Sampling estuarine fish species for stock assessment

C.A. Gray, B.C. Pease, S.L. Stringfellow, L.P. Raines, B.K. Rankin, T.R. Walford

NSW Fisheries Research Institute
P.O. Box 21, Cronulla, NSW, 2230
Australia

FRDC Project No. 94/042

March 2000

NSW Fisheries Final Report Series
No. 18
ISSN 1440-3544

Sampling estuarine fish species for stock assessment

C.A. Gray, B.C. Pease, S.L. Stringfellow, L.P. Raines, B.K. Rankin, T.R. Walford

Includes Appendices by

D.J. Ferrell

B.C. Pease, T.R. Walford

G.N.G. Gordon, C.A. Gray, G.W. Liggins

NSW Fisheries Research Institute
P.O. Box 21, Cronulla, NSW, 2230
Australia

FRDC Project No. 94/042

March 2000

NSW Fisheries Final Report Series
No. 18
ISSN 1440-3544

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

ACKNOWLEDEMENTS

This study would not have been successful without the continued support of estuarine commercial fishers in NSW, in particular those that cooperated with the sampling of commercial catches in the Richmond and Clarence Rivers, Wallis, Macquarie, Tuross and Wallaga Lakes, Port Stephens and St. Georges Basin and those that participated in the voluntary logbook. The managers, staff and processors at the various Fishermen's Cooperatives and the staff at the Sydney Fish Markets assisted with the logistics of sampling.

Numerous technical and field staff assisted with sampling commercial catches (including many late nights and early mornings at the Sydney Fish Market), processing and aging otoliths and sampling juvenile fishes; notably Samantha Stringfellow, Leeanne Raines, Brett Rankin, Venessa Gale, Adam Schmaltz, William MacBeth and Deannea McElligott. Glen Cuthbert, Martin Tucker, Fiona Staines, John Staines and Gavin Edmonson helped sample catches in the field.

Bruce Pease and Trudy Walford conducted the logbook component of the study.

Philip Gibbs and Kevin Rowling provided logistic support throughout the early and late stages of the project, respectively. Many other people at the Fisheries Research Institute assisted in a plethora of ways; thank you all.

The report was improved by the reviews of Kevin Rowling, Rick Fletcher and the anonymous referees.

NON-TECHNICAL SUMMARY

94/042 Sampling estuarine fish species for stock assessment

PRINCIPAL INVESTIGATOR: Dr Charles Gray

ADDRESS: NSW Fisheries Research Institute
PO Box 21, Cronulla, NSW, 2230, Australia
Telephone: 02 9527 8411; Fax: 02 9527 8576
Email: grayc@fisheries.nsw.gov.au

OBJECTIVES:

1). To investigate standard methods for independently sampling fish stocks in estuaries.

2). To determine adequate sample sizes for providing the breakdown of the age and sex composition of the major estuarine fish species.

3). To determine variability in age, length at age and sex composition of commercial catches of the main estuarine fish species at the major landing locations along the NSW coast over a two year period.

4). At each location, to determine the variability in age and sex composition between ocean caught and estuarine caught fish.

5). In association with industry, to determine and begin implementation of an efficient logbook system to monitor daily catch and effort of individual fishers at these locations.

6). To advise industry on the means of assessing estuarine fish stocks through explanations of the data requirements and of how these data are used. This would involve regular visits to regional areas to show the results of data collection and analysis. The aim would be to make the process as transparent as possible and the data as useful as possible to industry. It is hoped that in the future industry will be encouraged to play a major role in supporting longer term stock assessment projects.

NON TECHNICAL SUMMARY:

Estuarine fishes in NSW are exploited by commercial and recreational fishers and are subject to significant pressure from habitat degradation. The NSW commercial estuarine finfish fishery is highly complex as it is based on multi-species and many fishers using a variety of methods. Furthermore, there is very little biological information on which to assess the status of these stocks. Four key species were identified for investigation: yellowfin bream (*Acanthopagrus australis*), sand whiting (*Sillago ciliata*), dusky flathead (*Platycephalus fuscus*), and luderick (*Girella tricuspidata*).

Sampling of young (recently settled) juvenile fishes was used to assess recruitment variability in estuarine fishes. Quantitative sampling across several estuaries identified latitudinal gradients in the timing of recruitment of sand whiting, bream and luderick to estuarine habitats. The relative abundance of young fish

varied greatly among sites within an estuary as well as between estuaries. Future sampling of juvenile fishes to obtain indices of recruitment would need to be done over extended periods of time and across many locations within an estuary and estuaries and would therefore be relatively costly.

Sampling of commercial catches of the four target species across several estuaries identified spatial, temporal and gear-related patterns in the sex, size and age compositions of catches. Initial assessments of the fisheries for each species were made:

Bream: The majority of bream retained in commercial estuarine mesh net, haul net and fish trap operations were just over legal size, between 22-25 cm FL, and approximately 60% of the landings was comprised of females. This pattern was relatively consistent across all gear types, estuaries and throughout time and was also evident in ocean beach haul net catches. Despite this, the corresponding age structures of catches varied greatly. For example, bream captured in the Clarence River in 1997 were predominantly between 4 and 8 years old, whereas those caught in St. Georges Basin were primarily 3 and 4 years old. There was considerable variation in the size of bream at any given age, and thus fish length was a poor indicator of fish age. The data collected indicate that the bream stock in NSW is based on several year classes, but the predominance of any particular year class varied substantially between locations and throughout time. Continued assessment of the age structure of the bream stock is recommended.

Dusky flathead: Dusky flathead are primarily captured by mesh nets, and the size composition of catches was a function of the mesh size used. The 70 mm flathead nets used in Wallis Lake retained on average, smaller fish than the general purpose 80 mm mesh nets used in the Clarence River. The fishery for dusky flathead was primarily based on female fish, with females contributing approximately 95% of landings in the Clarence River, 70% in Wallis Lake and 60% in Lake Macquarie and St. Georges Basin. Female fish grew faster and attained a greater maximum size than males. Commercial catches were dominated by young fish, primarily between 2 and 4 years old, suggesting that the species is subject to a high total mortality. Because of this and the recent development of an export market which provides fishers with greater prices than traditionally obtained, continued assessment of the fