bait fish (Collette, 1974; Kailola, et al., 1993).
Garfish are generally herbivorous, feeding on seagrass, algal filaments, as well as diatoms, insect larvae, polychaetes and small crustaceans (Kailola et al., 1993). *Hyporhamphus australis* has been shown to consume seagrass and algae, however, it has also been shown to consume a high proportion of crustaceans (Thomson, 1959; SPCC, 1981; Parsons, 2002). The diet of *H. regularis* consists mainly of the seagrass *Zostera capricorni* (Parsons, 2002).

Iteroparity (the reproductive strategy where individuals reproduce several times throughout their life) is common amongst hemiramphids, and spawning generally occurs several times over a prolonged period, often during the warm months of the year (Graham, 1939; Ling, 1958; Talwar, 1962; 1967; Berkeley and Houde, 1978; Jones et al., 2002; McBride and Thurman, 2003; McBride et al., 2003). Batch fecundity within this group is also generally low (up to ~thousands of eggs per batch), but is compensated for by high spawning frequencies (Berkeley and Houde, 1978; McBride and Thurman, 2003).

Many oviparous hemiramphid species (including *Hyporhamphus* and *Arrhamphus*) produce moderate to large (1.1-3.5mm diameter) spherical eggs with attaching filaments (Collette et al., 1984; Trnski et al., 2000). It has been previously demonstrated that the eggs of several hemiramphid species are attached via these filaments to floating/demersal/drifting algae/seagrass in generally shallow water (Ling, 1958; Uchida et al., 1958; Berkeley and Houde, 1978; Jordan et al., 1998).

Incubation of hemiramphid eggs occurs over 17-30 days and larvae are hatched well-developed, already competent swimmers, and are capable of capturing food shortly after hatching (Berkeley and Houde, 1978; Collette et al., 1984; Jordan et al., 1998). Larvae are 3-11mm in length at hatching, with partially to fully pigmented eyes, an open mouth, fully flexed notochord, developing fin rays, and a small to moderate yolk sac (Collette et al., 1984; Watson, 1996).

Hyporhamphus australis, *H. regularis*, and *A. sclerolepis* are the most common and economically important hemiramphids in NSW. In the last decade there has been a large decline in the catches of eastern sea garfish, from 280t in 1992-93 to only 44t in 1999-2000. Since the late 1970s, landings of river garfish from NSW estuaries (Clarence River, Wallis Lake, Tuggerah Lakes, Lake Illawarra, and St. Georges Basin) have been less than half of the reported catch for the 1950s-1970s. Despite almost a century of exploitation, very little is known of the reproductive biology of commercially important garfish species in NSW.

Previous information on the reproductive biology for all three species is very limited. It has been suggested that spawning of eastern sea garfish occurs within coastal regions or estuaries in summer, and that eggs are laid near seagrass beds (Grant, 1999). Fish with ripe gonads have been found in Botany Bay during spring, and juveniles have been reported in late summer (SPCC, 1981). Based on GSI values, Smith (2002) suggested that spawning south of Sydney occurs in spring and in winter and early spring north of Sydney.

Anecdotal evidence from commercial fishers on the north coast of NSW suggests the development of river garfish ovaries during October-November (Smith, 2002). No reproductive information exists for snub-nosed garfish.

In this chapter, the reproductive biology of eastern sea garfish, river garfish, and snub-nosed garfish was examined and compared throughout their respective ranges in the coastal waters of NSW. The reproductive biology of the eastern sea garfish was compared between fish collected from the north and south coasts of NSW. River garfish reproductive biology was compared for fish from three major estuaries for this species: Lake Illawarra, Tuggerah Lakes, and Wallis Lake. Snub-nosed garfish were surveyed in its only important commercial estuary in NSW, the Clarence River. Analyses involved determination of gonadosomatic indices (GSI's), macroscopic staging of gonads, mean maximum oocyte size, size at 50% maturity, sex ratios and batch fecundities.

4.2. Materials & methods

4.2.1. Study area/sampling design

Eastern sea garfish *Hyporhamphus australis* were sampled from commercial catches between September 2000 and August 2003 from 14 ports on the NSW coast (Fig 4.1). Sea garfish were primarily collected using 'garfish haul' nets. River garfish *Hyporhamphus regularis* were sampled between November 2001 and March 2004 from Lake Illawarra, Tuggerah Lakes, and Wallis Lake, by commercial fishers and NSW Fisheries staff (Fig 4.1). River garfish were primarily caught using 'bullringing' nets. Snub-nosed garfish *Arrhamphus sclerolepis* were sampled by commercial fishers and NSW Fisheries staff between November 2001 and February 2004 from the Clarence River, primarily using 'bullringing' and prawn nets (Fig 4.1). All fish (other than those collected by NSW Fisheries staff) were purchased from local fishers, fishermen's co-operatives, or the Sydney

Fish Markets. A total of 1050 sea, 1673 river, and 476 snub-nosed garfish were used for analyses of reproductive biology.

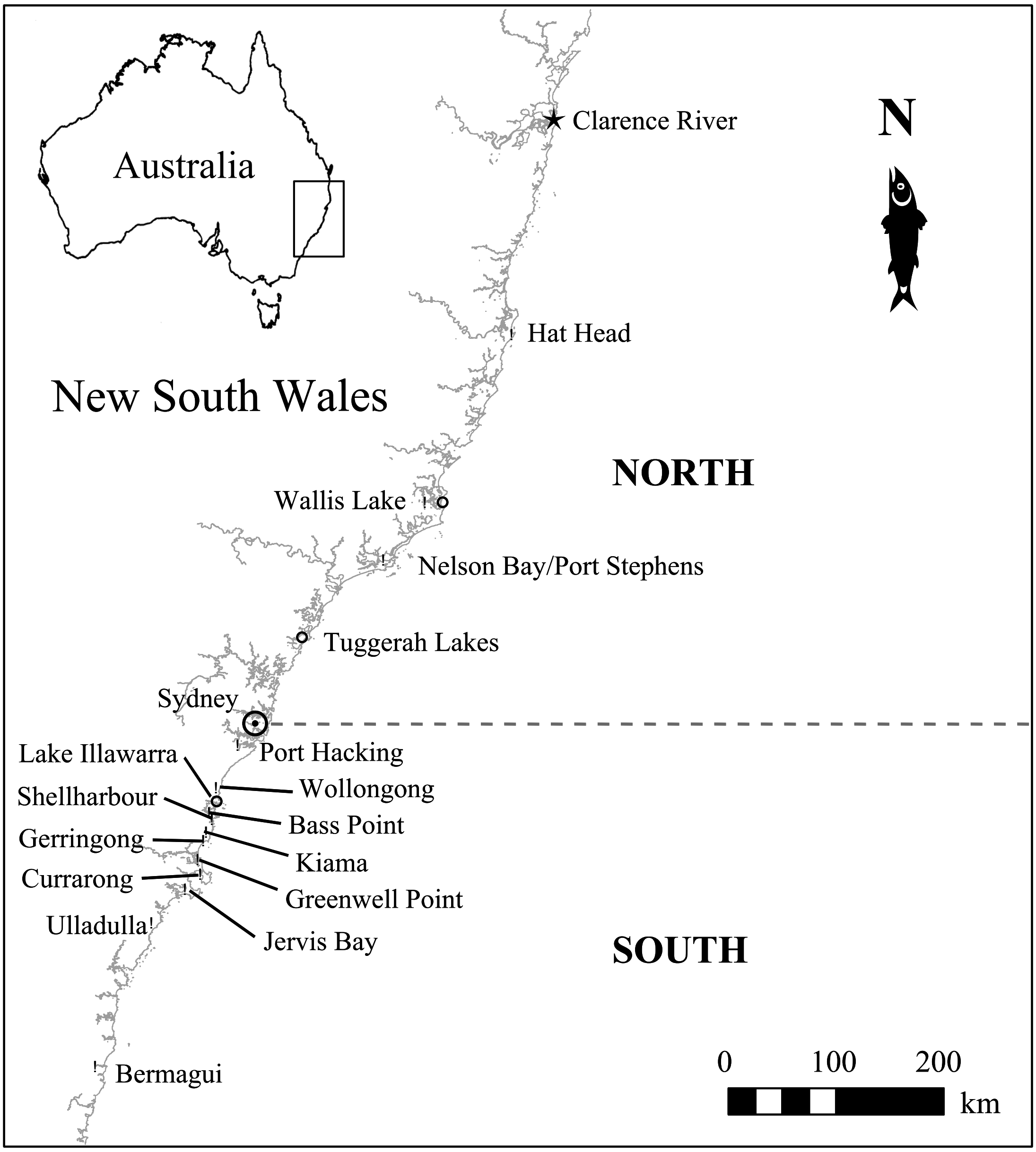


Figure 4.1. Locations where eastern sea garfish *Hyporhamphus australis* (•), river garfish *H. regularis* (o), and snub-nosed garfish *Arrhamphus sclerolepis* (□) were collected for examination of reproductive biology in NSW.

4.2.2. *Sample processing and analysis*

All fish collected were measured (fork length- FL) to the nearest mm, weighed to the nearest 0.1g, and had their gonads removed and weighed.

4.2.2.1. Macroscopic staging

The gonads of fish of both sexes were macroscopically examined and a reproductive stage assigned according to the developmental criteria based on size, colour, and visibility of oocytes outlined in Tables 4.1 and 4.2. Stages were adapted from those used by Ling (1958), and Jones et al. (2002), both for the southern sea garfish *Hyporhamphus melanochir*.

Table 4.1. Macroscopic ovary staging schedule used to assign reproductive stages to female eastern sea (*Hyporhamphus australis*), river (*H. regularis*), and snub-nosed garfish (*Arrhamphus sclerolepis*).

Stage	Characteristics
1- Immature	Ovaries small and threadlike, white in colour, and extending around one third of the length of the body cavity. Determination of sex difficult.
2- Developing/Resting	Ovaries extend between half and three quarters of the length of the body cavity. Ova visible and are white or pale yellow. Some large, clear ova may be visible in resting ovaries. A blood vessel runs along the dorso-lateral surface of the ovary, smaller ramifying vessels branching off may also be visible.
3- Ripe	Ovaries lie along the entire length of the body cavity and are very large. Only the large blood vessel is obvious. Ovary wall thin and easily ruptured.
4- Running Ripe	Ova shed through genital pore with gentle pressure on abdomen. Largest blood vessel still obvious.
5- Spent	Ovary flaccid, tough and leathery. May be bloodshot toward posterior end. Some large, clear residual ova remain. Many ova of smaller size classes may be visible.

Table 4.2. Macroscopic teste staging schedule used to assign reproductive stages to male eastern sea (*Hyporhamphus australis*), river (*H. regularis*), and snub-nosed garfish (*Arrhamphus sclerolepis*).

Stage	Characteristics
1- Immature	Testes small and threadlike, white in colour, and extending around one third of the length of the body cavity. Determination of sex difficult.
2- Developing/Resting	Testes cream to brownish/pink in colour and around one third the length of the body cavity. Testes fragile, flattened and strap-like, and lie up against body wall. Posterior end tubular and white in resting testes.
3- Ripe	Testes lie along the entire length of the body cavity are large and pale pink. Pink colour changes to white at the posterior end where milt is accumulating.
4- Running Ripe	White milt extruded with gentle pressure on abdomen. Testes soft and pale pink. Coiled tubules visible.
5- Spent	Testes rubbery, reduced in size and showing signs of blood, which colours the testes a dull brown.

4.2.2.2. Determination of GSI

Gonadosomatic indices (GSI) were calculated using the following equation:

$$GSI = (W_g / W_w) * 100,$$

where W_g = gonad weight, and W_w = whole fish weight.

4.2.2.3. Maximum oocyte diameter

The ovaries from all female fish collected were fixed in a solution of 10% formaldehyde, 5% glacial acetic acid, 1% anhydrous calcium chloride, and 84% seawater (FAACC) for one week, before being transferred to 70% alcohol for storage. One ovarian lobe from each sample was then split open, the oocytes separated into a petri dish, and the diameters of ten oocytes from the largest size-class measured. Trials indicated that ten oocytes was an appropriate sample size to accurately represent the average size of the largest oocyte size class (standard deviation < 10% of the mean). Oocytes were measured using a Wild Heerbrugg dissecting microscope and Philips CCD video camera interfaced with a computer installed with Scion Image 1.62c image analysis software.

4.2.2.4. Batch fecundity

For ovaries where significant oocyte development was evident (mean maximum oocyte diameter >1.5mm), a batch fecundity (BF) count was made. We considered that oocytes larger than 1.5mm diameter were developing (hydrating) into ripe ova and represented a single batch of eggs (number of eggs shed at one time). The entire ovary was weighed to the nearest 0.0001g, before a subsample of the ovary was taken (usually one lobe). The subsample was then weighed, and the largest size class of oocytes present was counted. Batch fecundity (BF) was calculated according to the equation:

$$BF = (W_t / W_s) * E_c,$$

where E_c = number of oocytes counted in subsample, W_s = weight of subsample, and W_t = total weight of the entire ovary.

4.2.2.5. Size at sexual maturity

The size at sexual maturity was estimated for males and females from gonad stage assignments (Tables 4.1 and 4.2). Those individuals with developed gonads (i.e. assigned a stage>1) were assumed to be capable of reproducing during the next spawning season and were defined as mature. The proportion of fish assigned as being mature in each 1cm length class was calculated and logistic curves were fitted to the data using a non-linear least squares procedure in Microsoft Excel (Solver).

4.2.2.6. Oocyte size frequency

To examine the sizes of oocytes within ovaries at each reproductive stage, an ovary sample representing each reproductive stage (1-5) for each species was randomly selected. From each of these samples, two hundred randomly selected oocytes were measured.

4.2.2.7. Oocyte shrinkage

Shrinkage of oocytes as a result of fixation (in FAACC) and long-term storage in alcohol was investigated in eastern sea garfish *Hyporhamphus australis* and river garfish *H. regularis*. Two mature (stage>1) eastern sea garfish, and three mature river garfish were randomly selected, the diameters of the largest 10 oocytes were measured 5 times from ovaries both before and after they were fixed and stored. It was considered that if shrinkage were to be significant, then it would be most obvious in the largest oocytes. A single factor analysis of variance (ANOVA) was used to test for changes in diameter for both species.

4.2.2.8. Daily timing of spawning in river garfish

To investigate the daily timing of spawning in river garfish *Hyporhamphus regularis*, fish were collected from Lake Illawarra at each of four sampling times (12pm, 6pm, 12am, and 6am) on the 13th and 14th of November 2003. Twenty female fish were collected with a 'bullringing' net at each sampling time. Each fish had its length (FL), weight (to the nearest 0.01g), gonad weight (to the nearest 0.01g), and ovarian reproductive stage recorded. Gonadosomatic indices were calculated (as above), and the diameter of 200 oocytes from each of five randomly chosen reproductively active (stage>1) fish from each sampling time were measured to examine diel changes in oocyte size distribution.

4.3. Results

4.3.1. Seasonality of reproduction

Sea garfish

Major peaks in male and female GSI occurred in November and December for populations of fish sampled south of Sydney, but occurred earlier between June and September in fish from areas north of Sydney (Fig 4.2). This pattern was consistently repeated each year of sampling. A smaller secondary peak in GSI occurred between February and April for north coast fish in both 2002 and 2003. Sample maximum GSI values for female south coast fish occurred during November 2001 (13.2%) and November 2002 (11.7%). During the spawning season, sample maximum GSI values for north coast females occurred in September 2000 (14.2%) and in July 2001 (11.7%) (Fig 4.2). Male mean GSI peaked between October and December for fish from southern NSW, and between July and October in northern NSW (Fig 4.4). Maximum sample GSI's for male southern fish were 5.4 (November 2001) and 3.5% (December 2002), and for northern males were 4.8 (September 2000) and 4.7% (August 2003). During peak spawning periods, both the ovaries and testes of eastern sea garfish were approximately 12 times their non-spawning weights.

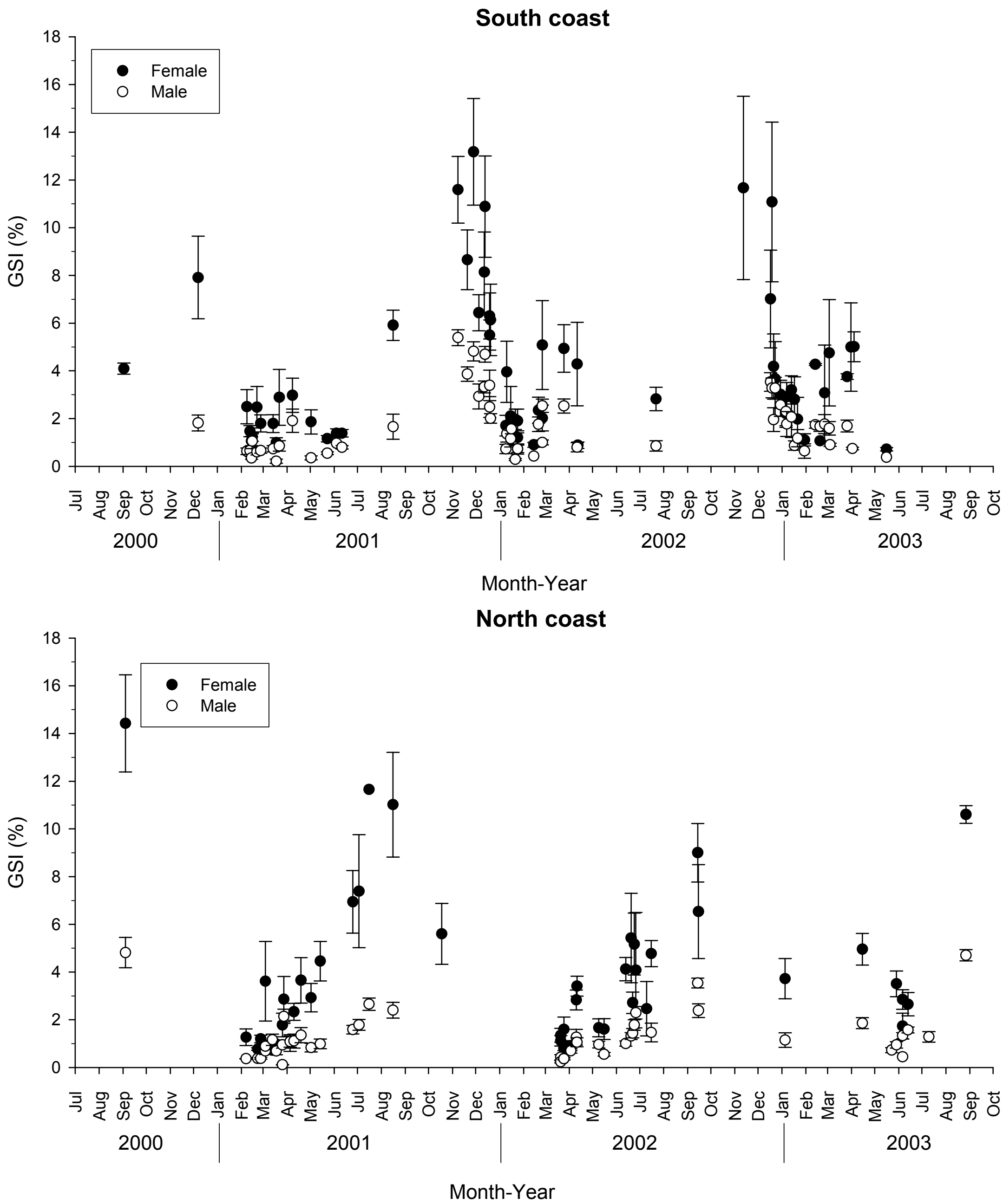


Figure 4.2. Sample gonadosomatic indices (GSI ± SE) from female and male eastern sea garfish *Hyporhamphus australis* collected from the north (n=46 samples) and south coasts (n=61 samples) of NSW between September 2000 and August 2003.

The ovaries of mature eastern sea garfish comprised two cylindrical lobes, roughly equal in size (Fig 4.3). The testes of mature fish were flattened and strap like, and lay up against the body wall (Fig 4.4).

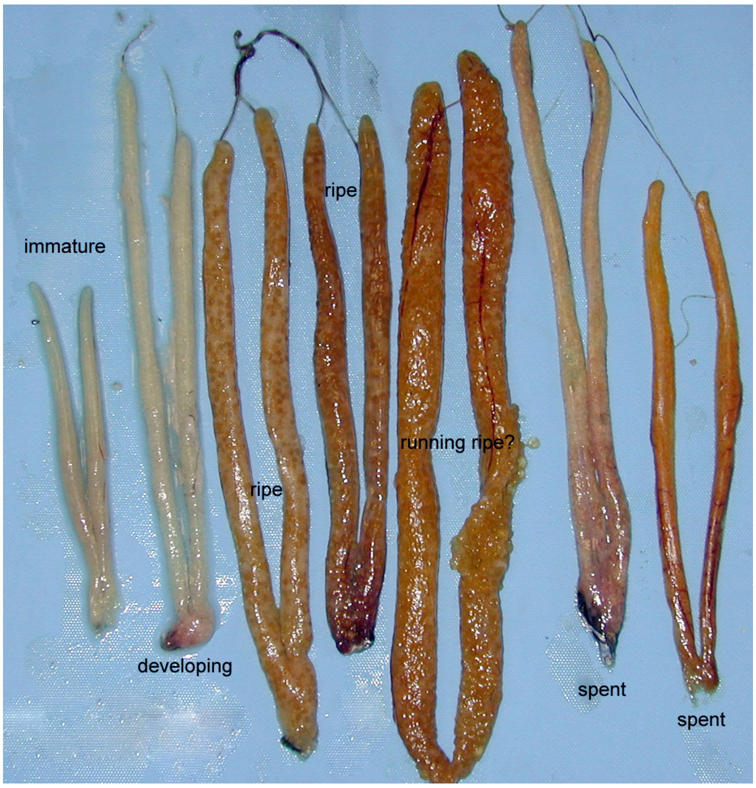


Figure 4.3. External appearance of eastern sea garfish *Hyporhamphus australis* ovaries of various stages. From left to right ovarian stages are 1, 2, 3, 3, 4, 5, 5.

Figure 4.4. External appearance of eastern sea garfish *Hyporhamphus australis* testes of various stages. From top to bottom teste stages are 2, 2, 3/4.

Macroscopic staging patterns for sea garfish gonads were highly variable. On the south coast, the highest proportions of stage 3 (ripe) female fish occurred during December 2001, March 2002, and December 2001 (Fig 4.5). The female November 2002 sample consisted of just two fish. The highest proportions of stage 3 (ripe) male fish occurred in December 2001, February-March 2002, December 2002, and February 2003. Stage 5 (spent) fish were most abundant from January through to April, indicative of the end of the spawning season in both 2002 and 2003 (Fig 4.5). The proportion of immature (stage 1) fish in catches increased from December onwards, especially in 2002-2003.

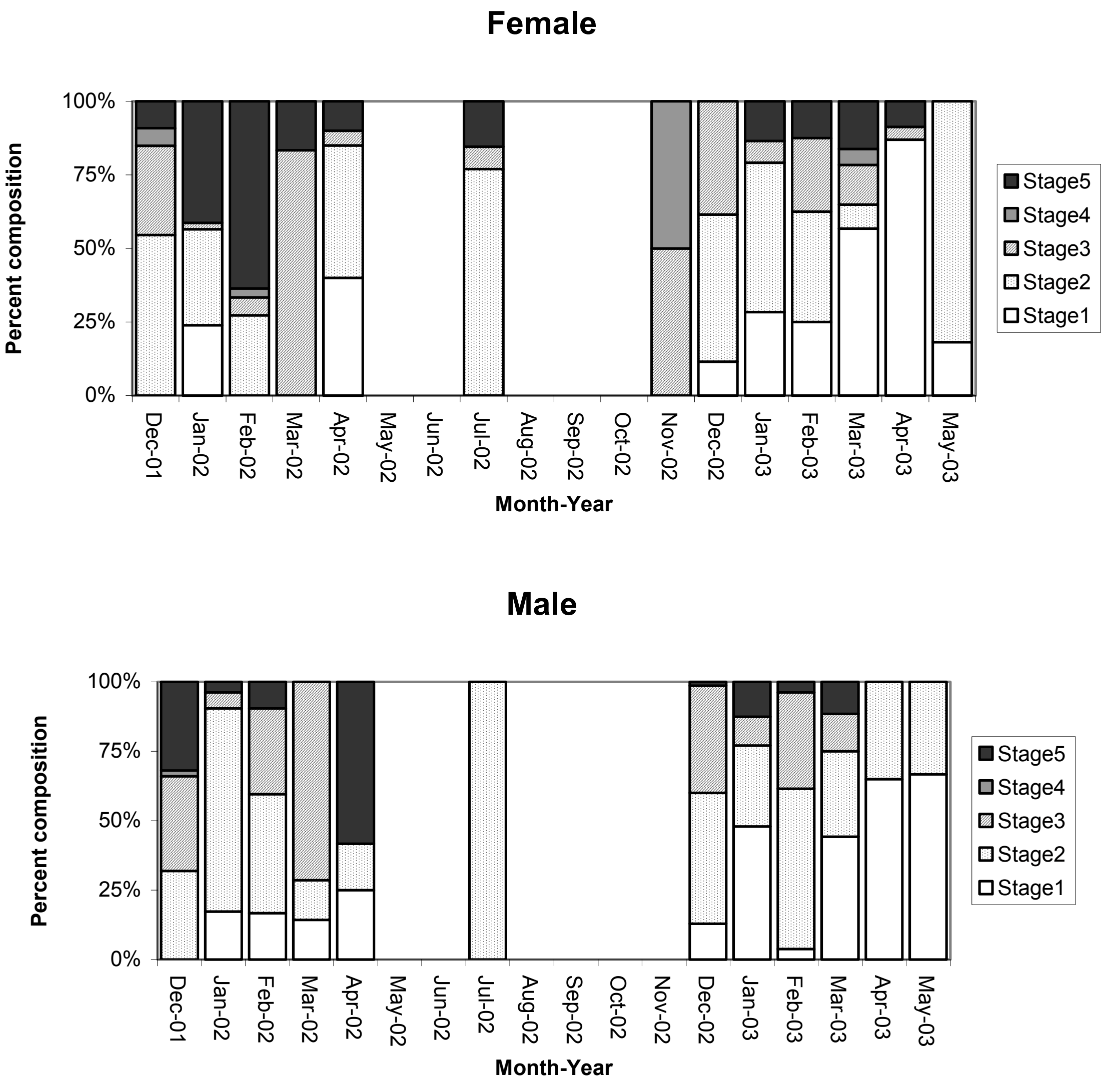
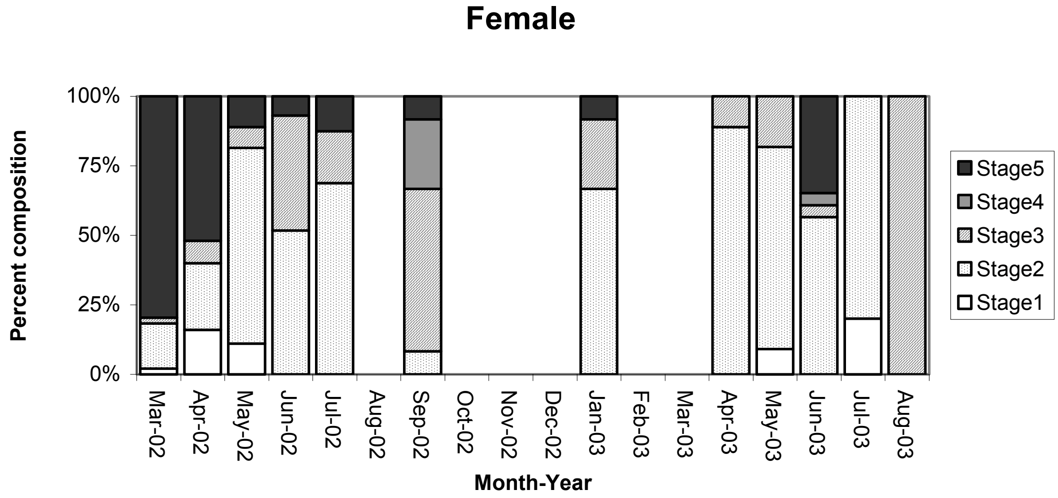


Figure 4.5. Monthly gonadal stages of male (n=302) and female (n=239) eastern sea garfish *Hyporhamphus australis* collected from the south coast of NSW between December 2001 and May 2003.

Variation in macroscopic staging patterns was also high for both male and female sea garfish collected from the north coast. Generally, the highest proportions of stage 3 (ripe) and stage 4 (running ripe) female fish occurred from June to September (Fig 4.6), with higher proportions of stage 5 (spent) and stage 2 (developing/recovering) fish occurring during the rest of the year. Male staging patterns were dominated by stage 2 (developing/recovering) fish for the entire study period (Fig 4.6).



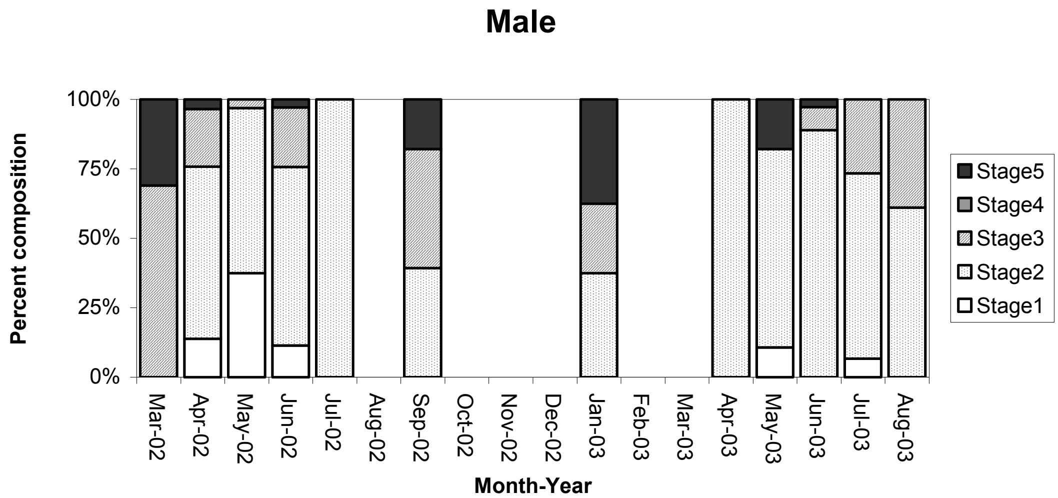
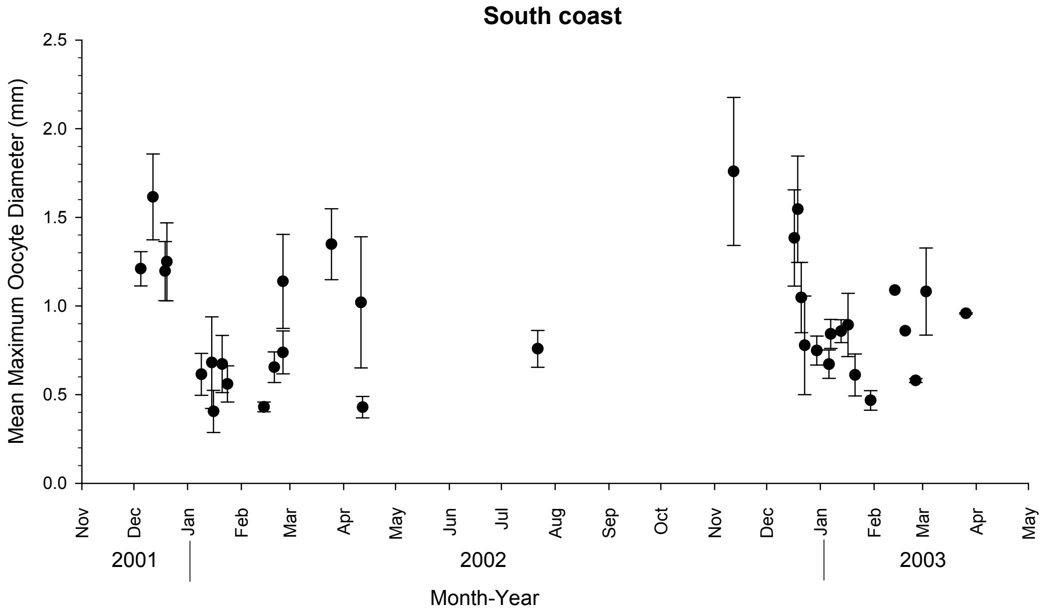


Figure 4.6. Monthly gonadal stages of male (n=280) and female (n=210) eastern sea garfish *Hyporhamphus australis* from the north coast of NSW collected between March 2002 and August 2003.

South of Sydney, mean maximum oocyte size peaked in November-December, and was smallest in January-February, with a slight increase in maximum oocyte size in April-May, in both 2001 and 2002 (Fig 4.7). On the north coast, the peak in mean maximum oocyte sizes occurred between June and September, but maximum diameter was also relatively high in April of 2002 and 2003. Standard errors were large, and indicate variation in oocyte development between fish in some months. For fish from both the north and south coast, maximum oocyte sizes occurred during the respective GSI-defined spawning seasons (south: max. dia. 1.8mm November 2002, north: max. dia. 1.5mm September 2002; Fig 4.7).



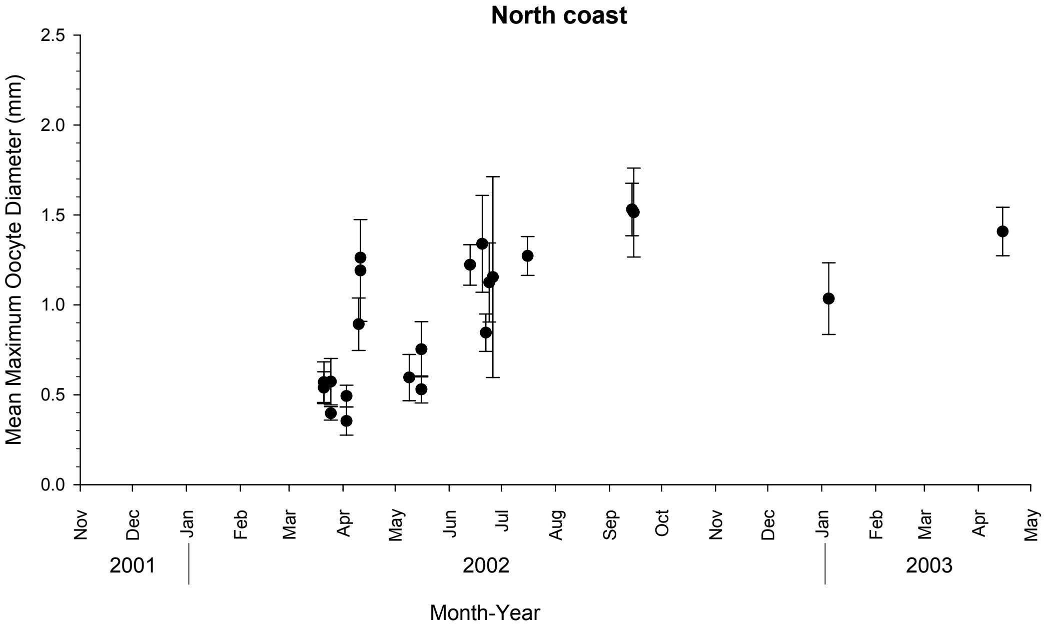


Figure 4.7. Mean maximum (largest 10) oocyte diameters (mm ± SE) of female eastern sea garfish *Hyporhamphus australis* collected from the south (n=34 samples) and north (n=22 samples) coasts of NSW between November 2001 and April 2003.

River garfish

Peaks in both female and male GSI occurred between August and December for fish collected from Lake Illawarra and Tuggerah Lakes, but between July and November for fish from Wallis Lake (Fig 4.8). In Lake Illawarra, maximum GSI values for females occurred during November 2001, November 2002, and October 2003 (8.4, 8.1, and 6.7% respectively). In Lake Illawarra, male maximum GSI's of 4.2, 4.1, and 4.2% occurred during November 2001, October 2002, and September 2003 respectively. In Tuggerah Lakes, female maximum GSI occurred in August 2003 (5.8%) and male maximum GSI in September 2003 (3.2%). Maximum GSI for females from Wallis Lake occurred during September 2001 (6.5%; Fig 4.8). For males from Wallis Lake, maximum GSI values both occurred in September 2003 (3.2 and 3.0% respectively) (Fig 4.8). During spawning periods, river garfish gonads increased in size by approximately 16 times their non-spawning weight.

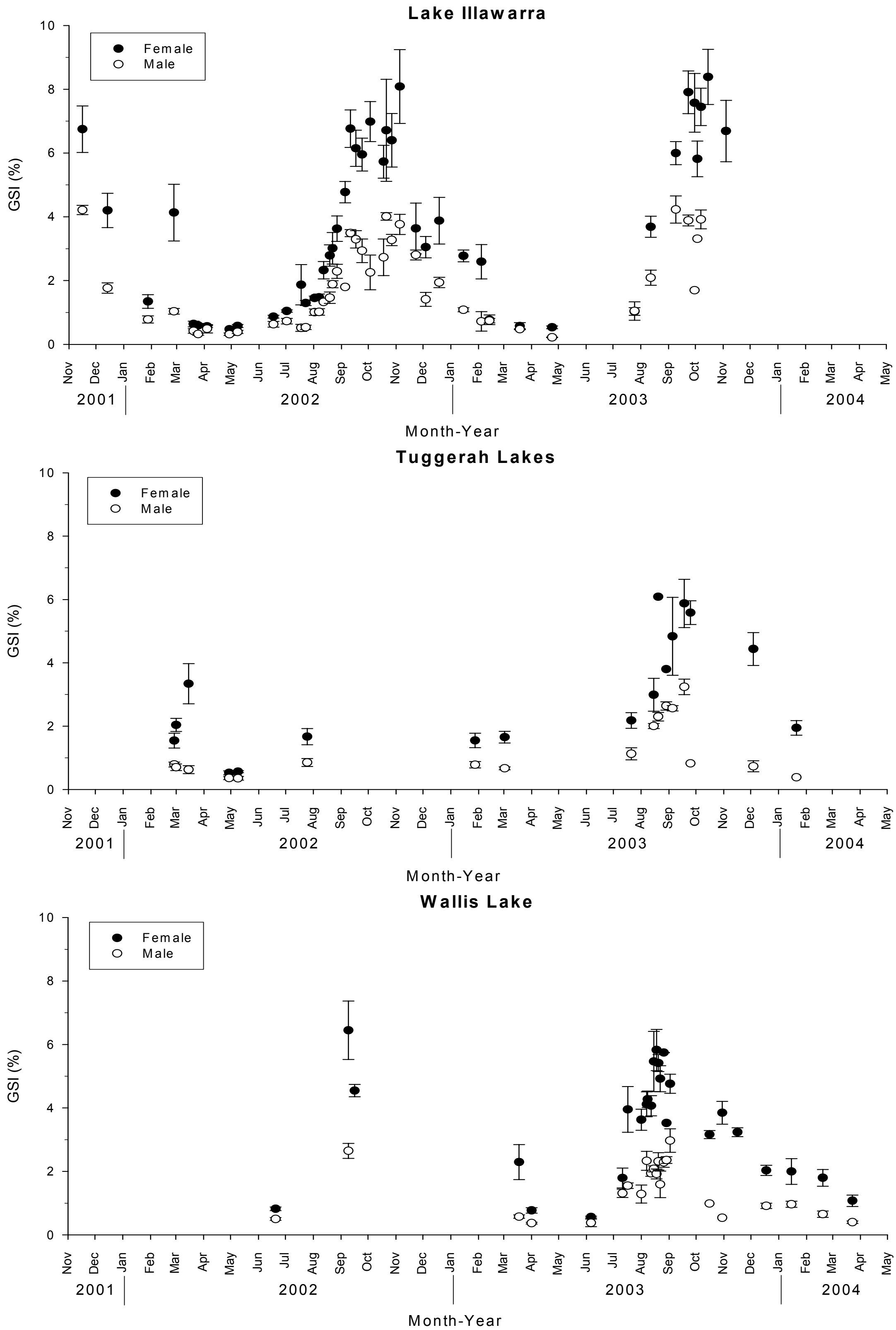


Figure 4.8. Sample gonadosomatic indices (GSI ± SE) from female and male river garfish *Hyporhamphus regularis* collected from Lake Illawarra (n=45 samples), Tuggerah Lakes (n=17 samples), and Wallis Lake (n=26 samples) between November 2001 and April 2004.

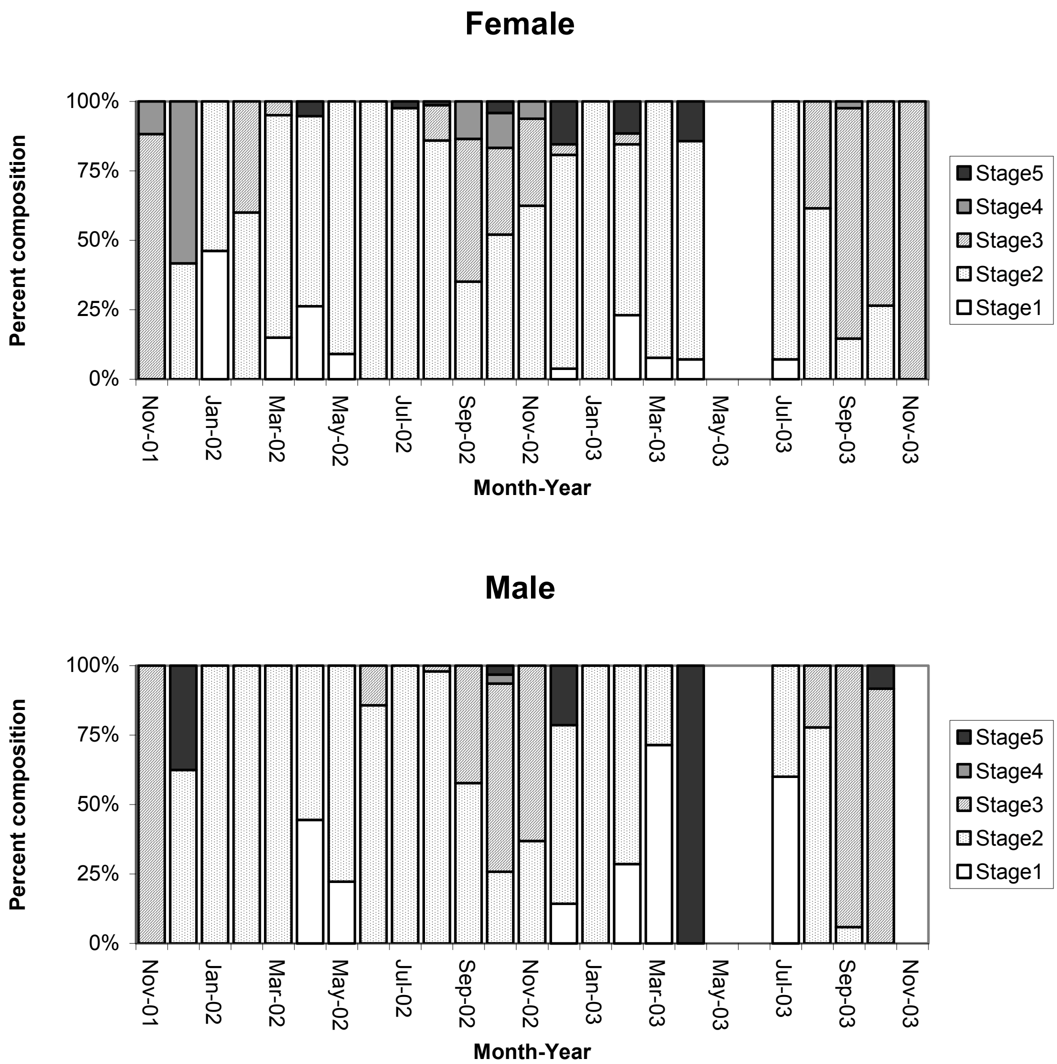


Figure 4.9. Monthly gonadal stages for male (n=313) and female (n=564) river garfish *Hyporhamphus regularis* collected from Lake Illawarra between November 2001 and November 2003.

This reproductive activity is also shown by the macroscopic staging patterns for river garfish gonads. In Lake Illawarra the highest proportions of stage 3 (ripe) fish occurred from September to November (Fig 4.9). Stage 1 (immature) fish first appeared in January-February, but had all developed into stage 2 (developing) or 3 (ripe) fish by August (Fig 4.9).

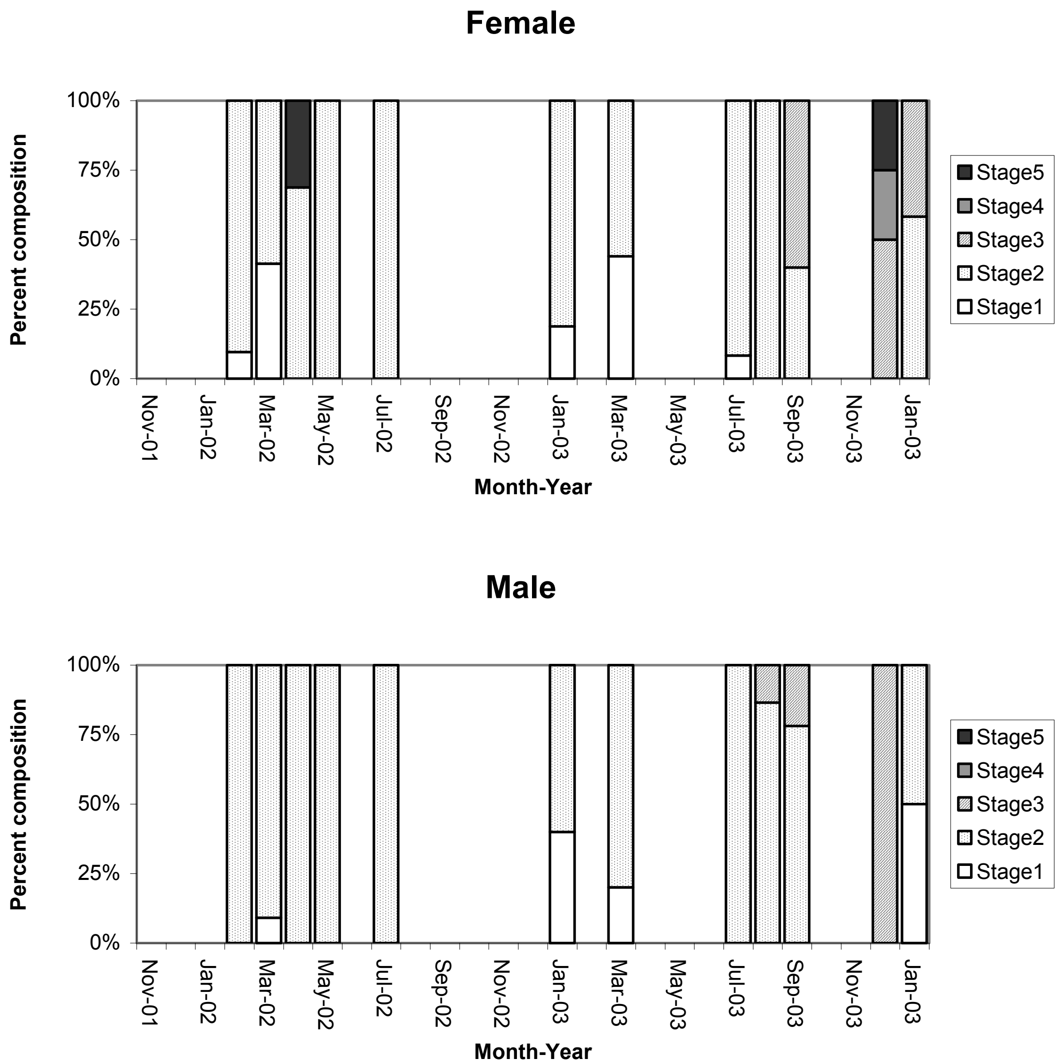
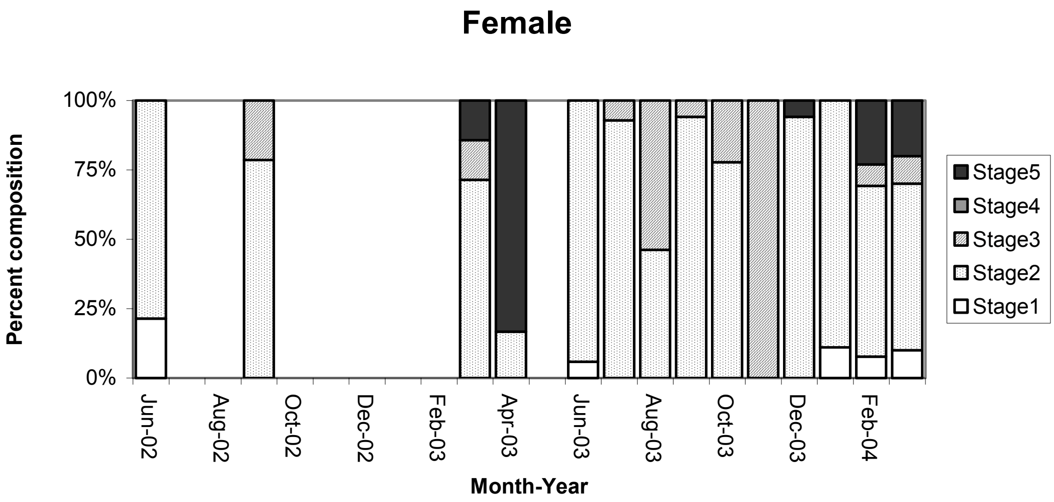


Figure 4.10. Monthly gonadal stages for male (n=160) and female (n=204) river garfish *Hyporhamphus regularis* collected from Tuggerah Lakes between November 2001 and January 2003.

Similarly, further north at Tuggerah Lakes, the highest proportions of stage 3 (ripe) fish occurred during September-December, with mainly stage 1 (immature) and stage 2 (developing) fish occurring during the rest of the year (Fig 4.10).



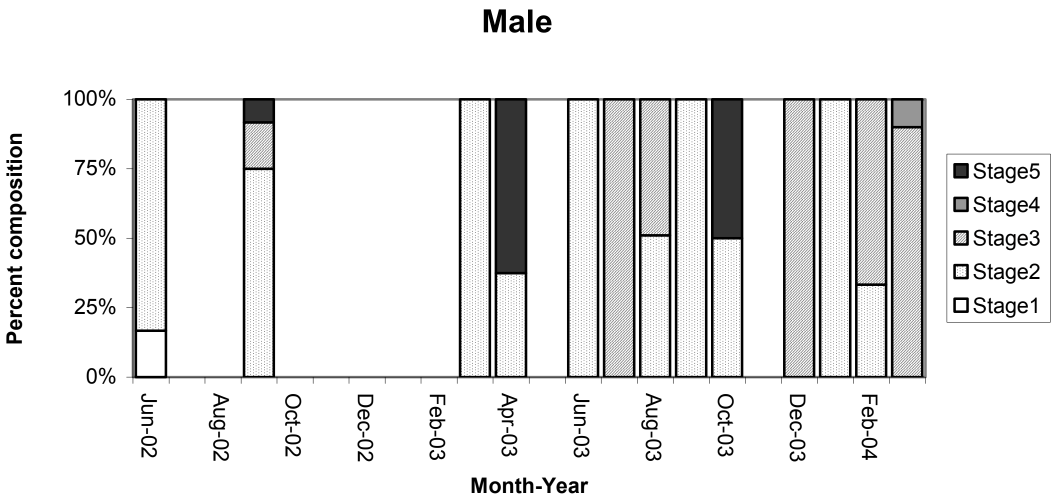


Figure 4.11. Monthly gonadal stages for male (n=186) and female (n=310) river garfish *Hyporhamphus regularis* collected from Wallis Lake between June 2002 and March 2004.

Most stage 3 (ripe) females were caught during July-November in Wallis Lake (Fig 4.11). Large numbers of stage 5 (spent) male and female fish were recorded in April.

The mean maximum oocyte size of fish from Lake Illawarra peaked between August and January (maximum diameters: 1.6mm November 2001, 1.7mm November 2002, and 1.8mm September 2003; Fig 4.12). Peaks in mean maximum oocyte diameters occurred in August-September for fish from Tuggerah Lakes (maximum diameters: 1.9mm August and September 2003; Fig 4.12). Maximum oocyte size for fish from Wallis Lake occurred in August 2003 (1.8mm dia.) and September 2002 (1.7mm dia.), with peaks in mean maximum oocyte size occurring between August and November (Fig 4.12).

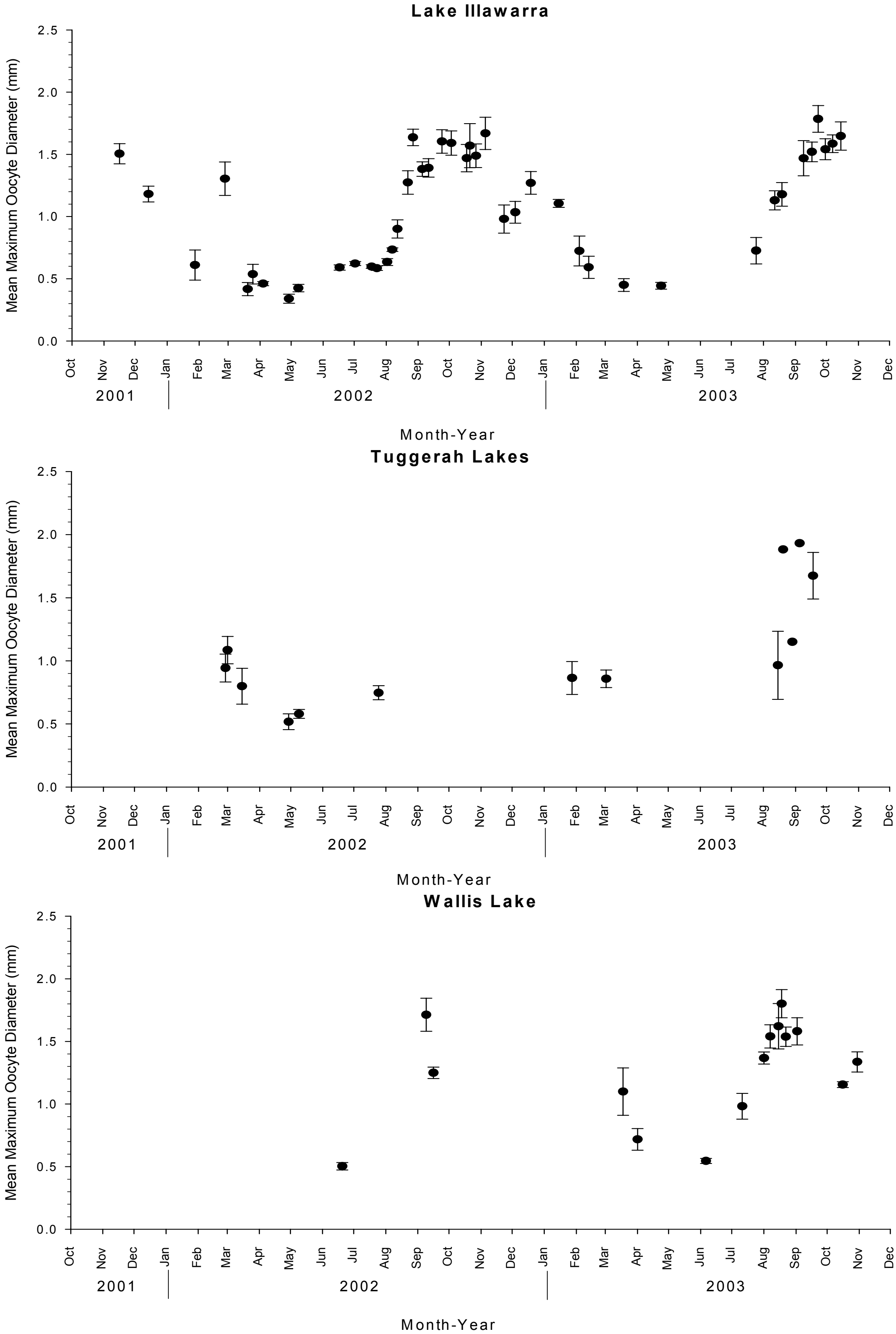


Figure 4.12. Mean maximum (largest 10) oocyte diameters (mm ± SE) for female river garfish *Hyporhamphus regularis* collected from Lake Illawarra (n=43 samples), Tuggerah Lakes (n=13 samples), and Wallis Lake (n=15 samples) between November 2001 and October 2003.

Snub-nosed garfish

Peaks in male and female GSI occurred between October and January each year (Fig 4.13). Female mean maximum GSI's of 4.9 and 4.3% occurred during November 2001 and November 2002. Maximum GSI's for male fish also occurred during November 2001 and 2002 (2.6 and 1.7% respectively). During spawning periods, snub-nosed garfish testes increased in size by more than 4 times, and female ovaries by up to 10 times, their non-spawning weights respectively.

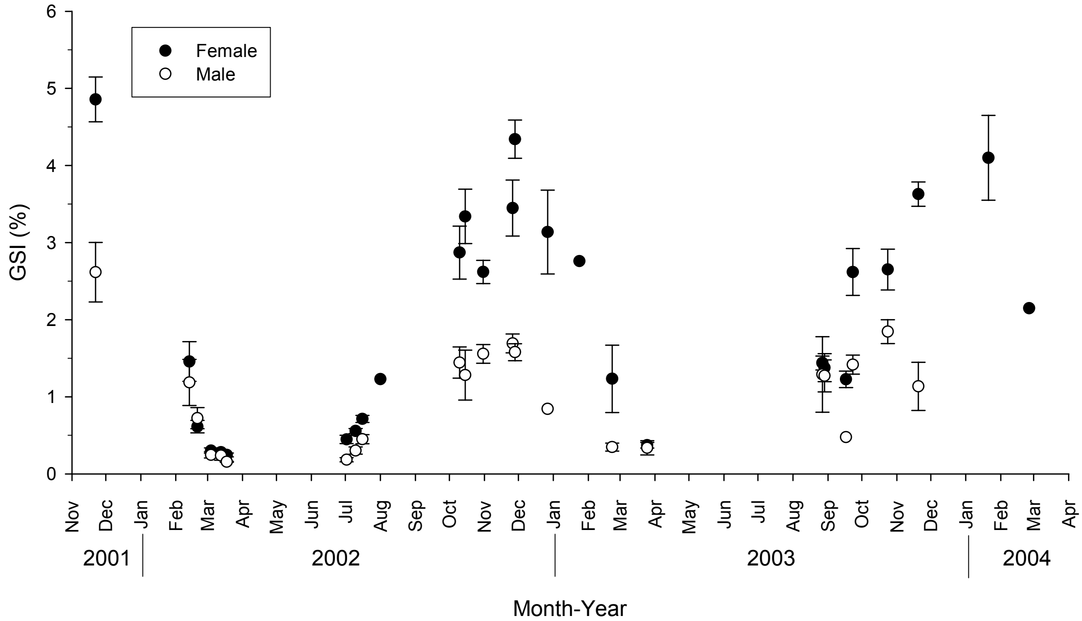
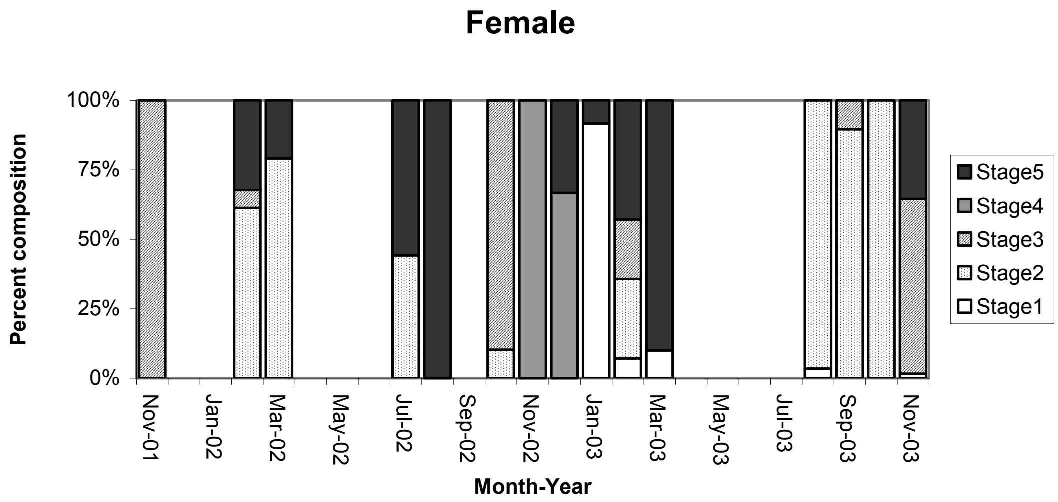


Figure 4.13. Sample gonadosomatic indices (GSI ± SE) from female and male snub-nosed garfish *Arrhamphus sclerolepis* collected from the Clarence River (n=27 samples) between November 2001 and February 2004.

Macroscopic staging and mean oocyte size closely mirrored GSI information for snub-nosed garfish, despite limited data. All stage 4 (running ripe) fish occurred in November and December, stage 5 (spent) fish began to appear in late November and made up the majority of fish sampled by March (Fig 4.14).



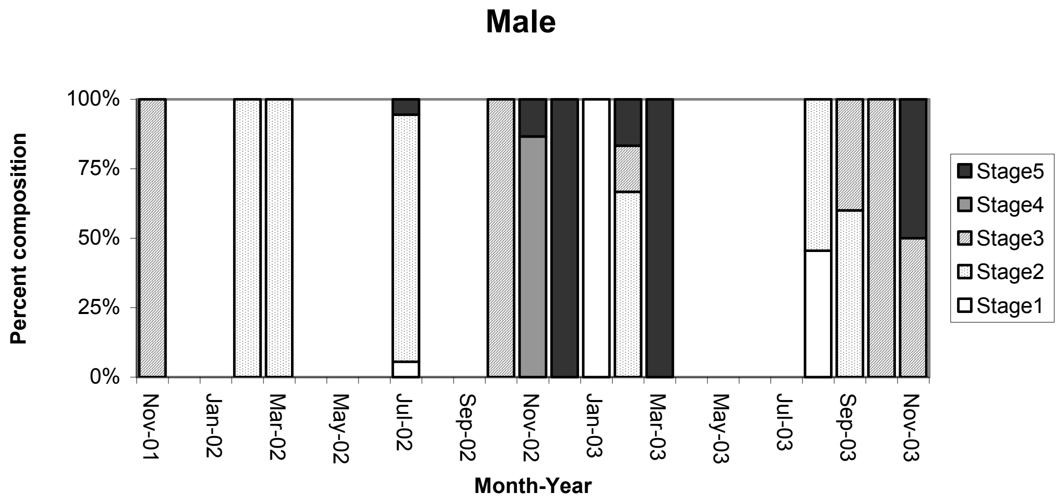


Figure 4.14. Monthly gonadal stages for male (n=119) and female (n=379) snub-nosed garfish *Arrhamphus sclerolepis* collected from the Clarence River between November 2001 and November 2003.

The large numbers of stage 1 fish present in January 2003 were all small fish taken from a prawn net sample, and may not have accurately represented the reproductive activity of the population. Mean oocyte sizes were greatest between October and December, with a maximum oocyte size of just 1.5mm diameter in November 2002 (Fig 4.15).

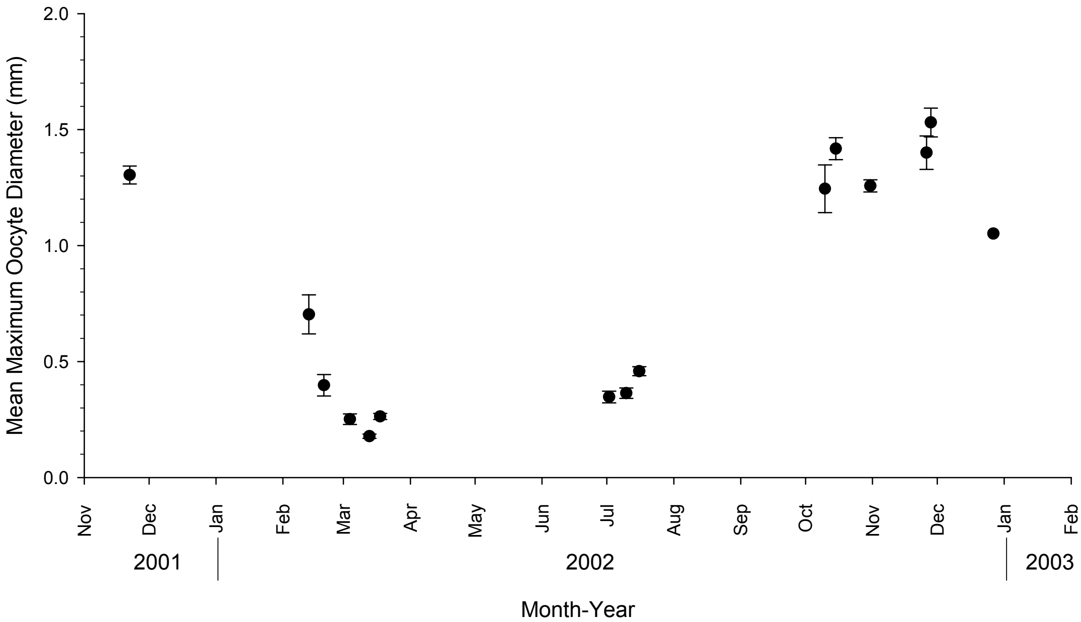


Figure 4.15. Mean maximum (largest 10) oocyte diameters (mm ± SE) for female snub-nosed garfish *Arrhamphus sclerolepis* (n=15 samples) collected from the Clarence River between November 2001 and December 2002.

4.3.2. *Sex ratios*

Sea garfish

Significantly more male sea garfish than females (1:0.81) were sampled from the north coast (χ^2=11.67, P<0.05; Fig 4.16), but similar numbers of males and females (1:0.99) were caught from the south coast (χ^2=0.01, P>0.05; Fig 4.16).

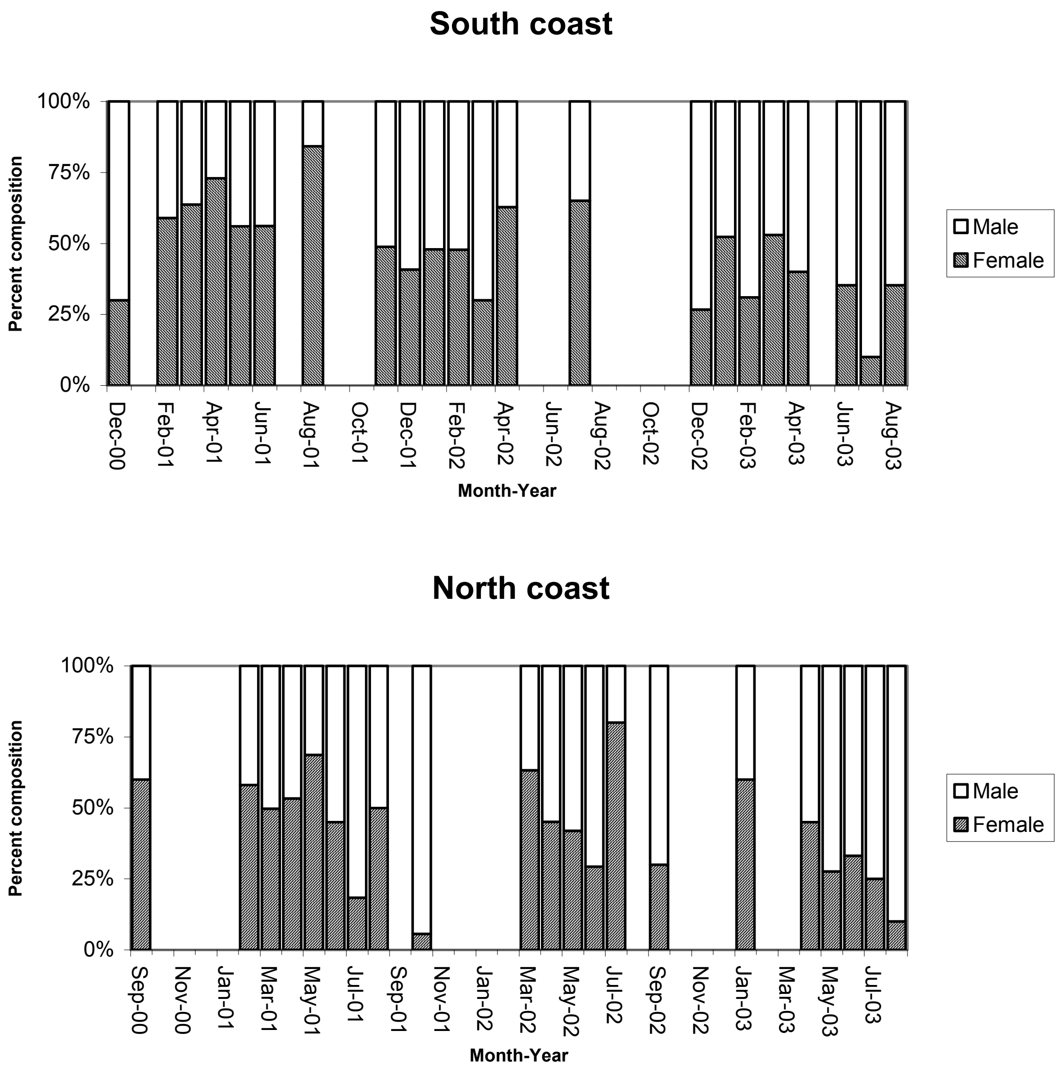


Figure 4.16. Monthly percentages of male and female eastern sea garfish *Hyporhamphus australis* collected from the south (n=1274) and north (n=1075) coasts of NSW between September 2000 and August 2003.

River garfish

The number of female river garfish caught was significantly higher than the numbers of males caught for all 3 estuaries (χ^2=67.55 (Lake Illawarra), 5.08 (Tuggerah Lakes), and 36.37 (Wallis Lake), P<0.05; Fig 4.17). This pattern persisted for the duration of the sampling period, with the exception of 2 samples from Lake Illawarra, 1 sample from Tuggerah Lakes and 2 samples from Wallis Lake. The average sex ratio (male:female) for samples from Lake Illawarra, Tuggerah Lakes, and Wallis Lake were 1:1.8, 1:1.3, and 1:1.7 respectively.

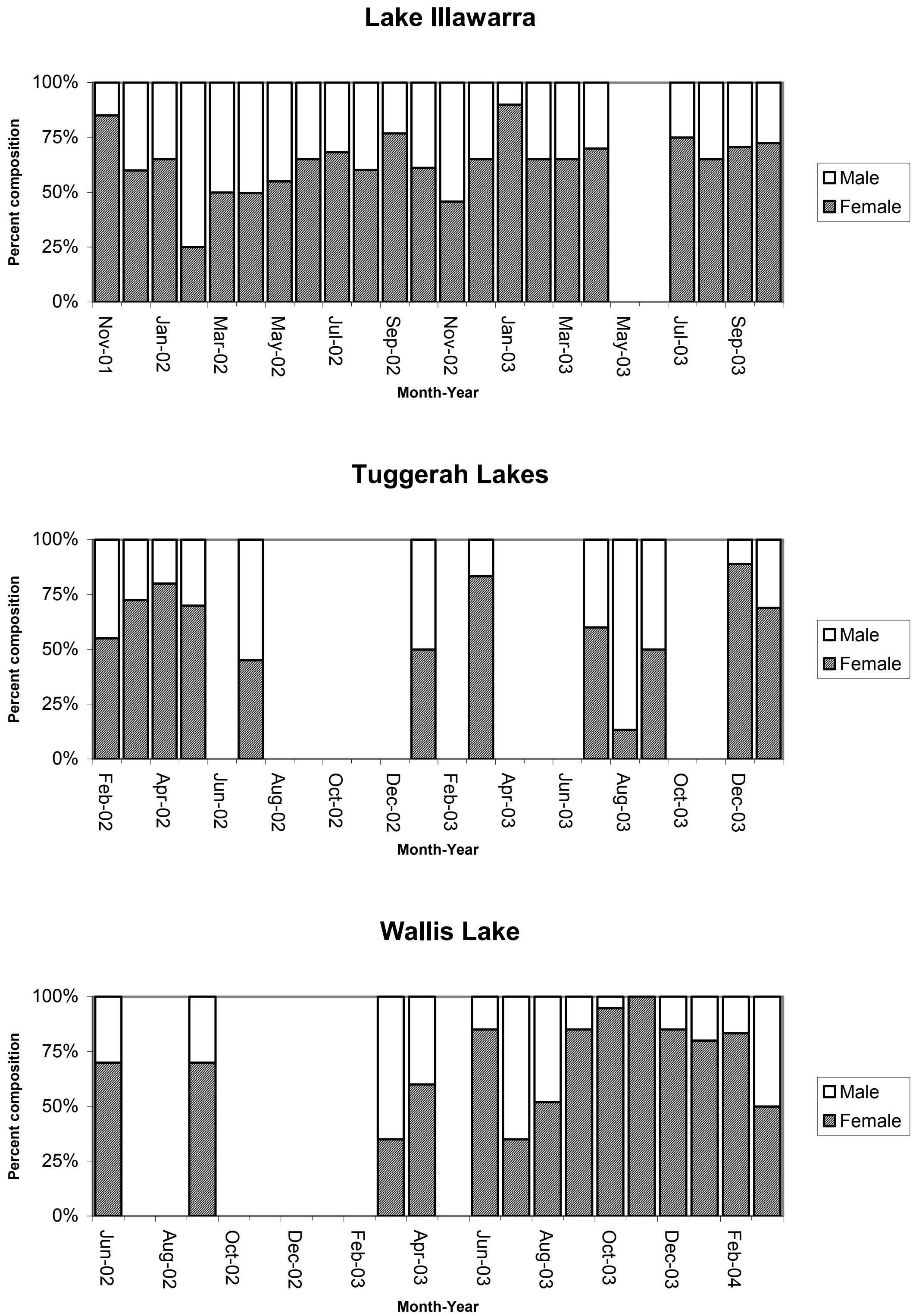


Figure 4.17. Monthly percentages of male and female river garfish *Hyporhamphus regularis* collected from Lake Illawarra (n=877), Tuggerah Lakes (n=366), and Wallis Lake (n=496) between November 2001 and March 2004.

<u>Snub-nosed garfish</u>

Female snub-nosed garfish made up the majority of fish collected in all samples bar one (October 2003; Fig 4.18). The average sex ratio (male:female) was significantly skewed towards female fish at 1:3.2 (χ^2=134.25, P<0.05).

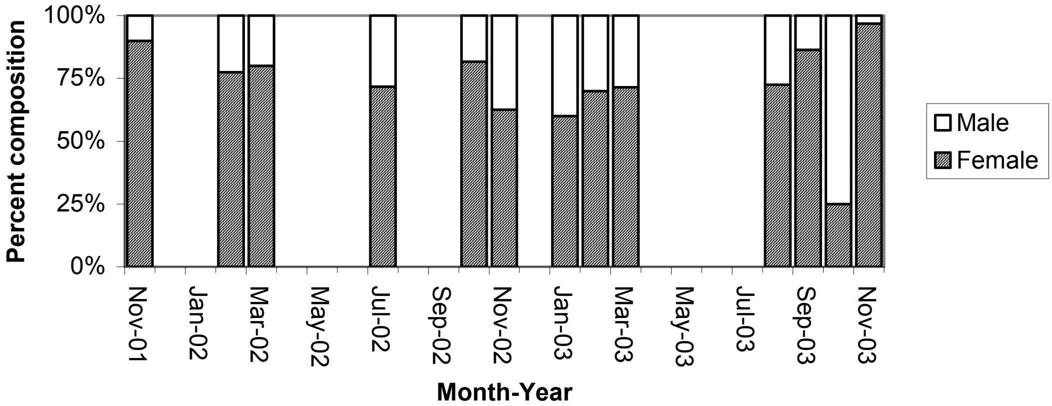


Figure 4.18. Monthly percentages of male and female snub-nosed garfish *Arrhamphus sclerolepis* (n=492) collected from the Clarence River between November 2001 and November 2003.

4.3.3. Batch fecundity

Sea garfish

Due to the small number of fish containing >1.5mm diameter oocytes (n=50), data for eastern sea garfish from the north and south coasts of NSW were pooled. There was a significant positive linear relationship between batch fecundity (BF) and fork length (FL) for sea garfish (BF=16.8FL–2909.7, R^2=0.52, P<0.05; Fig 4.19). Variation in BF was high for all FL's, BF ranging from just 98 to a maximum of 3449 ripe oocytes per female (Fig 4.19). In general, larger fish tended to carry more ripe eggs than smaller individuals.

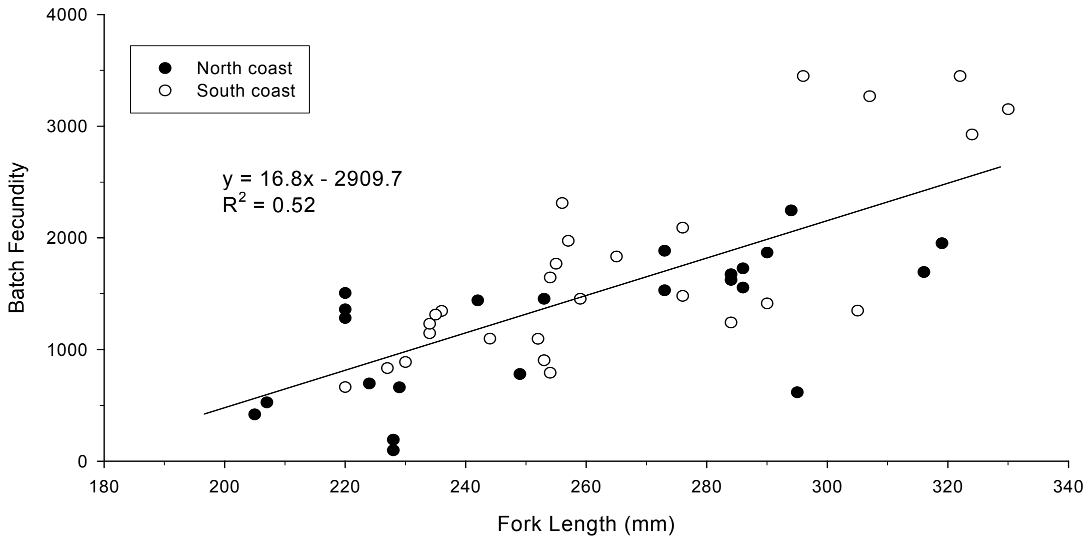


Figure 4.19. Relationship between batch fecundity and fork length (mm) for female eastern sea garfish *Hyporhamphus australis* (mean maximum oocyte diameter >1.5mm) collected from the north (n=23) and south (n=27) coasts of NSW between March 2002 and April 2003.

River garfish

BF data for river garfish was pooled for all estuaries sampled due to the small number of fish containing >1.5mm diameter oocytes collected from Wallis Lake (n=26) and Tuggerah Lakes (n=9). There was a significant positive linear relationship between BF and FL (BF=12.3FL–1934.7, R^2=0.41, P<0.05, n=130; Fig 4.20). Variation in BF was high for all given FL's, BF's ranging from 102 to 2268 ripe oocytes per fish (Fig 4.20). Overall, the ovaries of larger fish carried more ripe eggs than those of smaller individuals.

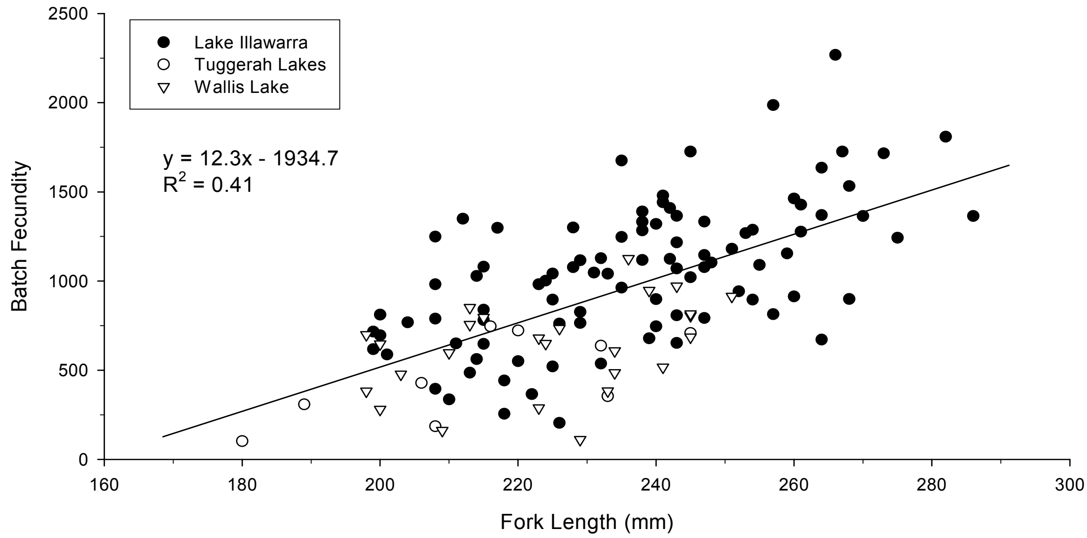


Figure 4.20. Relationship between batch fecundity and fork length (mm) for female river garfish *Hyporhamphus regularis* (mean maximum oocyte diameter >1.5mm) collected from Lake Illawarra (n=93), Tuggerah Lakes (n=9), and Wallis Lake (n=26) between November 2001 and October 2003.

<u>Snub-nosed garfish</u>

There was a weakly positive, but non-significant relationship between BF and FL for snub-nosed garfish from the Clarence River (BF=8.0FL–1280.8, R^2=0.05, P>0.05, n=22; Fig 4.19). Mean BF was low (606 ± 120), but variation in BF was large (min.=145, max.=2424 ripe oocytes per fish; Fig 4.21).

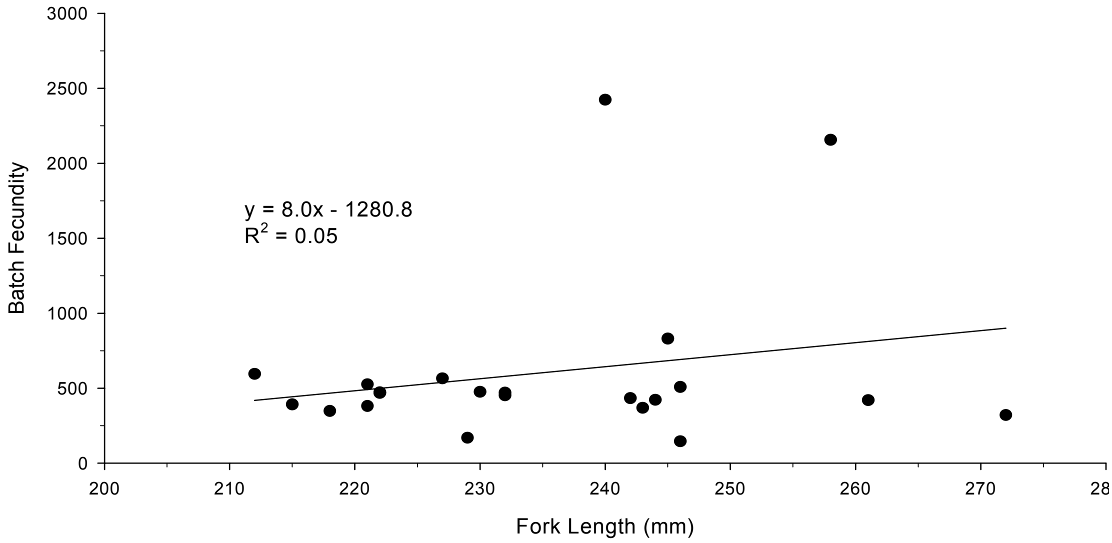


Figure 4.21. Relationship between batch fecundity and fork length (mm) for female snub-nosed garfish *Arrhamphus sclerolepis* (mean maximum oocyte diameter >1.5mm) collected from the Clarence River (n=22) between November 2001 and December 2002.

4.3.4. *Oocyte size frequency*

<u>Sea garfish</u>

In stage 1 (immature) sea garfish, nearly all oocytes were between 0.1 and 0.6mm diameter (Fig 4.22). Developing ovaries (stage 2) retained a small size class of eggs, but the majority were between 0.5 and 0.8mm diameter, with a peak at 0.6mm diameter. In stage 3 (ripe) fish, most oocytes were still found between 0.5 and 0.8mm diameter, but a larger size class (1.2-1.4mm dia.) was also evident. These oocytes continued to develop in running ripe (stage 4) fish into a batch of hydrated spawning sized ova (>1.5mm dia.). In spent (stage 5) fish no hydrated oocytes remained.

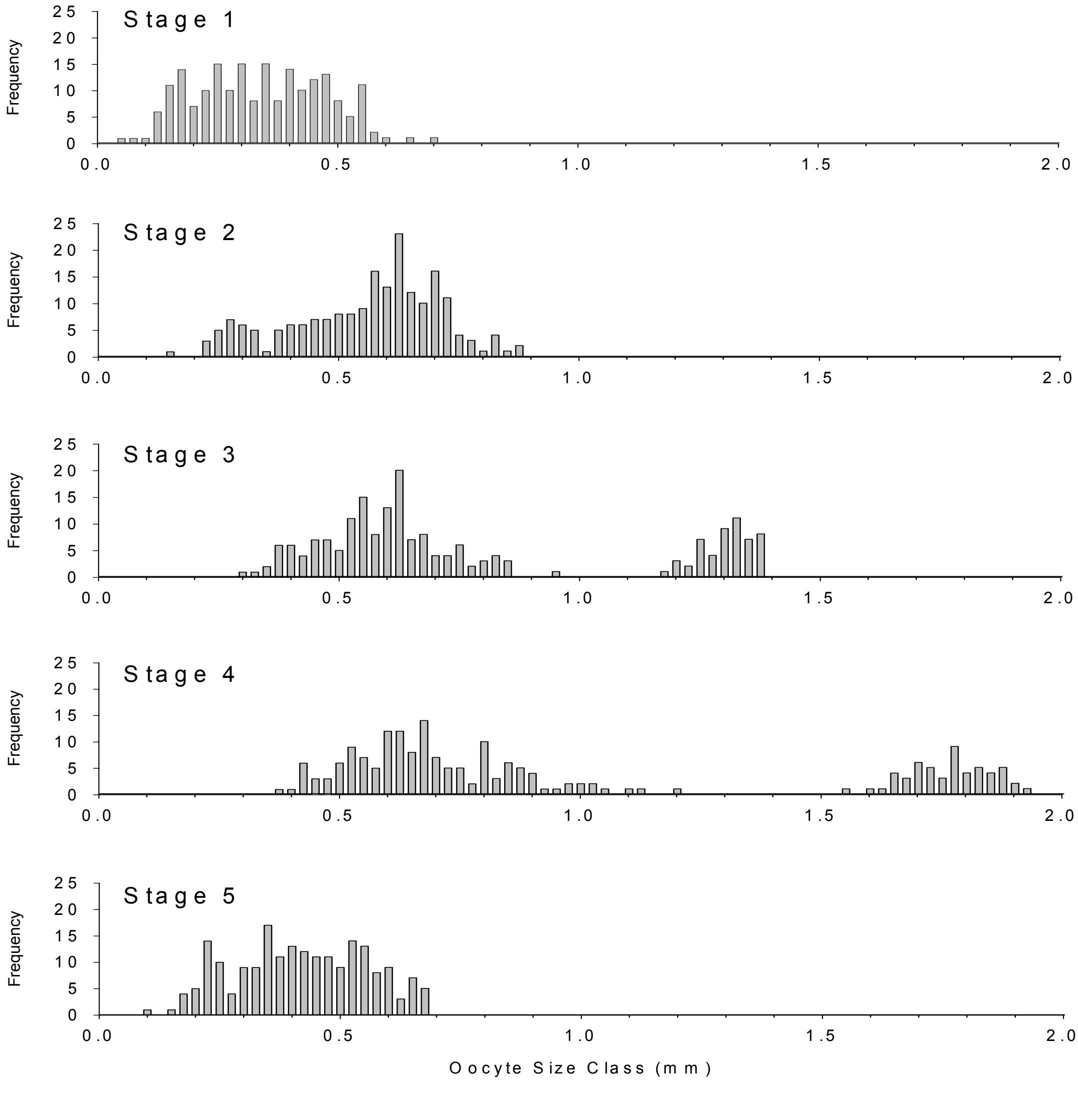


Figure 4.22. Oocyte size frequency distributions for 200 oocytes taken from a randomly chosen female eastern sea garfish *Hyporhamphus australis* of each reproductive stage.

River garfish

In stage 1 (immature) river garfish, all oocytes were of a small size class (0.1-0.6mm dia., with a major peak at 0.2mm dia.; Fig 4.23). The major size class in stage 2 (developing) ovaries was between 0.4 and 0.9mm diameter, but some eggs were also evident up to a diameter of 1.4mm. In stage 3 (ripe) fish, the pattern was similar to that for stage 2 ovaries, but a larger size class (1.5-1.8mm dia.) representing hydrating ova was evident. Most eggs in stage 4 (running ripe) fish were hydrated ova ready for spawning (1.8-2.4mm dia.). No ripe eggs remained in the ovaries of stage 5 (spent) fish.

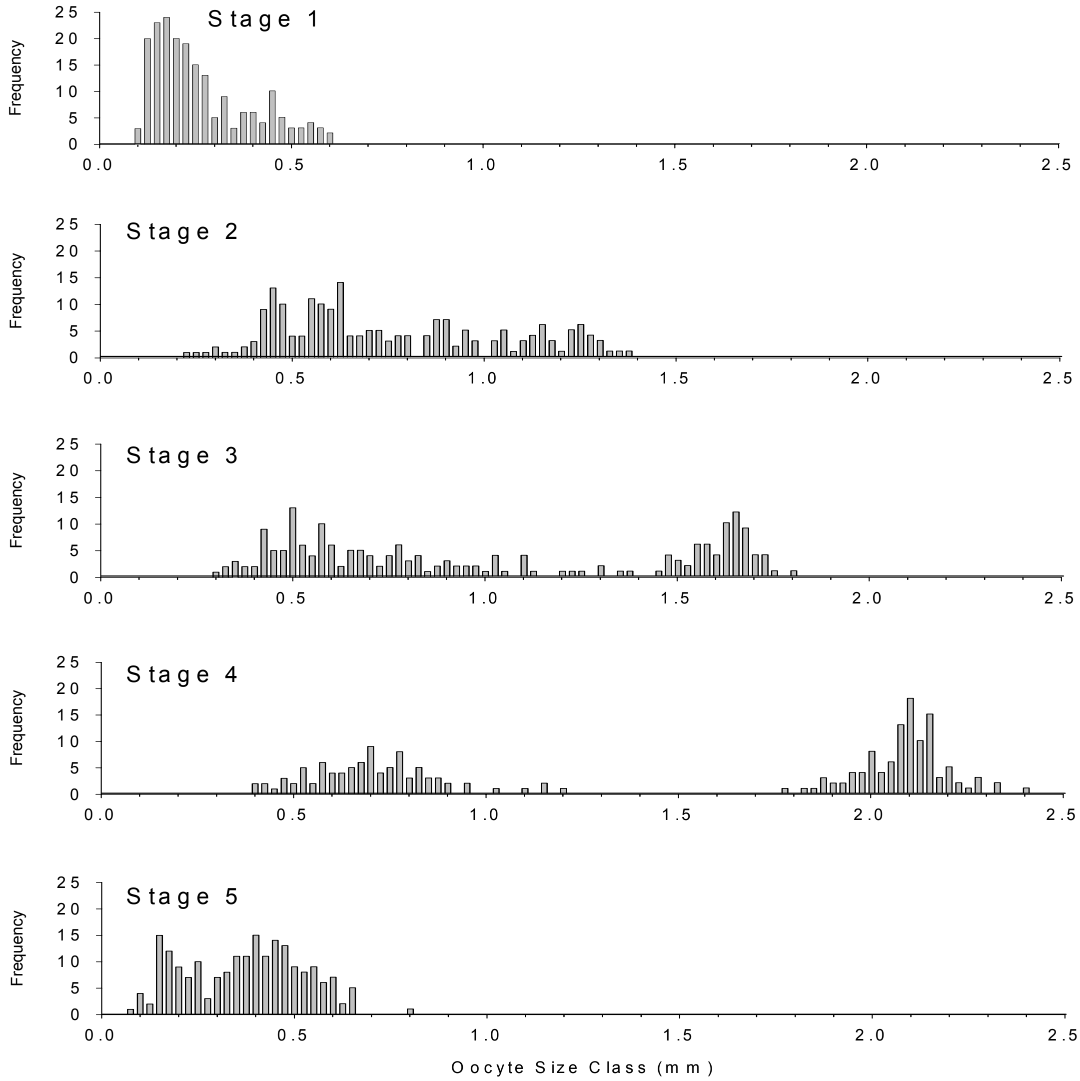


Figure 4.23. Oocyte size frequency distributions for 200 oocytes taken from a randomly chosen female river garfish *Hyporhamphus regularis* of each reproductive stage.

Snub-nosed garfish

Immature (stage 1) snub-nosed garfish contained mainly very small oocytes (0.1-0.3mm dia.; Fig 4.24). Stage 2 (developing ovaries) contained a broad batch of oocytes between 0.2 and 1.3mm diameter, but two distinct size classes were obvious with peaks at 0.5 and 1.2mm diameters respectively. In stage 3 (ripe) fish, the two size classes seen in stage 2 fish remained, but a greater proportion of eggs were of the larger size class (1.0-1.5mm dia.). In the ovaries of stage 4 (running ripe) fish this larger size class continued to mature to 1.4-1.7mm diameter and likely represented a single hydrated spawning batch. In spent (stage 5) fish no hydrated oocytes remained.

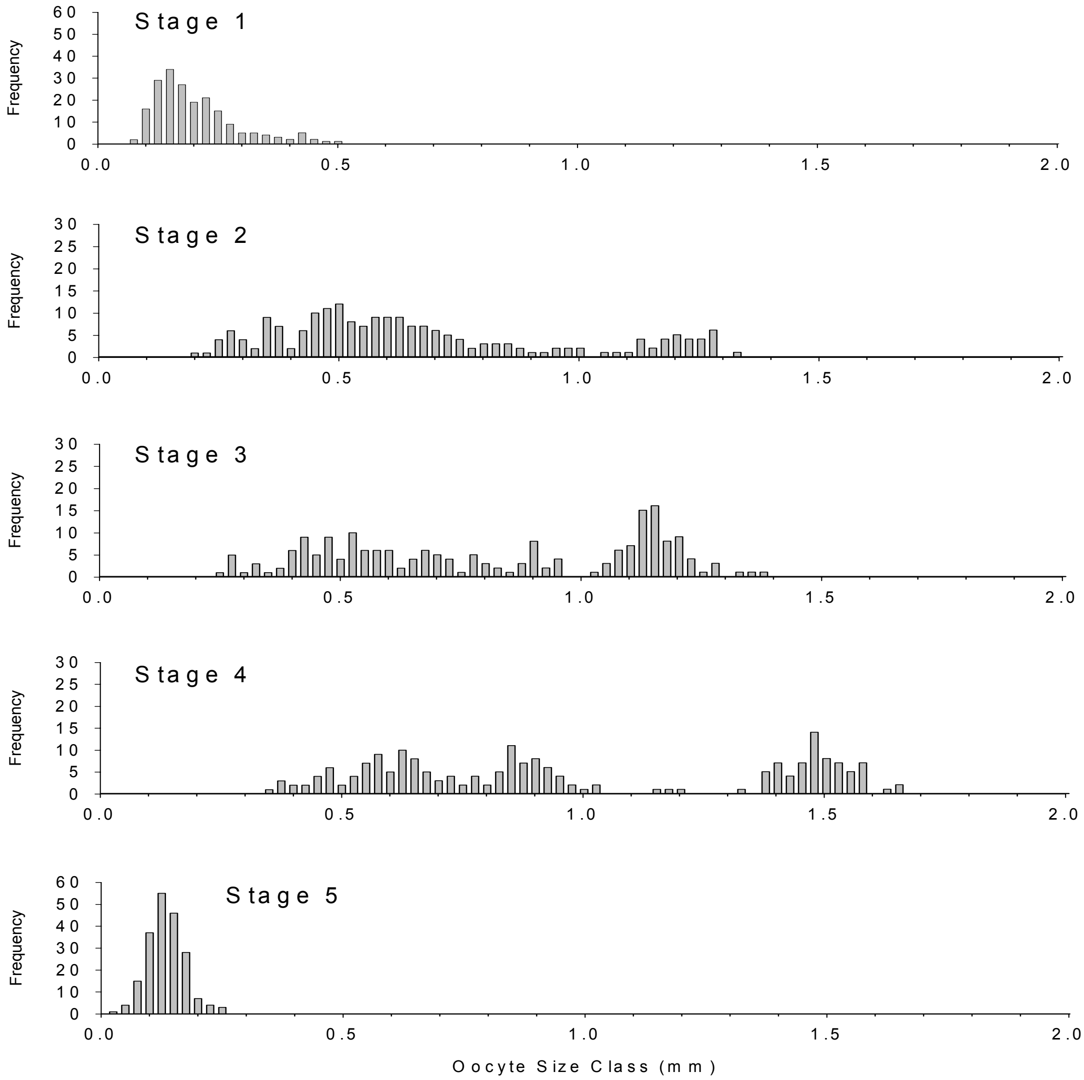


Figure 4.24. Oocyte size frequency distributions for 200 oocytes taken from a randomly chosen female snub-nosed garfish *Arrhamphus sclerolepis* of each reproductive stage.

4.3.5. Oocyte shrinkage

Single-factor ANOVA's indicated that shrinkage of oocytes due to fixation and storage was significant for both eastern sea garfish and river garfish (P>0.05; Table 4.3). For the two stage 3 eastern sea garfish examined, the diameters of oocytes after fixation and storage was reduced by between 8.5 and 11.7% that of fresh oocytes. For one stage 2 and one stage 3 river garfish examined, oocyte diameters were reduced by 14.1 and 14.6% that of fresh oocytes respectively. However, no shrinkage was evident for the oocytes of the other stage 2 river garfish examined. Mean maximum fresh oocyte diameter for this individual (1.17mm) was considerably less than for either of the other two river garfish (1.37 and 2.11mm), or the two sea garfish (1.48 and 1.74mm) examined, which did show significant oocyte shrinkage after fixation (Table 4.3).

The largest fixed oocytes recorded for each of eastern sea, river, and snub-nosed garfish were 2.45, 2.58, and 2.16mm diameter respectively. After sizes were adjusted for around 15% shrinkage (Table 4.3), actual maximum egg sizes were approximately 2.76, 2.72, and 2.40mm diameter for eastern sea, river, and snub-nosed garfish respectively.

Table 4.3. Comparison of fresh and fixed/stored eastern sea (*Hyporhamphus australis*), and river garfish (*H. regularis*) oocyte diameters. *=significant at P<0.05, ns=non-significant; ANOVA

Species	Ovarian stage	Mean fresh oocyte diameter (mm ± SE)	Mean fixed oocyte diameter (mm ± SE)	Percent shrinkage
H. australis	3	1.48 ± 0.01	1.36 ± 0.01	8.5 *
H. australis	3	1.74 ± 0.01	1.54 ± 0.01	11.7 *
H. regularis	2	1.17 ± 0.01	1.19 ± 0.01	-1.7 ns
H. regularis	2	1.37 ± 0.01	1.18 ± 0.01	14.1 *
H. regularis	3	2.11 ± 0.02	1.81 ± 0. 01	14.5 *

4.3.6. *Size at sexual maturity*

<u>Sea garfish</u>

Estimated size at 50% sexual maturity for female eastern sea garfish (20.9 ± 0.2cm) was larger than for males (19.5 ± 0.3cm) (Fig 4.25). Logistic curves for both sexes were comparable, so we pooled data for both sexes to give us a 'best' estimate of L_{50} for sea garfish of 20.1 ± 0.2cm. Females and males were estimated to reach 100% maturity at similar sizes (28 and 29cm respectively; Fig 4.25).

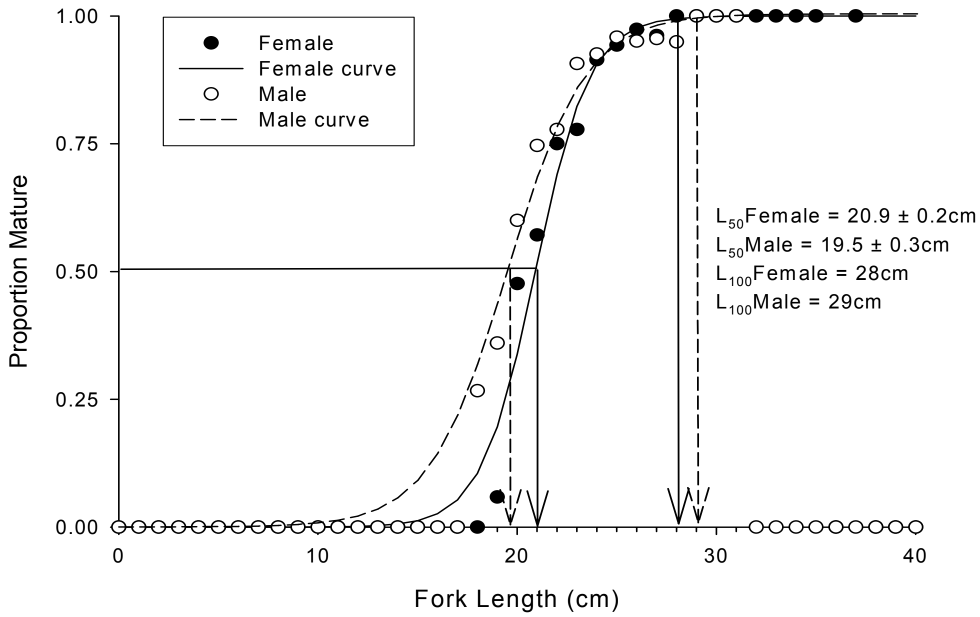


Figure 4.25. Size at reproductive maturity (50 and 100%) of female (n=546) and male (n=704) eastern sea garfish *Hyporhamphus australis*.

River garfish

Estimated size at 50% sexual maturity for female (16.7 ± 0.3cm) river garfish was slightly larger than for males (15.8 ± 0.4cm) (Fig 4.26). Logistic curves for both sexes were comparable, so we pooled data for both sexes to give us a 'best' estimate of L_{50} for river garfish of 16.1 ± 0.3cm. Females and males were estimated to reach 100% maturity at similar sizes (22 and 23cm respectively; Fig 4.26).

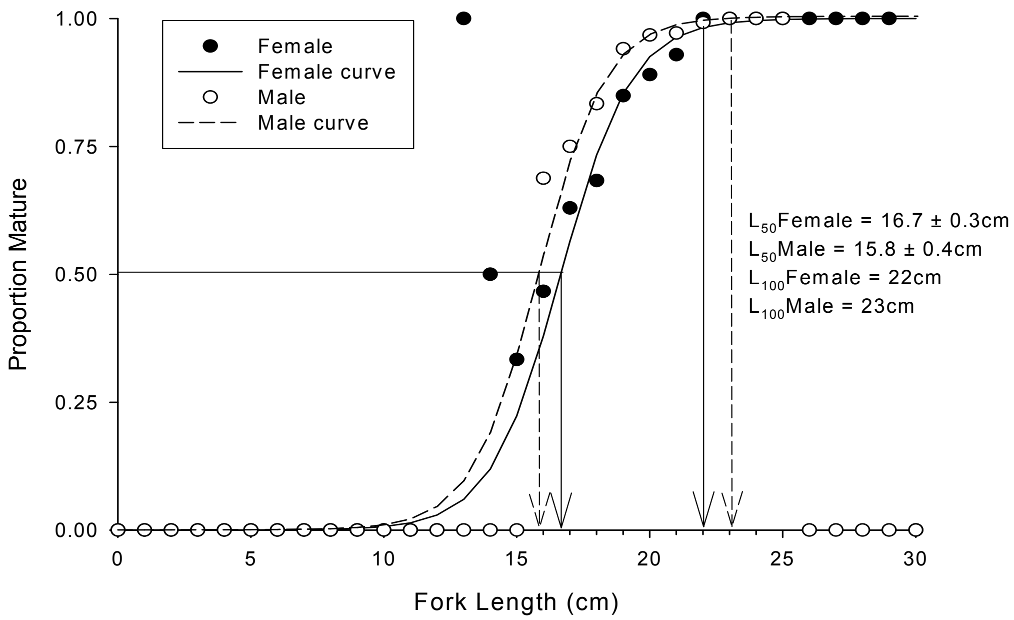


Figure 4.26. Size at reproductive maturity (50 and 100%) of female (n=1114) and male (n=681) river garfish *Hyporhamphus regularis*.

Snub-nosed garfish

There was no significant difference in the estimated size at 50% sexual maturity for male (17.8 ± 0.8cm) and female (17.8 ± 0.4cm) snub-nosed garfish (Fig 4.27). As both L_{50} estimates and logistic curves for both sexes were comparable, we pooled data for both sexes to give us a 'best' estimate of L_{50} for snub-nosed garfish of 17.6 ± 0.4cm. Females and males were estimated to reach 100% maturity at similar sizes (23 and 24cm respectively; Fig 4.27).

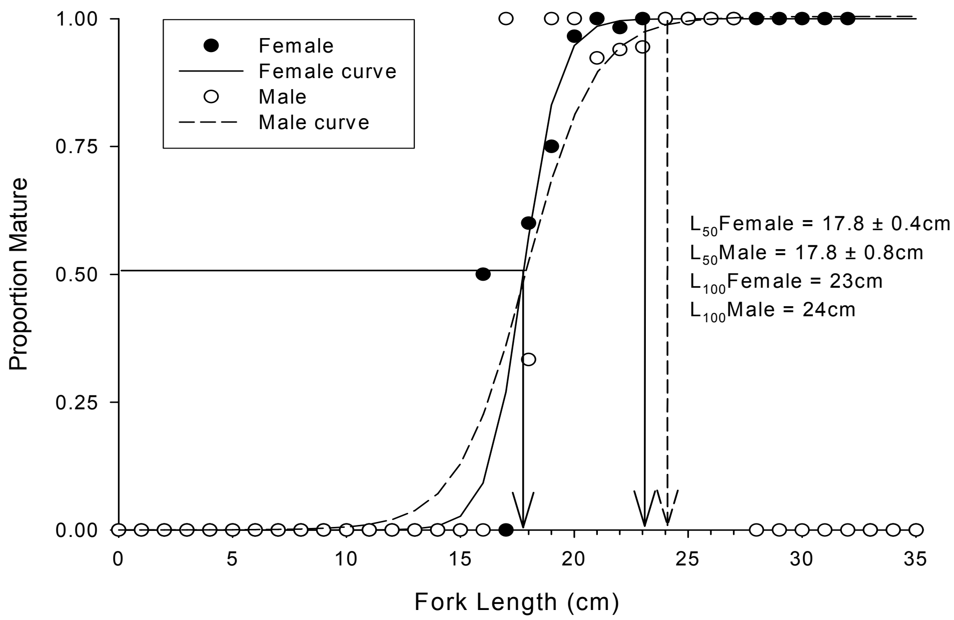


Figure 4.27. Size at reproductive maturity (50 and 100%) of female (n=386) and male (n=120) snub-nosed garfish *Arrhamphus sclerolepis*.

4.3.7. Daily timing of spawning in river garfish

During the 24-hour sampling period, reproductively active (stage>2) female river garfish showed similar size frequency distributions of eggs at all sample times (Fig 4.28). Several distinct size classes of oocytes were present at all four sample times. The two most obvious were a group containing eggs with diameters of between approximately 0.1 and 0.7mm, and a group of large, hydrated eggs (dia. approximately 1.8-2.2mm). A group of oocytes of diameters between 0.7 and 1.0mm were also present at all sample times. Between this group, and the hydrated size class, was a fourth group of oocytes found in various positions between 1.0 and 1.8mm diameter, which were probably oocytes in the process of hydration (Fig 4.28). This group of oocytes was present at all sample times except 12am.

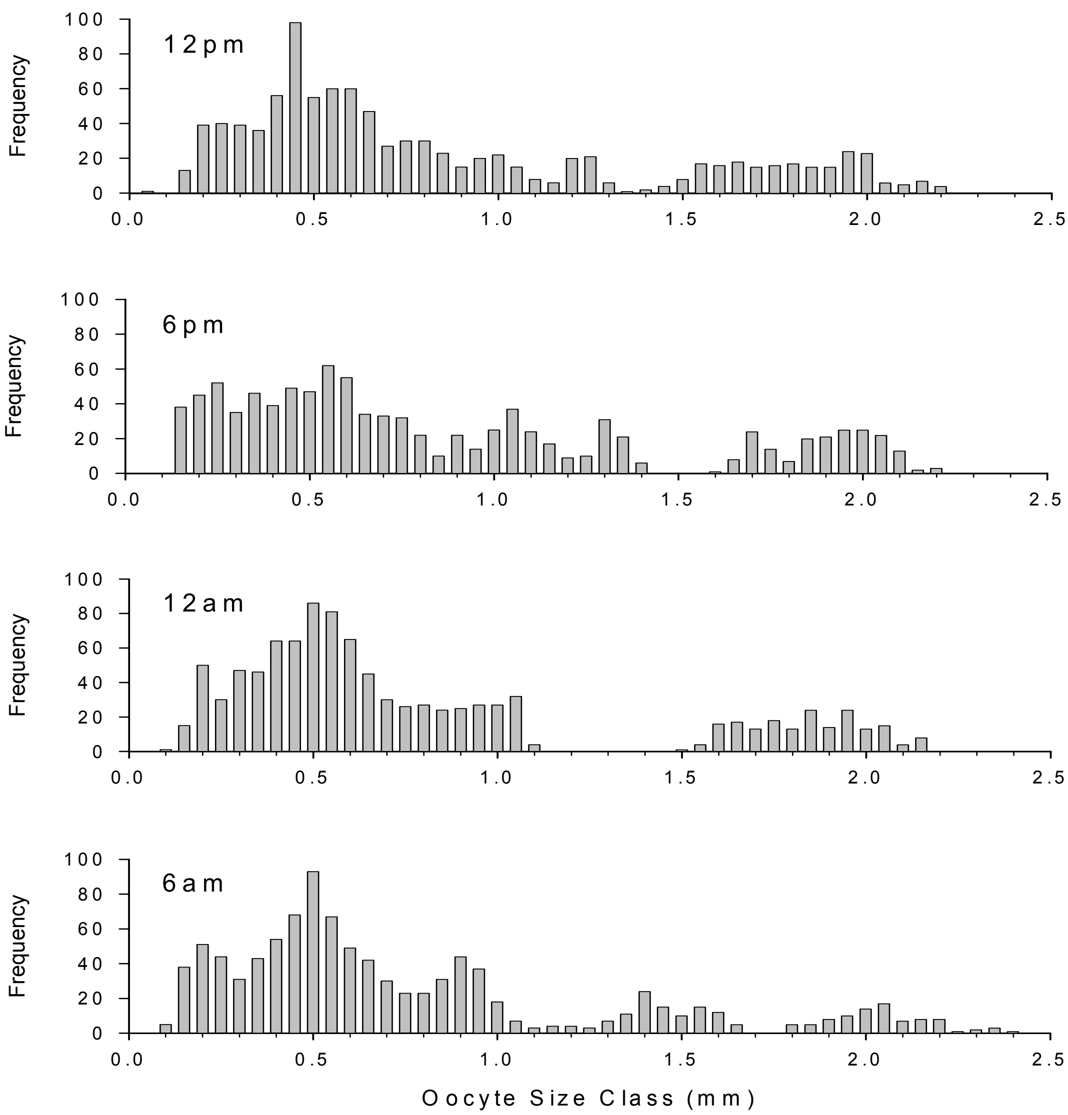


Figure 4.28. Oocyte size frequency distributions for 200 oocytes taken from each of 5 randomly chosen reproductively active (stage>2) female river garfish *Hyporhamphus regularis* from each sampling time. Fish were collected from Lake Illawarra between 12pm, 13 November and 6am, 14 November 2003.

The proportion of each spawning stage was typical of those for Lake Illawarra fish during the spawning season (see Fig 4.9). Most stage 3 (ripe) and stage 4 (running ripe) females occurred at 6pm, and most stage 5 (spent) fish occurred at 12am (Fig 4.29). However, both stage 3 and 4 females were present throughout the entire sampling period indicating that river garfish may be capable of spawning at any time of the day or night.

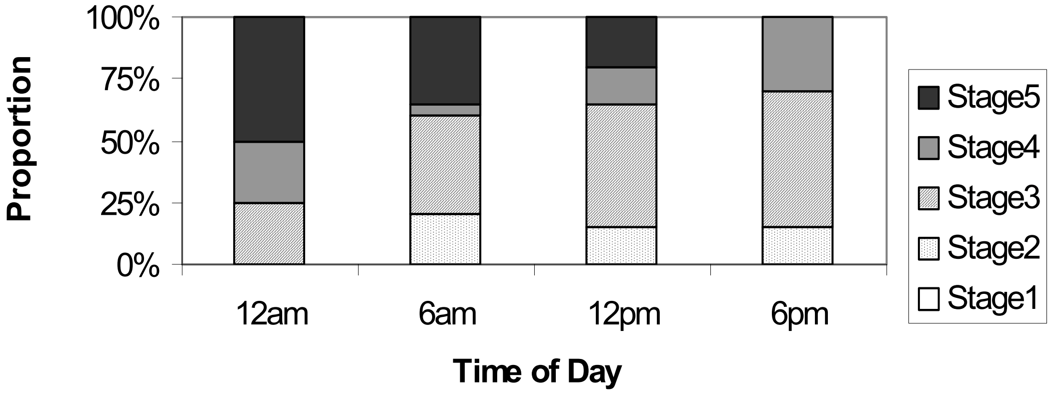


Figure 4.29. Ovarian staging for female river garfish *Hyporhamphus regularis* from each sampling time (n=20 for each time). Fish were collected from Lake Illawarra at 12 and 6pm (13 November), and 12 and 6am (14 November, 2003).

There were no differences in mean GSI throughout the sampling period (ANOVA: F=2.61, P<0.05; Fig 4.30), although there was a trend with highest GSI values occurring at 6pm (8.85 ± 3.20), gradually decreasing through the night to 6am (6.19 ± 2.41), and then increasing again to 8.61 ± 3.95 at 12pm. GSI values for the sampling period (mean 7.76 ± 3.33) were indicative of fish in spawning condition and typical of those for female Lake Illawarra fish during the spawning season (see Fig 4.8).

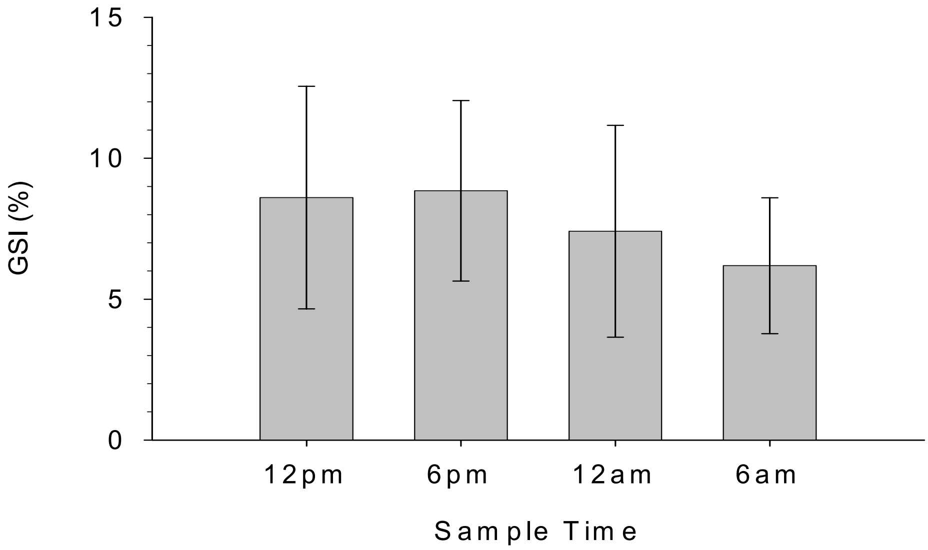


Figure 4.30. Gonadosomatic indices (GSI ± SE) for female river garfish *Hyporhamphus regularis* from each sampling time (n=20 for each time). Fish were collected from Lake Illawarra between 12pm, 13 November and 6am, 14 November 2003.

4.3.8. Appearance of spawned ova

When spawned, fresh ova for all three species were very large and spherical (Fig 4.29), but differed in size between the three species. For spawning-sized eggs of all three species, the chorion was smooth and unpigmented and covered by approximately 85-100 chorionic filaments, which were approximately 5-10mm long (Fig 4.29).

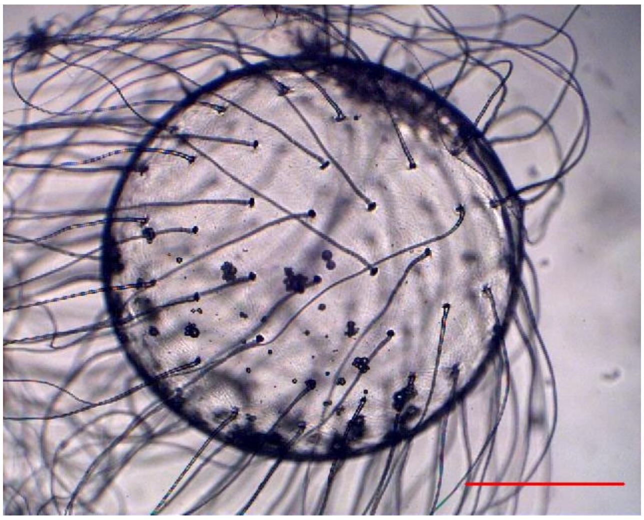


Figure 4.31. One-day-old eastern sea garfish *Hyporhamphus australis* ovum. Scale bar equals 1mm.

4.4. Discussion

4.4.1. Seasonality of reproduction

Eastern sea garfish *Hyporhamphus australis* in NSW have a prolonged spawning season with significant reproductive activity occurring at least somewhere along the coastline over a seven-month period between June and December (Fig 4.2). Peaks in GSI, mean maximum oocyte size, and the presence of fish with stage 3 (ripe) and stage 4 (running ripe) gonads clearly indicated that spawning occurs in late spring and early summer (Nov-Dec) on the south coast, and in winter and early spring (Jun-Sep) on the north coast.

The peak-spawning season for eastern sea garfish in Botany Bay has previously been estimated using GSI values to be October-December (SPCC, 1981). This is consistent with our spawning season estimate of November-December for fish on the south coast. The decline in numbers of fish found by the SPCC study during winter was attributed to a seaward migration of adult fish. Our data suggests that this winter migration was likely northward as well as seaward.

We consider eastern sea garfish in NSW to represent a single migratory stock and that individuals may travel up and down the NSW coast following the seasonal distribution of warm water provided by the East Australian Current (EAC). Eastern sea garfish appear to be associated with low turbidity oceanic water of 19-21°C. The flow of the EAC is strongest in summer, when warm nutrient poor clear blue water from the Coral Sea (>20°C) may reach as far south as Bass strait (www.marine.csiro.au). In winter, the EAC's flow is reduced by half, and warm water does not penetrate as far south. We suggest that as this warm clear water retreats north in autumn/winter, adult eastern sea garfish move northward and become largely absent from south coast waters (see also Chapter 2).

River garfish *Hyporhamphus regularis* also showed a protracted spawning season (Jul-Dec) in NSW. Peak activity suggested by GSI's, mean maximum oocyte diameters, and gonad staging indicated a winter-early summer spawning season of seven months length. However, unlike sea garfish, the peak spawning periods varied by sampling location, as river garfish are generally year round residents and complete their life cycle in estuaries, rivers and coastal lakes. The peak spawning period was marginally earlier in Wallis Lake (Jul-Nov), the most northerly estuary sampled, compared with Tuggerah Lakes and Lake Illawarra, which are further south (both Aug-Dec). This is possibly an artefact of our sporadic sampling at Wallis Lake (see Fig 4.8). The peak spawning period for snub-nosed garfish *Arrhamphus sclerolepis* also occurred over a relatively long period in late spring-early summer (Oct-Jan).

Prolonged reproductive seasons have been noted for many other hemiramphids (e.g: *Hyporhamphus melanochir*: Ling, 1958; Jones et al., 2002; *Zenarchopterus kampeni*: Coates and Van Zwieten, 1992; *Hemiramphus brasiliensis* and *Hemiramphus balao*: Berkeley and Houde, 1978; McBride et al., 2003; McBride and Thurman, 2003). Similar studies on the related southern sea garfish *Hyporhamphus melanochir* have also demonstrated a prolonged (8 months: Sep-Apr) spawning season across southern Australia (Vic, SA, WA, and Tas) (St. Hill, 1996; Jordan et al., 1998; Jones et al., 2002). The spawning cycles of temperate marine fishes are generally closely linked to environmental cues, most commonly day length and/or temperature (Bye, 1990). It has been suggested that timing of spawning for *Hyporhamphus melanochir* is linked to the summer bloom in productivity in southern Australian shelf waters (Jones et al., 2002). The north-south migratory behaviour of eastern sea garfish with the seasonally advancing and retreating warm water stream along the NSW coast possibly represents similar behaviour related to spawning in this species. Jones et al. (2002) were also able to show that larval southern sea garfish concentrated mainly on zooplankton as prey, and that spawning is timed to coincide with blooms of this important larval food source.

For all three species, the presence of individuals with ripe (stage 3), running ripe (stage 4), and spent (stage 5) gonads outside of their respective peak spawning periods suggests that some spawning activity may occur outside of peak periods. In two species of tropical Atlantic hemiramphids, ballyhoo *Hemiramphus brasiliensis* and balao *Hemiramphus balao*, spawning of young (0+ year old) females was strongly seasonal during late spring-early summer, but older female fish spawned throughout the entire year (McBride and Thurman, 2003). We suggest that the peak spawning seasons seen for eastern sea, river, and snub-nosed garfish in NSW may be due in part to the commencement of spawning activity in fish aged 0+ years.

4.4.2. Sex ratios

Sex ratios were biased toward male sea garfish on the north coast of NSW, but were not significantly different on the south coast (Fig 4.16). Despite the fact that until recently, the mesh size used in sea garfish hauling nets had been smaller (25mm) on the north coast compared with that generally used by fishers on the south coast (28-30mm), both male and female sea garfish grow at a similar rate for the first year (Chapter 3), and it is thus likely that the observed sex ratio patterns are real and not a result of gear selectivity. However, variation from month to month and between years is considerable in sex ratios of samples collected from both the north and south coasts. These observed sex ratios suggest that the fishery for eastern sea garfish targets both sexes equally on the south coast, and mainly males on the north coast.

Sex ratios were significantly biased toward both female river, and snub-nosed garfish (Fig 4.17 and 4.18). Female river and snub-nosed garfish grow significantly faster than their male counterparts (Chapter 3). Thus it could be reasonably expected that female individuals, that are generally larger than males, are caught more often in 'bullringing' nets, potentially producing the observed biases in sex ratios for the two species. However, these sex ratio patterns were consistently evident, irrespective of the gear used or the method of collection (i.e.: 'bullringing', hauling, or prawn nets) indicating that the observed sex ratios for river, and snub-nosed garfish are likely real, and not an artefact of gear selectivity of the principal collection technique, 'bullringing'. These observed sex ratios suggest that the fishery for river and snub-nosed garfish targets mainly females, simply because there are more females in the populations.

Several studies on the southern sea garfish *Hyporhamphus melanochir* in Victoria, WA, SA and Tasmania also found that sex ratios were biased toward females (Ling, 1958; St. Hill, 1996; Jones et al., 2002). Jones et al. (2002) indicated that these biases could be largely attributed to differences in the spatial distribution and schooling behaviour of the sexes. In SA, female southern sea garfish tended to form large schools in shallow inshore waters, which were easily targeted by commercial fishers, whereas males were more widely dispersed in deeper water. A similar situation certainly occurs at least for river garfish in NSW estuaries where females are found in large numbers over shallow seagrass beds, and particularly during the peak spawning season, it is not uncommon for sample hauls to consist almost exclusively of female fish. As suggested by Jones et al. (2002), this may constitute a strategy that increases the chance of ripe females encountering males in spawning condition.

4.4.3. Batch fecundity

Batch fecundity (BF) for all three species was low compared with those for many other marine fish species (eg: Militelli and Macchi, 2001; Nieland et al., 2002; White et al., 2003; Macchi et al., 2004). Batch fecundity was slightly higher for eastern sea garfish than for river garfish across the range of mature sizes examined. The BF for both sea and river garfish were higher than for snub-nosed garfish, possibly due to the analysis of too few samples from which to gain a realistic and accurate representation of the BF pattern for snub-nosed garfish (n=22). The variable influences of biotic and abiotic factors such as fish size, age, and condition, as well as environmental conditions also have the potential to affect BF (Thomson, 1957; Bagenal, 1978). Batch fecundity also increased more rapidly with increasing fish size in sea garfish (R^2=0.52; Fig 4.19) than river garfish (R^2=0.41; Fig 4.20). With the exception of just two data points, BF for snub-nosed garfish did not increase with fish size (R^2=0.05; Fig 4.21). Even amongst hemiramphids, BF for snub-nosed garfish was unusually low. In this study, BF was estimated as the number of oocytes that became hydrated and were larger than 1.5mm diameter on the day the fish was caught. One possible explanatory mechanism is that fully hydrated snub-nosed garfish eggs when fixed are slightly smaller than 1.5mm diameter. In fact, snub-nosed garfish mean maximum oocyte diameter was >1.5mm for just one sample (November 2002; Fig 4.15). Alternatively, the fact that the snub-nosed garfish samples for this study were collected during the day may have resulted in low numbers of hydrated eggs in ovaries. If it is assumed that snub-nosed garfish spawn around dusk as suggested for river garfish (this study- see below) and *Hemiramphus brasiliensis* and *Hemiramphus balao* (McBride et al., 2003), then it is possible that eggs to be spawned at dusk may not have reached a sufficiently hydrated state when the fish were collected. It is also possible that the handling of fish during capture and processing may have resulted in the inadvertent 'stripping' of spawning sized eggs in running ripe (stage 4) fish.

The low batch fecundities seen for eastern sea, river, and snub-nosed garfish in the present study are typical for species from the order Beloniformes (Berkeley and Houde, 1978; Collette et al., 1984) and have been previously demonstrated for other hemiramphid species (eg: *Hyporhamphus melanochir*: Ling, 1958; Thomson, 1957; St. Hill, 1996; Jones et al., 2002; *Hemiramphus brasiliensis* and *Hemiramphus balao*: McBride and Thurman, 2003). By spawning regularly over a prolonged spawning season, this low batch fecundity may be effectively compensated for with respect to overall annual or lifetime fecundities. In fact, it has been suggested that this reproductive style actually permits hemiramphids to achieve similar annual or lifetime fecundities when compared to other similar sized fish (McBride and Thurman, 2003).

4.4.4. Oocyte size frequency

For all three species of garfish, oocytes developed in a group-synchronous pattern. It was possible to follow the development of single spawning batch size classes of eggs from maturation through to ovulation (Figs 4.22, 4.23, 4.24). Mature female fish of all three species had distributions of oocyte diameters consisting of three or four modes, which strongly suggests a multiple spawning strategy during the spawning season. The smallest mode (0.1-0.7mm dia.) likely represents a reservoir of primary growth oocytes and vitellogenic oocytes and could be seen in all three species at all stages of ovary development. Oocytes with diameters 0.7-1.0mm present in stage 2-4 ovaries of all three species likely represent oocytes beginning final oocyte maturation (FOM). A larger mode consisting of oocytes of between 1.0 and 1.5mm diameter appear to be undergoing FOM in stage 2 sea garfish ovaries, and stages 2 and 3 river and snub-nosed garfish ovaries. The largest group of oocytes (1.5-2.0mm dia. for sea and snub-nosed garfish, 1.75-2.5mm dia. for river garfish) represent hydrating/ed oocytes. The group-synchronous nature of oocyte development and large spawned egg sizes seen for the three species examined here, have been recorded for several other hemiramphid species (eg: *Hyporhamphus melanochir*: Ling, 1958; *Hemiramphus marginatus*: Talwar, 1967; *Hemiramphus brasiliensis* and *Hemiramphus balao*: McBride and Thurman, 2003). For spawning-sized eggs of all three species, the chorion was smooth and unpigmented and covered by 85-100 chorionic filaments, which were approximately 5-10mm long (Fig 4.30). Such filaments are suggested to allow eggs to attach to (floating/benthic) vegetation (Ling, 1958; Talwar, 1962; 1967; Berkeley and Houde, 1978; McBride et al., 2003).

4.4.5. Size at maturity

Eastern sea garfish approached 50% maturity at a larger size (average for both sexes: 20.1cm) than snub-nosed (17.6cm), or river (16.1cm) garfish. In this study, size at 50% sexual maturity estimates for female (20.9 ± 0.2cm) eastern sea garfish were considerably larger than length at first maturity (LFM) estimates from a previous study of the species in Botany Bay, which found an LFM of just 17cm for females (SPCC, 1981). However, the LFM estimate for males (19cm) was very similar to our calculated size at 50% maturity (19.5 ± 0.3cm). In comparison to our study however, the SPCC study occurred over a very small spatial scale (Botany Bay only), and reported very small sample sizes.

Snub-nosed and river garfish grow more slowly than eastern sea garfish, but all three species can be considered as fast growing fishes (Chapter 3). Using information generated by the von Bertalanffy growth models (Chapter 3), all three species reach sexually mature sizes at ages of less than 12 months, and are thus probably capable of spawning in the spawning season immediately after the one in which they were born. This strongly suggests that these species may be similar in terms of reproductive biology to two species of tropical coral reef hemiramphids, *Hemiramphus brasiliensis* and *Hemiramphus balao* (McBride and Thurman, 2003). Both these species mature at comparable sizes (size at 50% maturity=16.0cm for *Hemiramphus balao*, 19.8cm for *Hemiramphus brasiliensis*) to the species examined here, and also mature in their first year. Size at 50% maturity for the southern sea garfish *Hyporhamphus melanochir* ranged between 18.8 and 22.8cm SL in southern Australia (Vic, SA, WA), but occurred at ages of 17.5-19.0 months, at least 6 months older than for the three species examined here (Jones et al., 2002).

The percentage of eastern sea garfish in commercial landings (1999/2000-2003/04) that were smaller than their estimated size at maturity (pooled sexes 20.1cm FL; Fig 4.25) averaged 21% (min.=12%, max.=32%; Fig 2.14). However, a recent management change for the fishery, which has increased the mesh size which can be used in garfish hauling (lampara) nets from 25mm to 28mm, is expected to reduce the number of immature eastern sea garfish caught to approximately

5% of the total catch. For river garfish, only 0.4% of the commercial 'bullringing' and hauling catch (2000/01-2003/04; Fig 2.25) was smaller than the estimated size at maturity for this species (16.1cm FL; Fig 4.26). Similarly for snub-nosed garfish, an average of just 0.3% of the commercial 'bullringing' catch (2000/01-2003/04; Fig 2.31) was smaller than the estimated size at maturity for this species (17.6cm FL; Fig 4.27). Snub-nosed garfish are also a bycatch species in the prawn net fishery in the Clarence River. Up to 80% of snub-nosed garfish caught using prawn nets (Fig 2.32) were smaller than their size at maturity, however snub-nosed garfish caught using this method make a negligible contribution to the total catch (Chapter 2). There is currently no minimum legal length for any of these garfish species in NSW waters, but the minimum lengths of fish in commercial catches for all three species indicate that the major fishing techniques and gear selectivity targets almost entirely mature fish.

Size at 50% maturity was 50.8% of the maximum body size for eastern sea garfish (39.8mm SL), 58.0% for river garfish (28.0mm SL), and 64.3% for snub-nosed garfish (27.7mm SL) (all max. sizes from Collette, 1974). Size at maturity is around 60% maximum body size for many hemiramphids for which this calculation can be made (eg: 58.2% for *Hemiramphus limbatus*: Silva and Davies, 1988; 58.0% for *Zenarchopterus kampeni*: Coates and Van Zwieten, 1992; 63.3% for *Hemiramphus brasiliensis* and 58.6% for *Hemiramphus balao*: McBride and Thurman, 2003). Eastern sea garfish do not follow this pattern, possibly because growth is faster than for river or snub-nosed garfish (Chapter 3), or these other species. It has been previously suggested that this percentage may be useful in predicting the size at maturity for an unstudied hemiramphid species (McBride and Thurman, 2003). We caution the use of this generalisation in the approximation of such an important biological parameter given our precise size at maturity estimate of 50.8% of maximum body size for eastern sea garfish. To further illustrate this point, a size at maturity estimate of 40.1% of maximum body size occurs for another Australian species, the southern sea garfish *Hyporhamphus melanochir* (maximum size 52.0mm SL: Collette, 1974).

4.4.6. Daily timing of spawning in river garfish

Several modes were evident in the size distribution of river garfish oocytes for the entire 24-hour sampling period (Fig 4.28). The smallest mode (0.1-0.7mm dia.) represented a reservoir of primary growth oocytes and vitellogenic oocytes and could be seen at all sample times. Oocytes with diameters 0.7-1.0mm were present at all sample times and were probably beginning final oocyte maturation (FOM). Another mode which consisted of oocytes of between 1.0 and 1.8mm diameter appear to be in various stages of FOM, and had a mode or modes in various places within this size class depending on the reproductive stage of the 5 individual river garfish which made up the sample group. The largest group of eggs (dia. approximately 1.8-2.4mm) represent hydrated ova ready for spawning, and were present at all sample times. Evidence for spawning between 6pm and 12am is provided by data from macroscopically staged ovaries (Fig 4.29), and the gradual increase in GSI values (Fig 4.30). However, the presence at all sample times of some females with stage 3 or 4 ovaries, hydrated spawning-sized oocytes, and large GSI's implies that at least some female river garfish were capable of spawning at any time of the diel cycle. In the Atlantic coral reef halfbeaks, *Hemiramphus brasiliensis* and *Hemiramphus balao*, the pattern of final oocyte maturation also follows the diel cycle and occurred over 30-36 hours, and both species were shown to spawn at dusk (McBride et al., 2003). Histological analyses of ovaries during the spawning season would serve to identify the presence of postovulatory follicles (POF's) and the stage of nucleus migration, and thus provide a more accurate estimation of spawning frequency for river garfish.

5. OUTCOMES AND RECOMMENDATIONS

5.1. Benefits

This study has provided comprehensive information on the biology and fisheries for eastern sea, river and snub-nosed garfish in NSW. This information will be of major benefit to the garfish stocks and commercial and recreational fishers, who will benefit from improved fisheries management arising from this study.

The development of validated ageing methods, and descriptions of growth rates and reproductive biology, are the first for these species. There have been few similar studies on hemiramphid species and our work will be of interest to scientists studying these fish around the world.

5.2. Further Development

Further extension of the projects' results will be done once the University of Wollongong have completed their research on the importance of different habitats to these species of garfish. Much of this work will be written and published in the international scientific literature to ensure it is disseminated globally.

5.2.1. Future research and monitoring

Future, ongoing monitoring of the garfish fisheries in NSW is essential for effective fisheries management. The NSW DPI should commit sufficient resources to ensure that this can be done adequately each year. At present these resources do not exist.

It is imperative that monitoring be done that will provide: (i) information on the status of the fisheries, and; (ii) an assessment of the effectiveness of various management changes in achieving their objectives.

<u>Sea garfish</u>

Available evidence indicates that the stock of eastern sea garfish along the NSW coast is at a historically low level. Indices of this low abundance include: (i) anecdotal reports from fishers, particularly those from the northern and southern ends of the species' range; (ii) historically low levels of commercial landings and CPUE; (iii) the lack of fish older than 2 years in landings despite the potential to live for at least 4+ years, and; (iv) high estimates of total annual mortality rates with fishing mortality potentially 3.5 times greater than natural mortality. Fortunately, these indices of relative abundance can be monitored to determine whether management measures designed to promote recovery of the stock are working (see Recovery Program – Appendix 3).

We recommend the following requirements for future monitoring of the sea garfish fishery in NSW:

(i) Commercial catch statistics

The monthly catch and effort returns submitted by commercial fishers have the potential to be extremely useful in monitoring the status of the sea garfish fishery. However, significant improvements are required if use of these catch statistics is to provide reliable assessments. There is currently a time-lag of at least 6 months before fishers' information becomes available and many fishers do not even file returns. Fishers need some incentive to submit their catch returns, and in a timely fashion, if up-to-date assessments are to be made. Fishers need to be taught how to complete their catch returns accurately and unambiguously, as incorrect reporting in a fishery with relatively few participants may result in misleading estimates of CPUE. An improvement in quality control within the catch records system of the NSW DPI is also needed. The small-scale of the fishery for sea garfish should allow for careful scrutiny of catch returns as they arrive to ensure their validity, and the contacting of individual fishers a simple task to clarify discrepancies.

We envisage the index of CPUE of reported catch of sea garfish per day fishing using the garfish hauling net, will provide the best indication of the relative abundance of sea garfish. In addition, in an effort to obtain more refined estimates of CPUE (such as catch per boat and catch per shot) we have started trialing a voluntary daily logbook. Twelve fishers completed log-books for us during 2003/04 and provided daily information on catch, the number of shots, where they fished, whether they were boat or shore-based and on water conditions. The logbooks will be issued to helpful fishers again during 2004/05.

(ii) Measuring sizes of sea garfish in landings

Measuring the sizes of sea garfish in commercial landings should be done to monitor changes in the fishery and to assess the effectiveness of removing the concession to use 25mm mesh in garfish hauling nets. The relative scarcity of large fish (>25 cm FL) during 2002/03 was correlated with the lowest landings and CPUE on record, and may have indicated a weak year class. We expect less than 5% of the catch to be smaller than 20 cm FL if using 28 mm mesh. If small fish are observed to be more prevalent than this in landings then a review of fishers nets and their configurations should be triggered.

Wherever possible measurements should be made at the point of landing to minimise the potential for unrepresentative samples being measured (due mainly to export or bait markets). If such export and bait markets are small then these measurements could be done in a cost-effective manner at the Sydney Fish Markets.

(iii) Estimating the age structure in landings

Our analyses of the age structures in landings during 2001/02 and 2002/03 suggest very high annual mortality rates. Estimates of mortality rates suggest that fishing mortality may be up to 3.5 times greater than natural mortality. If management changes designed to reduce fishing mortality are successful we would expect to see some decrease in total mortality estimates made from catch curve analyses. Annual variations in recruitment and natural mortality may swamp any indications of reductions in fishing mortality, however age-based monitoring will at least assist in estimating total mortality rates. Otoliths for age estimation may be collected at the same time as landings are being sampled for length composition.

<u>River and snub-nosed garfish</u>

This study has provided baseline information on the biology and fisheries for river and snub-nosed garfish in NSW. The results indicate that both fisheries are fully exploited but show no sign of declines in recent years. Size and age monitoring of the composition of landings, while interesting and useful, may not be cost-effective in such small fisheries. If the commercial fishers' catch reporting system is improved, then we believe that the index of CPUE of the catch per day of fishing using the bullringing net will provide sufficient information by which to assess the fishery. Resources should be made available by the NSW DPI to examine the catch statistics for river and snub-nosed garfish in detail (to the level of individual fishers) each year.

5.2.2. Compliance

The management measures designed to reduce fishing pressure and promote recovery of the fishery require some level of compliance resources to be allocated. The majority of fishers who target sea garfish have modified their fishing practices to assist in the recovery of the stock, and it is important that fishers continue to fish appropriately. There was significant anecdotal evidence during 2003/04 of the inappropriate use of small-meshed nets (such as the pilchard, anchovy bait net) by some fishers to take small sea garfish for sale as bait. This unlawful behaviour is effectively stealing fish from those fishers who target sea garfish at larger sizes for human consumption. Targeted compliance operations should be organised to examine such behaviour.

5.2.3. Management

Restrict the recreational catch of sea garfish

Sea garfish stocks are at historically low levels, and fishery managers and commercial fishers have introduced many restrictions designed to reduce fishing pressure and promote recovery of the stock (Appendix 3). Recreational fishers in NSW take significant quantities of sea garfish (Henry & Lyle, 2003). Unfortunately, the recreational catch of sea garfish is currently unrestricted in terms of size and bag limits because they are listed as a baitfish species in NSW. It is important that recreational fishers contribute to the recovery of the stocks of sea garfish, and this should be done through the introduction of a bag-limit. Spatial and temporal recreational fishing closures may also be considered. We do not consider size-limit restrictions to be appropriate for sea garfish because of their fragile nature and suspected high discard mortality rates.

Re-open the commercial Estuary General Fishery for sea garfish

The fishery for sea garfish in the Estuary General Fishery was closed in 2003 until 'the fishery has recovered'. However, no index of 'recovery' was prescribed. The Estuary General Fishery had traditionally taken around 10% of the total NSW catch and targeted sea garfish that had entered the estuary from the ocean. This closure was seen as being inequitable and was extremely unpopular with industry. Most fishers affected by the closure were based around the Port Stephens estuary and also target sea garfish in ocean waters. As a result of this closure there has since been a lack of co-operation in research and monitoring. Given that future monitoring of the sea garfish fishery will rely heavily on the co-operation of industry (in terms of accurate catch records and the sampling of landings for size and age composition) we recommend that the fishery be re-opened. Preliminary information for 2004/05 indicates some stock recovery, with a substantial recruitment of fish aged 1+ into the fishery and catch rates being much greater than during the previous few years. As such, the benefits of having a co-operative industry in ongoing monitoring should outweigh any small increase in fishing mortality in the estuary fishery. The Estuary General Fishery may be re-opened under a permit system with a condition of the permit requiring fishers to assist in research and monitoring.

The sea garfish recovery program

Finally, the 'Sea garfish recovery program' (Appendix 3) has implemented some excellent, but restrictive management measures designed to reduce fishing pressure. The general biology of sea garfish suggests that the stock will recover if mortality can be minimised in the short-term and environmental conditions are suitable. The recovery plan should provide for some restrictions to be removed if the stock recovers and abundance increases significantly, so that industry can harvest the resource in an economically and environmentally sustainable manner.

5.3. Planned Outcomes

The planned outcomes of this project were:

- a validated method of ageing eastern sea garfish and river garfish;

Achieved. We validated the technique of using sectioned otoliths to estimate age of sea, river and snub-nosed garfish (Chapter 3). We used several well accepted methods to validate our ageing technique including: (i) staining fish with a vital stain; (ii) marginal increment analyses, and; (iii) examining otoliths from young-of-the-year fish.

- information about the reproductive biology of the two main species, including time of spawning, age (and length) at maturity, initial estimates of growth rates;

Achieved. We successfully defined the spawning seasons, age and sizes at sexual maturity and growth rates of eastern sea, river and snub-nosed garfish in NSW (Chapters 3 & 4).

- information about the habitat requirements, particularly the role of seagrass and other vegetated areas as juvenile nursery areas and as feeding and spawning sites for adults;

Pending. These results will be provided in a separate report by the University of Wollongong.

- information concerning the fishery, including estimates of size, age structure and reproductive state of garfish in commercial landings for the main species;

Achieved. We have comprehensively described the fisheries for eastern sea, river and snub-nosed garfish in NSW (Chapters 2, 3 & 4). Estimates of the size and age composition in landings during the study period have provided baseline information for these species. This baseline information was used in preliminary stock assessments (using per recruit analyses) for these garfish. Information on the reproductive state of garfish in commercial landings has provided fishery managers with an insight into the appropriateness of the selectivity of the gears being used.

5.4. Conclusions

The key objectives of this study involved researching the biology and fisheries for garfish in NSW, and providing information that may lead to improved management of their fisheries. These objectives have been achieved.

The general biology of the three species studied (eastern sea, river and snub-nosed garfish) was fairly typical of the family Hemiramphidae. Each species grew rapidly and reached sexual maturity after approximately 1 year. Maximum ages estimated during the study were 4 years for sea garfish and 7 years for river and snub-nosed garfish. All three species were shown to be multiple batch spawners with asynchronous oocyte development and protracted spawning seasons (at least 7 months). Reproduction involved the production of very large eggs (approximately 2.4 to 2.8 mm in diameter) that were covered with hairs approximately 5-10mm long, that anchored the eggs during incubation. The trade-off for producing such large eggs is that only a small number can be produced at a time.

Sea garfish were observed to recruit to the fishery during their first year, while river and snub-nosed garfish weren't fully recruited until aged 2 years. The fisheries for each species were seasonal because of their distribution and behaviour. The fishery for sea garfish is generally during summer/autumn when they occur in large schools in shallow coastal waters. The fisheries for river and snub-nosed garfish are in estuarine waters, mainly during the winter/spring months when they aggregate in shallow waters to spawn.

In-depth analyses of reported commercial catch and effort information, in addition to preliminary stock assessments based on per recruit models (yield, egg and spawner biomass) using the information determined during this study, allowed some estimation of the exploitation status of the stocks.

Stocks of sea garfish are undoubtedly at extremely low levels. Reported landings and several indices of CPUE have continued to decline and were at historically low levels during the final year of the study (2002/03). Estimates of annual mortality rates were extremely high (i.e. approximately 96% of fish greater than 1 year old die each year) and much of this was due to fishing mortality. Per recruit models indicated that the spawning stock may be as low as 10% of unfished levels. The life-history strategy of sea garfish, in being short-lived with recruitment likely to be dependent upon favourable environmental conditions, means that recruitment failure at this apparent low stock level is possible. The NSW DPI, in conjunction with commercial fishers, have developed a recovery program (Appendix 3) that is mainly designed to reduce fishing pressure on the stock. This reduction in fishing pressure, declaration of sanctuary areas through Marine Parks, and the life-history of sea garfish (having fast growth rates with sexual maturity occurring at around 1 year of age) suggest that the stock should recover if favourable environmental conditions for recruitment occur.

Preliminary information from 2003/04 indicates an increase in the average size of sea garfish landed, and a considerable increase in the index of CPUE of landings per day fishing using the method of garfish hauling. These figures are extremely promising. It is important that the recommendations in this report are adopted and that sufficient resources are made available to monitor the status of sea garfish stocks in NSW.

Stocks of river and snub-nosed garfish may be heavily exploited (commercially and recreationally), but there is little evidence that they are being over-exploited. There are relatively few estuaries of commercial importance and the selectivity of the nets used to catch them appears suitable (i.e. they retain very few juvenile garfish). Indices of CPUE have been stable since 1997/98. These species are restricted to estuarine waters and it is likely that environmental degradation and water quality issues will be important in their management. The second component of this study, to be delivered by the University of Wollongong, should provide information on the importance of different habitats to garfish in NSW.

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7. APPENDICES

7.1. Appendix 1 - Intellectual Property

No patentable inventions or processes were developed as part of this project. The work presented in this report remains the intellectual property of the authors, and they should be acknowledged when citing this work.

7.2. Appendix 2 - Staff

Staff directly employed on this project by the NSW DPI were:
John Stewart – Scientific Officer
Christopher Walsh – Fisheries Technician
Julian Hughes – Fisheries Technician
Darren Reynolds - Fisheries Technician (casual)
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7.3. Appendix 3 - Eastern Sea garfish (*Hyporhamphus australis*) Recovery Program

Eastern Sea Garfish (*Hyporhamphus australis)* Recovery Program

February 2005

NSW DEPARTMENT OF
PRIMARY INDUSTRIES

1. Overview

The Fishery Management Strategy for the Ocean Hauling Fishery (OHFMS) and the associated environmental impact statement (EIS) have identified that eastern sea garfish are likely to be overfished and require a recovery program. This paper provides a brief overview of the eastern sea garfish fishery, identifies current issues affecting the stock, and summarises the objectives and actions that will be taken to recover the stock.

Eastern sea garfish constitute a relatively small, high value fishery in NSW. The fishery has a long history of supply to local markets and, over the last 15 years, has also supplied fish for export. Fishing effort for eastern sea garfish and reported catch levels reached a maximum of 280 tonnes in 1992/93. A significant decline in commercial landings since 1997/98 has prompted concerns about the status of the stock. Catch levels have recently been as low as 15% of the values from the early 1990s and is likely to reflect a decline in abundance of the species.

There is strong evidence that the current size of the eastern sea garfish stock is relatively low, notwithstanding some uncertainty surrounding reported commercial catch statistics and the reason for the decline in catches. In addition to fishing mortality, possible causes include a natural decrease in population size because of unfavourable environmental conditions. However regardless of the reason, a high level of fishing pressure at a low level of abundance might result in a long term, negative impact on the eastern sea garfish stock. Until the status of the eastern sea garfish stock has been assessed as having fully recovered, a precautionary management approach is warranted.

The eastern sea garfish recovery program has been designed to significantly reduce the adverse effects of fishing on the stock. It includes a number of actions that have been implemented recently, such as year-round weekend closures, the restriction of fishers to one ocean hauling region and a change in the operational mesh size from 25mm to 28mm. Future measures to be implemented include limiting the activation of latent effort to ensure that harvest levels do not climb back to unsustainable levels as the stock recovers, and using opportunities to monitor eastern sea garfish stocks.

The recovery program will be refined over time in light of the results of further research and monitoring of eastern sea garfish, any relevant actions required under the forthcoming fishery management strategy for recreational fishing or other relevant material. The Department of Primary Industries will consult the relevant fisheries advisory bodies about any further changes.

2. Status of stock

Although analysis of commercial catch statistics indicated that the fishery was in decline when the fishery management strategy was drafted, there was insufficient information available to determine if the fishery was overfished using accepted formal definitions. These definitions require an understanding of trends in the size and/or age composition of the catch, growth rates and relative rates of fishing mortality and population biomass. In the absence of this information, the fishery management strategy listed eastern sea garfish as overfished/depleted, as a precautionary measure.

Recent research on the life history, reproductive biology and fishery for eastern sea garfish has provided information on growth rates and the sizes and ages of fish in commercial landings. Preliminary reports estimate that fishing mortality is up to 3.5 times greater than natural mortality and that current stock indices are between 10-25% of the unexploited level. Considering the life history of the species, these estimates suggest that the species has been greatly over exploited and has been in danger of recruitment failure.

Several issues may have contributed to the current status of the eastern sea garfish stock, including over capacity in the fishery, retention of fish below optimum size, changes in the efficiency of operations, loss of habitat and environmental dynamics. Additional issues of concern are the reliability of the catch record system and lack of species biological knowledge. The management responses in the ocean hauling fishery management strategy have been designed to address these issues.

3. Fishery and Management Arrangements

Prior to 1995 the fishery was open to any licensed commercial fisher. In an effort to limit fishing effort, access to the ocean hauling fishery and estuary general fisheries has been capped by their declaration as restricted fisheries. At present fishers require a specific endorsement on their commercial licence to use a garfish hauling net and persons assisting must also be endorsed as crew.

The ocean hauling and estuary general fisheries are now in the process of moving from being restricted fisheries to category 1 share management fisheries under the *Fisheries Management Act 1994*. This involves a staged process to issue shares, limit access to shareholders and commence operation under a statutory management plan.
Most of the eastern sea garfish taken by ocean hauling fishers are caught using garfish hauling nets. Currently, 68 fishers are endorsed to use garfish hauling nets in the ocean-hauling fishery. These fishers are spread along the NSW coast with the greatest concentration (40%) now located in region 4 (Diamond Head near Laurieton to Wamberal on the Central Coast). Approximately 320 estuary general fishers were previously authorised to take garfish using bullringing or hauling nets in estuary waters. Approximately 38% of these fishers are also located in region 4. Under the Estuary General FMS, the taking of eastern sea garfish in estuary waters was prevented pending the development of this recovery plan.

Between 1998/99 and 2002/03 catches of eastern sea garfish have averaged approximately 55 tonnes per year. On average, 90% of landings occurred in ocean waters, and 10% in estuaries (primarily in Port Stephens). Most landings of eastern sea garfish occur in ocean waters within ocean hauling Regions 4, 5 and 6. Within the recreational sector, a twelve-month survey of recreational fishing in NSW was conducted in 2000-01 and indicated that recreational fishers in NSW harvested around 23 tonnes of “garfish”, which is most likely comprised of eastern sea garfish and other garfish species to which this program does not apply (including river garfish).

Since commencement of the Ocean Hauling and Estuary General FMS’s a number of management responses have been implemented to address the issues identified as potentially contributing to the current status of the eastern sea garfish stock. Additional management actions are also needed to help promote the recovery of the stock. A description of the existing and future management actions follow.

Management responses already implemented

The taking of garfish prohibited on weekends in ocean hauling fishery (OHFMS *Response 2.5.1 j)*. This management response is designed to reduce fishing mortality by reducing the total number of available fishing days.

New zoning rules for garfish fishers and monitoring the impact of zoning on the harvest of eastern sea garfish (OHFMS *Response 2.5.1 f & g)*. This management response is designed to reduce potential fishing effort by preventing fishers from operating in multiple regions. Zoning rules limit a fisher’s operation to one of seven ocean hauling regions along the NSW coastline. Approximately 10 active fishers were endorsed to operate in more than one region prior to commencement of this response. The Ocean Hauling Management Advisory Committee (OHMAC) has estimated that up to 40% of effort may have been removed in some areas.

Better enforcement of current mesh size for garfish hauling net and evaluation of alternative sizes (*OHFMS Response 2.5.1 i and k).* The permissible mesh size in a garfish hauling net has been 28mm for many years. However, a concession to use 25mm mesh was in place prior to the commencement of the *Fisheries Management (General) Regulation 1995,* and some specific permits were also issued after that time. With the approval of the Ocean Hauling FMS, no further permits are being issued and enforcement of the minimum size has commenced. Additionally the maximum permissible net length has been capped at 300m. The results of a net selectivity study have shown that 25mm mesh retains a large proportion of immature eastern sea garfish, and that at least 28mm mesh is recommended as the most appropriate mesh size for use in garfish haul nets at this time. Future work may be needed to look at ways of further improving the nets to selectively harvest larger size fish in order to increase the yield of the fishery.

Continue the use of transfer guidelines in the ocean hauling fishery (OHFMS *Response 2.3 c)*. Transfer policies prevent activation of latent effort from endorsements which were granted under low entry criteria being issued to new owners and utilised at much higher levels. Current guidelines require that a fishing business contain a catch history of at least 1 tonne of eastern sea garfish taken over at least 8 months during the period 1986 to 1990. Approximately 80% of businesses transferred to date met this minimum requirement.

Continue existing programs on garfish assessment and monitoring and where appropriate expand those programs (OHFMS *Response 2.5.2 l)*. A two and a half year study, funded by Fisheries Research and Development Corporation, University of Wollongong and NSW Fisheries, commenced in December 2001. The study will provide, among other things, age and growth estimates of eastern sea garfish that will be used to inform assessments of the stock status of the species. Estimates of growth rates, the sizes and ages in the fishery and the reproductive biology of garfish will be used to determine an appropriate harvest size for garfish.

Prevention of taking of sea garfish in the estuary general fishery during development of recovery program (EGFMS Response 2.5.2 a). A closure is currently in place that prevents commercial fishers taking sea garfish in all estuary waters. Estuary waters have historically accounted for less than 10% of the overall catch. Some estuarine garfish hauling areas are located over *Posidonia* seagrass beds where hauling methods have been prevented under other responses in the management strategy (See EGFMS Response 1.2 a (i)).

Remove the method of garfish bullringing from the ocean hauling fishery (OHFMS Response 2.5.1e). This method is not a historical ocean hauling method and produces an inferior product by meshing fish. It is believed that improving the quality of the eastern sea garfish catch in this way should promote better market prices.

Future Management Responses

Continue prevention of taking of sea garfish in the estuary general fishery, other than in conjunction with research or monitoring.

The general provision prohibiting the taking of sea garfish in the estuary general fishery will remain until it is determined that the resource has adequately recovered and that the stock can sustain additional fishing effort, or alternate long-term management arrangements for the estuary fishery are developed.

However, to assist in collecting information on the fishery and monitoring stock status in the meantime, a limited number of permits to take sea garfish will be issued for specific estuarine areas. The aim of the permit scheme is to improve the scientific information on eastern garfish stocks and the fishing activity by:

- quantifying the sizes, species composition and rates of the retained and discarded catch
- validating the accuracy of reporting using standard monthly returns and the proposed daily logbook
- comparing the catch composition of sea garfish caught in estuary waters with those caught in the ocean hauling fishery, and
- documenting the interaction with fish habitats and threatened species.

Any permits issued will be subject to conditions requiring additional monitoring and requiring the permit holder to carry, or co-operate with, an authorised scientific observer. Permits will be revoked if these conditions are not complied with.

See also Section 4 'Monitoring Arrangements' below.

In the ocean hauling fishery, identify the level of active effort for the garfish hauling net and implement appropriate minimum shareholdings.

Comparison of the annual catch per fisher before recent declines indicates that active fishers, on average, took in the order of 2 to 6 tonnes per year, although averages in the boat based sector have historically been up to 10.3 tonne per fisher.

Since 1998/99, on average, 25 Class A - Garfish Hauling endorsement holders per year indicated that they participated in the fishery to any degree. Only approximately 46 have participated at any time over the 5 years 1998/99 to 2002/03 despite more than 80 garfish endorsements being present in the fishery at the time. Of those participating only 40% caught more than 1 tonne per year. Even before recent declines and limitation of access, on average, less than 40 fishers accounted for 90% of the catch.

To prevent the activation of latent effort within the fishery it is proposed that minimum shareholdings be set through the share management plan at a level to reflect activity levels immediately before approval of the Ocean Hauling FMS. The Ocean Hauling MAC has discussed this proposal and indicated its in-principle support, whilst noting that any minimum shareholdings should be set on a regional basis considering the potential catch and effort within the area. The Ocean Hauling FMS (management response 4.3a) provides for such arrangements to be developed.
This action is designed to limit the potential effort that can be applied to the fishery in the event that the stock recovers.

Develop an index of relative fishing power between boat-based and beach-based hauling and introduce appropriate management controls based on the differences in fishing power(OHFMS Response 2.2i).

A definition of the relative fishing power between beach and boat based methods can be used to correct for differences in fishing power and adjust minimum share levels that define access. This will require differentiation between beach and boat based hauling.

Comparing calculations of catch per fisher indicates that overall boat-based fishers achieve greater than twice the annual catch of beach fishers (Smith, K.A. 2002).

It is therefore proposed that within the share management plan, the minimum shareholding necessary to participate in boat-based garfish hauling should be set at twice the minimum level set for participation in the shore based sector of the garfish fishery, having regard to region specific issues. Endorsement holders with insufficient shares to conduct boat based operations will be limited to waters adjacent to a beach within 200m of the low tide mark.

The Ocean Hauling MAC has discussed this proposal and indicated its in-principle support, whilst also indicating that any measures should be implemented on a regional basis considering the potential catch and effort within the area. Depending on the outcome of the share allocation and management plan development processes, options to set differing shareholdings for a particular region or for existing operators can be considered. This action will address the increases in effective effort that occurred as beach fishers adopted more efficient boat-based hauling methods.

Develop appropriate actions for the recreational fishery during development of the recreational fishery FMS/EIS.

Eastern sea garfish are currently listed as a 'bait' species and as such is not subject to a recreational bag limit. Actions to address the 'overfished' status of the stock that are commensurate with the recreational harvest of the eastern sea garfish will be developed as part of the process of preparing a recreational fishery management strategy and associated environmental assessment.

A bag limit of 20 has been suggested by the Advisory Council on Recreational Fishing (in the context of the existing commercial fishery management arrangements) and is being considered as part of the bag and size limit review process.

4. Monitoring Arrangements

Under the Ocean Hauling FMS, commercial fishers will continue to submit records on a monthly basis detailing their catch and fishing effort (management response 8.2a). The information includes total landed catch for each species, the effort expended (for each method) to take the catch (i.e. days fished), and the area/s fished. This information will enable analyses of fishing catch and effort levels.

There are a number of management responses under Goal 4 of the Ocean Hauling FMS to improve the quality and reliability of the information provided, including a review of the current catch returns and validation of catch and effort data under the proposed scientific monitoring program.

Daily logbook

A logbook to capture daily catch and effort information to assist in monitoring and assessment of the fishery for eastern sea garfish will be introduced on a trial basis. Information reported on a daily basis would allow for calculation of more accurate catch per unit effort (CPUE) and provide greater detail on the fishing practices of fishers targeting garfish. This information will be used to check the accuracy of the information provided on the standard monthly return and evaluate the level of data collection needed for the longer term.

Commercial catch composition

Ongoing monitoring of commercial landings undertaken by the NSW Department of Primary Industries either through the observer program or through port monitoring will be used to collect information on the size and age composition of fish taken in the fishery.

5. Review

An annual fishery performance review is the formal mechanism for monitoring the performance indicators in the approved fishery management strategies. As part of this process information on commercial catches will be collated and assessed against trigger points.

Restrictions to commercial fishing activity outlined in this recovery program should have the desired effect of reducing fishing mortality. It is unlikely that landings or catch rates will climb to historical highs even if the stock recovers.

Targets for recovery of the eastern sea garfish resource will be developed in consultation with key stakeholder advisory bodies once the results of the recent 2½ year research program on sea garfish have been finalised, and those targets will form part of the recovery program.

The following parameters will be assessed for use as performance indicators for eastern sea garfish whilst the recovery program is in effect, having regard to the limitations of catch per unit effort as noted in Part 9, section F of the Ocean Hauling Fishery Management Strategy.

Catch per Unit Effort

CPUE (catch per boat day): Catch per fisher and more importantly catch per boat day can be determined from the proposed daily logbook and the new monthly returns.
CPUE (catch per shot): Catch per shot can be determined using monthly returns and validated from the daily logbook.

Length frequency monitoring

Proportion of the catch >25cm Fork Length (FL): Fish greater than 25cm FL are graded as extra large (XL). They are the fish that are most targeted and tend to gain the highest market prices.

Proportion of the catch <20cm FL: This indicator will be used to monitor the impact of removing 25mm mesh from the fishery. It is predicted that fishers who previously used 25mm mesh should catch fewer juvenile eastern sea garfish (<20cmFL). Assuming no differences in the sizes of fish available, it is expected that fewer than 5% (by numbers) of total landings will be less than 20cm FL.

Combinations of CPUE and Length frequency

These will be calculated from the catch and effort information recorded in the daily logbook and monthly catch returns with the length frequency information from monitoring of retained fish. Any increase in abundance of large fish (due to good recruitment and decreased fishing mortality) should be reflected in a greater CPUE for XL fish. CPUE for small fish will be used to: (i) examine the initial impact of an increase in mesh size, and (ii) be used as an ongoing index of recruitment.

Age Composition of landings

Despite an estimated maximum age of 4 years, the commercial fishery has been based almost exclusively (97%) on fish aged less than 2 years old. It is expected that following years of good recruitment and reduced fishing mortality that there will be an increase in the proportion of fish aged 2 years and greater in landings. It is anticipated that if fishing mortality is reduced to be similar to natural mortality (see Deriso, 1987), then following several years of good and constant recruitment that at least 10% of the catch should be of fish aged 2 years and greater.

Further Reading

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7.4. Appendix 4 - Determining an optimal mesh size for use in the lampara net fishery for eastern sea garfish (*Hyporhamphus australis*).

Fisheries Management and Ecology, 2004, **11**, 403 410

Determining an optimal mesh size for use in the lampara net fishery for eastern sea garfish, *Hyporhamphus australis*

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Abstract The selection properties of three experimental mesh sizes were examined in the lampara net fishery for eastern sea garfish, *Hyporhamphus australis* (Steindachner), in New South Wales, Australia. The sizes of fish retained in 25-, 28- and 32-mm mesh nets were compared with those retained in a control 12-mm mesh net. The 25-mm mesh net retained significant numbers of immature *H. australis*, the 28-mm mesh net retained predominantly only mature fish and the 32-mm mesh had very low catch rates. Catch rates decreased linearly with increasing mesh size and there was a significant linear relationship between mesh size and the 50% selection size (L_{50}). Given this species is being overfished, the 28-mm mesh size is recommended as the most appropriate for use in the fishery.

KEYWORDS: garfish, halfbeaks, *Hyporhamphus*, lampara net, mesh size, selectivity.

Introduction

Eastern sea garfish, *Hyporhamphus australis* (Steindachner), is distributed from southern Queensland, throughout New South Wales (NSW) and eastern Victoria, Australia (Kailola, Williams, Stewart, Reichelt, McNee & Grieve 1993). It is a highly mobile, small, pelagic species growing to a maximum size of 45 cm, fork length (FL) (Grant 1991). In NSW, *H. australis* forms the basis of a small, but lucrative, seine or haul fishery that supplies fish for human consumption to local and export markets. Landings of *H. australis* have declined from an average 200 t yr^{-1} during the early 1990s to an average of 47 t yr^{-1} since 1999/2000. An index of catch per unit effort (kg per fisherman for the top 10 fishermen each year) also declined more than 40% during the same period, prompting serious concerns for the status of the stock. *H. australis* is currently listed as overfished, and is the first commercially harvested species in NSW to have a recovery programme to address this status. This recovery programme aims to reduce fishing mortality and to protect juveniles so that they have the chance to spawn at least once before being recruited into the fishery. Either setting a minimum legal size limit or regulating the selectivity of the nets through mesh sizes can achieve both of these objectives. A minimum legal size limit is unlikely to be practical for a species such as *H. australis*, which is fragile and unlikely to survive being captured and released.

Hyporhamphus australis is targeted by two commercial fishing groups: (i) beach-based fishermen who use boats to encircle schools of fish with their haul nets and retrieve them onto the beach; and (ii) boat-based fishermen who actively seek schools of fish, aggregate them by feeding with bran, encircle them and haul the net back to the boat. Boat-based fishing is considered to be much more efficient than beach-based and lands the majority of the catch. Boat-based fishing is generally done from boats smaller than 6 m and generally with a crew of two. The nets used are of a lampara type, designed to fish the surface layers. Net lengths are currently unspecified but generally have wings of up to 150 m with a drop of around 7 m. A pocket (or bunt) of around 6 m is sewn into the middle of the net. A rope of not more than 300 m can be used to close the net and herd fish towards it. This is a daytime fishery and the nets are hand-hauled with the wings acting to herd fish into the bunt.

It is assumed that any mesh size selectivity in lampara type nets occurs once fish are confined to the bunt section. These nets have a legal permissible mesh size in the wings and bunt of not less than 28 mm. However, in 1985 the NSW Fisheries

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Department issued a special concession permitting a tolerance of 3 mm, effectively allowing the use of 25 mm mesh. Many have used this 25 mm mesh, arguing that the 28 mm mesh damages larger export-quality fish. There is, however, evidence to show that this smaller mesh retains large numbers of sexually immature, low value *H. australis* (Smith 2002), and it is important that the appropriateness of these two mesh types (25 and 28 mm) is assessed, given the status of the stock.

While previous studies have described the selectivity of general haul nets (e.g. Gray, Larsen & Kennelly 2000), no such studies have been carried out on the boat-based lampara type nets. It is generally accepted that the selectivity of a haul or seine net is determined by fish behaviour and the ability to fit physically through the meshes. Methods used to estimate the selectivity for trawls and hauls include alternate hauls, covered cod-ends and trouser trawls (Wileman, Ferro, Fonteyne & Millar 1996; Millar & Fryer 1999). The lampara type net used in the fishery for *H. australis* precludes the use of a trouser trawl arrangement and logistical difficulties preclude the use of any covered cod-end design. Catch rates and selection properties of three different mesh sizes (25, 28 and 32 mm) in the bunts of garfish hauling nets were thus estimated using alternate hauls. This information, along with estimates of the numbers of fish becoming meshed in each mesh size, were used to recommend an optimal mesh size for use in this fishery.

Materials and methods

This study was carried out by chartering a commercial boat to fish on known commercial garfish grounds near Currarong and Jervis Bay (150°50′ E, 34°59′ S) for 10 days between 24 March and 4 April 2003.

A standard commercial garfish haul net was used. The wings of this net consisted of 25 mm mesh, were 60 m long and tapered from 7 m (where they joined the bunt section) to 0.3 m. Four experimental bunt sections, each with different mesh sizes, were built with configurations similar to those nets used in the commercial fishery. Each bunt section had a headrope length of 11 m with the meshes hung at a ratio of 70%, a footrope length of 1.9 m with the meshes hung at a ratio of 50%, and a depth of 7 m. The four mesh sizes used were 12 mm (referred to as the control mesh), 25 mm and 28 mm (which are used in the fishery), and 32 mm. The mesh used in each experimental bunt was knotted, six-ply, 210D (as is used in the commercial fishery), while the control 12 mm mesh was knotted, four-ply, 210D. Zips were sown along the end of each wing section and onto the end of each experimental bunt section to allow for quick, easy changing of the bunts. A 100 m length of rope was attached to one end of a wing section to herd the fish and to close the net.

The sizes of 20 randomly selected meshes for each bunt were measured prior to the experiment and again at the completion to check for shrinkage or expansion. Meshes were measured as the stretched length between inside knots using a standard net measure of 1810 g (in accordance with local fisheries regulations).

Sampling protocol

On each fishing day, fish were sighted and aggregated using bran. When sufficient fish were feeding the net was deployed by dropping a buoy attached to one end of the net, running the boat around the fish while paying out the net, picking up the buoy and hand-hauling both wings until the bunt was brought to the side of the boat and the fish secured. The bunt was lifted aboard and the catch emptied into an ice-slurry. Any fish stuck in the mesh of the bunt were removed, identified as being caught by the gills or around the middle of the body, and kept separate for later counting and measuring.

At the completion of each fishing day the catch was processed. The total mass of each haul was recorded and the fish measured (FL to the nearest half centimetre rounding down). In cases where the catch was too large to measure each fish, the catch was subsampled by measuring fish from a random scoop of between 5 15 kg.

Alternate hauls using the control, 28 and 32 mm meshes were carried out over 5 days (25 28 and 31 March). The order of these three mesh types was randomised in blocks of 3 and as many hauls as possible were made each day.

Alternate hauls were carried out using the two mesh sizes used in the fishery (25 and 28 mm) and the control mesh each day between 1 and 4 April. The order of these hauls was randomised in blocks of three as in the previous trials.

Fitting selectivity curves

The selectivity experiment was a comparative (indirect) one in which estimates of selectivity were made by comparing the sizes of fish captured in 25-, 28- and 32-mm mesh bunts with those captured in the control mesh bunt. The size distribution of the catch retained in the 12-mm mesh bunt was assumed to be representative of the fish available during the experiment.

The SELECT (Share Each LEngth's Catch Total) model (Millar 1992; Millar & Walsh 1992; Wileman *et al.* 1996) was used to fit data to logistic functions. Because there were relatively few replicate hauls of each mesh size, a combined-hauls approach (Wileman *et al.* 1996) was used where the combined catch data from all replicate hauls were analysed as if they were taken from a single haul. There were unequal numbers of hauls for the experimental and control nets, so the split parameter P was estimated for each analysis. Between haul variability was examined from paired hauls performed within a block of three hauls using the replication estimate of dispersion (REP) (Wileman *et al.* 1996). Only those length classes where the proportion of the catch taken in the experimental mesh net was between 0.1 and 0.9 of the total catch were used, and the standard errors of the parameters from the combined hauls adjusted by multiplying by the square root of the dispersion parameter.

Results

Thirty-one hauls were completed, 10 with the 12-mm mesh, five with the 25-mm mesh, 10 with the 28-mm mesh and six with the 32-mm mesh. Of these, four hauls of the 25-mm mesh, nine hauls of the 28-mm mesh and five hauls of the 32-mm mesh could be paired with hauls of the control mesh (i.e. were done in a randomised block of three hauls).

Catch rates (average number of fish caught per haul) decreased linearly with mesh size (mm) according to:

$$Catch\ rate \quad 55.735 \times mesh\ size + 1809 \quad r^2 \quad 0.99$$

There were significant differences in catch rates between the bunt types (one-factor ANOVA, F 4.32, P 0.01). The control bunt caught significantly more *H. australis* (mean ± SE of 1079 ± 349), than the 25-mm bunt (401 ± 84), which caught more than the 28-mm bunt (177 ± 96), which caught more than the 32-mm bunt (33 ± 22) (Student Newman Keuls tests, α 0.5).

Selection properties of experimental bunts

Combined hauls. The combined data from all hauls (see Fig. 1) for each mesh type were fitted to the logistic model (Table 1). The standard errors for the parameters L_{50}, SR and P were adjusted by multiplying by the square root of the REP values from Table 1. There were significant differences between the combined haul selectivity parameters (L_{50} and SR) when compared simultaneously between each mesh type (Wald tests, $P < 0.001$ in each case, Kotz, Johnson & Read 1996).

Table 1. Logistic curve parameter estimates (with standard errors) for the combined hauls analyses. L_{50} is the size at 50% retention in centimetre fork length. Selection range is the number of centimetres between the 25 and 75% retention sizes. REP is the replication estimate of dispersion

Mesh size	25 mm	28 mm	32 mm
No. hauls	5	10	6
L_{50}	18.8 (1.68)	20.1 (0.10)	24.54 (2.15)
Selection range	2.71 (2.08)	1.095 (0.87)	2.56 (1.09)
P (fishing efficiency)	0.2684 (0.10)	0.385 (0.16)	0.191 (0.09)
Model deviance	182.99	142.83	82.19
d.f.	41	41	42
REP	24.0	13.0	2.7

There was a significant linear relationship between the mesh size and the estimated selection size (L_{50}) for each bunt type:

$$L_{50} \quad 1.037 \times mesh\ size \quad 8.767, \quad r^2 \quad 0.997$$

Meshed fish. Net wings. There were no significant differences in the average numbers of *H. australis* meshed per haul in the wings of the nets for each experimental bunt type (one-factor ANOVA F 1.41, P 0.26). There were no significant differences in the size distributions of fish meshed in the wings of the 25 and 28-mm bunts, and only slight differences between these and the sizes of fish meshed in the wings of the control and 32-mm meshes (Fig. 2, Kolmogorov-Smirnov tests, P 0.05). This suggests that overall, schools of similar sizes and numbers of fish were encountered when using each mesh type.

Bunts. There were significant differences between the proportions of the catch being meshed in each of the four different mesh sizes (chi-square test, $P < 0.005$). Tukey-type multiple comparison tests (α 0.1) ranked the proportions of the catch being meshed in each mesh size as: control (0.0005), < 25 mm (0.36), < 32 mm (0.485) and < 28 mm (0.581).

The sizes of fish meshed in each bunt type were significantly different from each other (Kolmogorov Smirnov tests P 0.05), with the average size of fish meshed increasing with increasing mesh size (Fig. 3). Of those fish meshed in the experimental bunts, the ones caught by their gills were, on average, slightly larger than those caught around their bodies.

Mesh sizes and bunt configurations. Measurements of the meshes before being used showed that they differed from the manufacturers specifications by

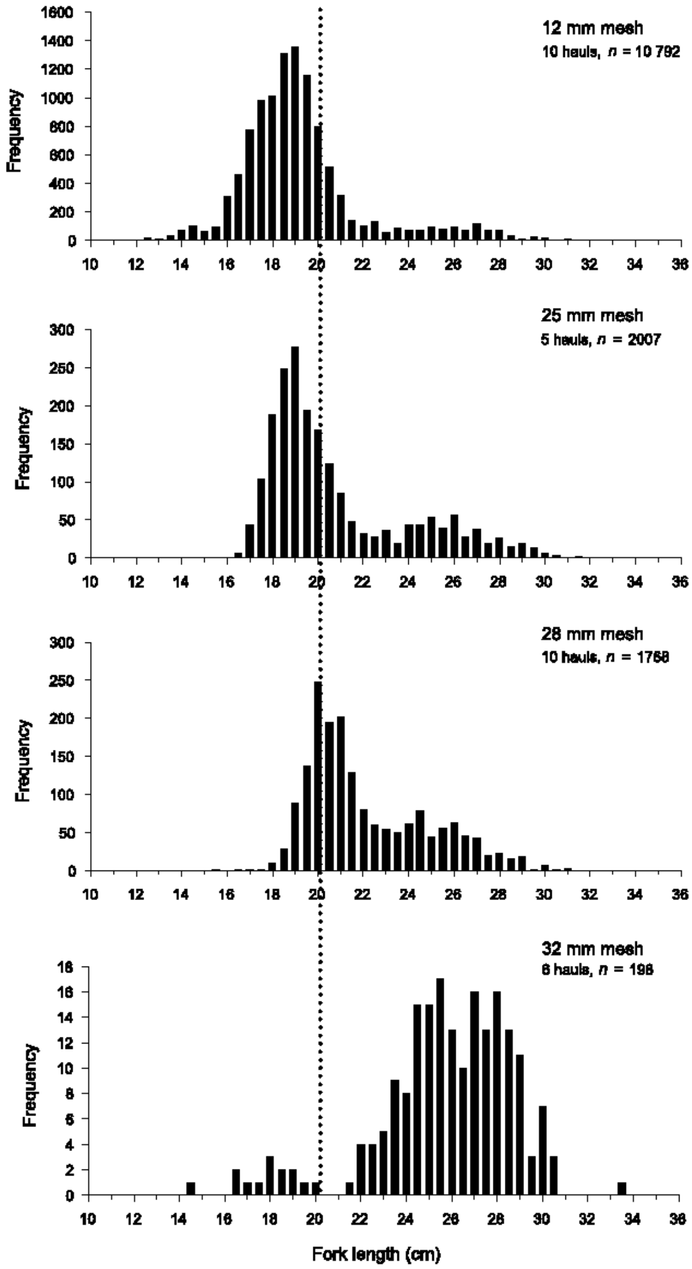

Figure 1. Length frequency of *H. australis* captured in each of the experimental mesh bunts. The dotted line indicates the size at 50% sexual maturity for *H. australis*.

Table 2. Mean mesh sizes (with SE) used in the experiment

Mesh size	Marketed size (mm)	Size at start (mm)	Size at end (mm)
Control	12	13.0 (0.16)	15.0 (0.12)
25 mm	22 (7/8″)	26.4 (0.12)	26.6 (0.11)
28 mm	25 (1″)	28.1 (0.26)	28.2 (0.14)
32 mm	28 (1 1/8″)	32.0 (0.27)	33.5 (0.17)

between 8 and 20% (Table 2). Further increases in mesh size of between 0.4 and 15.6% were found at the conclusion of the fieldwork, presumably because of stretching. Further increases of around 5% were observed after being soaked for 10 min.

The hanging ratios along the headropes at the completion of the study differed slightly between mesh types. The hanging ratios of the three experimental bunts varied between 0.69 (28-mm mesh), 0.71 (25-mm mesh) and 0.77 (32-mm mesh) and the hanging ratio of the control bunt was 0.92. These differences were not considered to have had a major impact on the selection curve parameters (see below).

Discussion

This study is the first to document the size selection characteristics of a lampara type net used for targeting members of the family Hemiramphidae. Information on catch rates and the selectivity of four different mesh sizes can now be used, with knowledge of the biology and fishery for *H. australis*, to recommend the most appropriate mesh size to be used in the fishery. This is a highly targeted fishery with very little by-catch (personal observation) and any change in mesh size is unlikely to create any complicating by-catch issues.

Catch rates were directly related to mesh size with the greatest catch rates being obtained using the smallest mesh bunt. These differences can largely be attributed to the selection properties of the meshes. There is no discarding of *H. australis* in this fishery, with markets for bait existing for small fish and markets for human consumption for the larger fish. The stock of *H. australis* off the coast of NSW is in serious decline and listed as overfished. As such, fishery managers wish to reduce fishing mortality and mesh regulations should address this issue.

Hyporhamphus australis becomes sexually mature at around 20 cm FL in NSW (unpublished data). The 25-mm mesh retains many fish smaller than this (see Fig. 1) and so may not be appropriate in this fishery. The 28-mm mesh selects 50% of fish at 20.1 cm and is therefore well tuned to protect a large proportion of juveniles. The 32-mm mesh does not retain juveniles, but may not be appropriate in this fishery because of the low catch rates and damage to export quality fish through meshing. Consequently, of all the mesh sizes tested in the present study, the size-selectivity of the 28-mm mesh is considered the most appropriate.

The selection range estimated for the 28-mm mesh, for which the most data were available, was estimated to be only 1.095 cm. The narrow selection ranges estimated for each mesh size (Table 1) suggest that selectivity in this fishery is relatively knife-edged. Jones (1982) also found narrow selection ranges for the closely related *Hyporhamphus melanochir* (Valenciennes) in 32-mm mesh nets using a covered codend designed experiment. This relatively knife-edged selectivity is not surprising given the long slender shape of these species and the slow rates at which the nets are hauled. Consequently, it should be possible to design a mesh size in this fishery that is finely tuned to exclude fish of any given size.

Previous work on mesh selectivity of gears demonstrated linear relationships between L_{50} and mesh size (Pope, Margetts & Hamley 1975; Perez Comas & Pikitch 1994). Although there was a linear relationship between the estimated L_{50}s and mesh sizes, which may be used to predict the selection sizes of different mesh sizes in lampara haul net bunts, it was based on three data points so should be viewed with caution. However, for relatively small fisheries such as this one (averaging around AUS$ 300 000 yr^{-1} at the point of first sale since 1997), it may not be economically viable to repeat such studies and this relationship may need to be used as a rough guide to estimate the impacts of any future mesh size changes.

High rates of meshing for all mesh sizes tested (excluding the control mesh) were observed. Fishermen do not want their nets to act as gill nets because meshing the fish damages them, often to an extent that they cannot be marketed for human consumption. Unmeshing fish also slows the fishing operation and may reduce the number of hauls made each day. Six-ply mesh was used in this experiment, which is in general use in the fishery. Many studies have demonstrated that increasing twine diameter decreases the likelihood of gilling fish (e.g. Hovgard 1996; Holst, Wileman & Madsen 2002). Future work should examine the effect of twine thickness on meshing rates and size selectivity in this fishery.

In this study, each of the bunts was designed to be the same and the same wings were attached by zippers in an attempt to create equal fishing efficiencies between gear types. However, meshes can both stretch

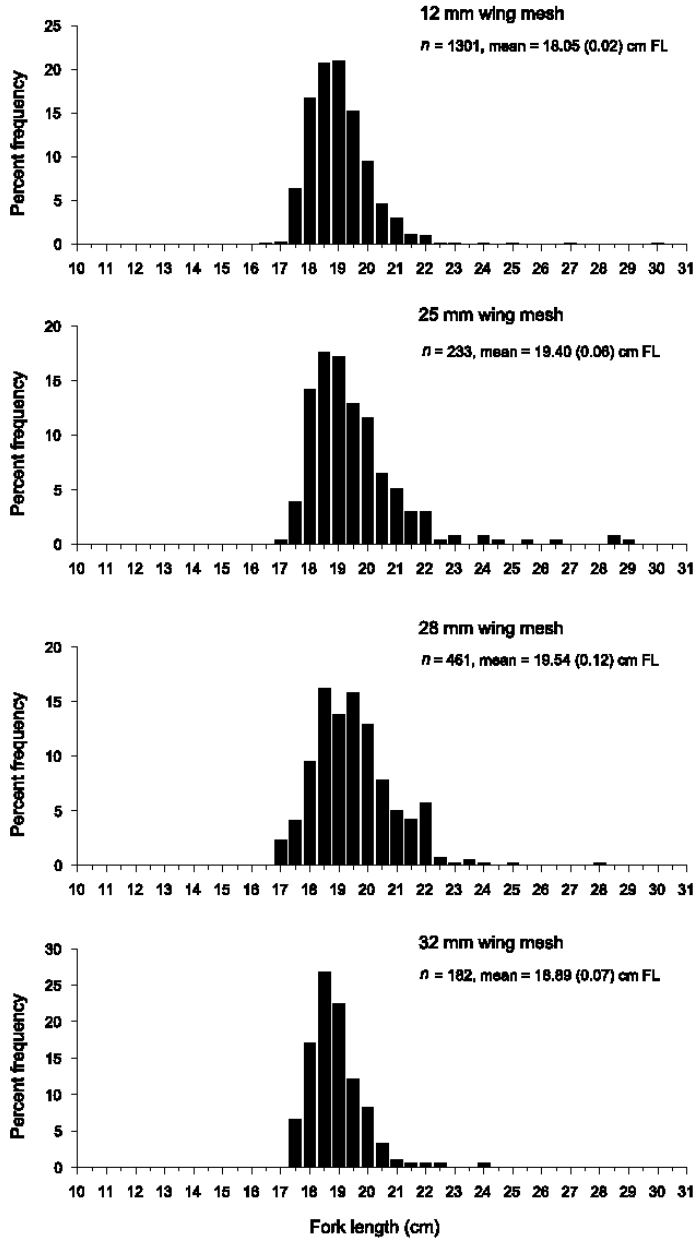

Figure 2. Length frequency of *H. australis* meshed in the wings of the net for each bunt type.

and shrink depending on conditions and as such the working hanging ratios of nets are difficult to define accurately. Measurements at the completion of the study showed that the hanging ratios on the headropes differed slightly, with the control net (0.92) being greater than the 25-mm (0.71), 28-mm (0.69) and the

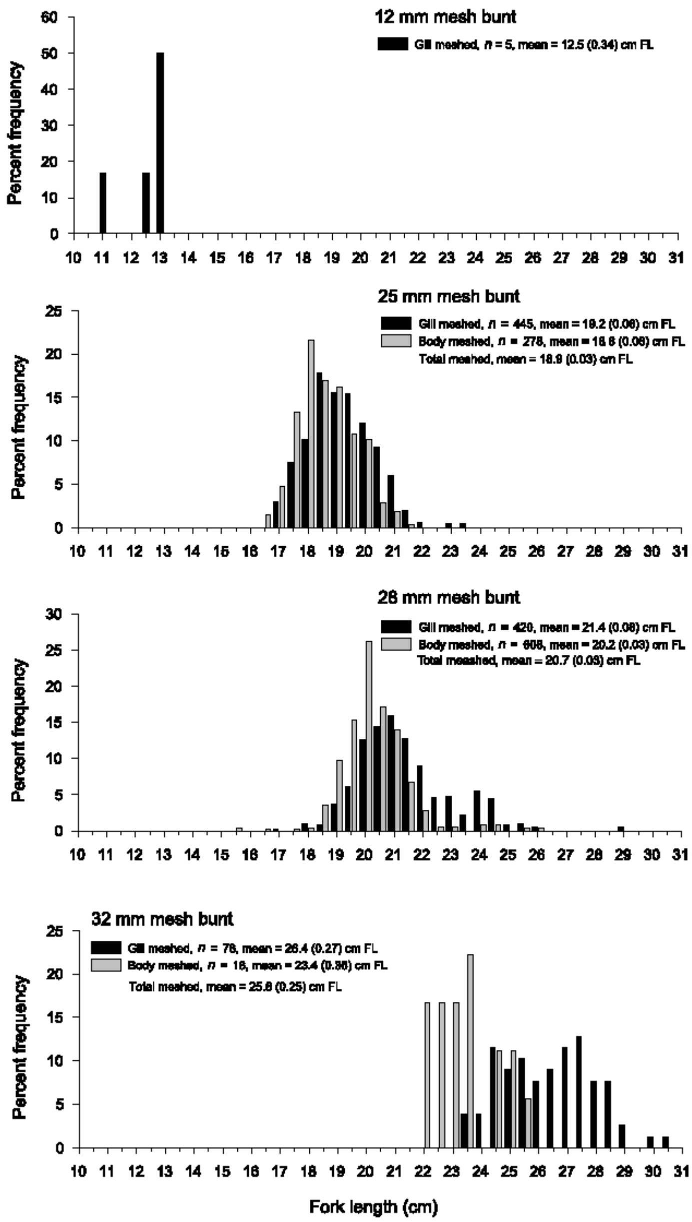

Figure 3. Length frequency of *H. australis* meshed in the bunts for each mesh type.

32-mm (0.77) experimental nets. This was not considered to be a major problem as the control bunt appeared to retain all fish encountered and therefore acted as a good control. The slight differences between the experimental bunts may have affected their fishing configurations (Shin, Imai, Fuwa & Ishizaki 1999) and this should be considered when comparing results. Few studies report on the hanging ratios at the completion of fishing experiments, but they are important in determining mesh selectivity (Hamley 1975; Samaranayaka, Engas & Jorgensen 1997) and should be discussed.

This study provided a better understanding of the selectivity of lampara type haul nets. The results on catch rates and size selectivity for different mesh types will be directly applied to the management of the fishery for *H. australis* in NSW. Rates of meshing in the commercial fishery should be quantified and, if found to be high, research needs to be carried out into ways of reducing meshing rates.

Acknowledgments

Dr Matt Broadhurst and Damian Young of the Conservation Technology Unit, Coffs Harbour helped in the design of the experiment and analyses of the results. We thank Russell Millar for help in analysing the selectivity data. Commercial fishers Phil and Paul Zaccagnini provided their expertise in finding and catching the fish. Dr Steve Kennelly provided useful comments on the manuscript.

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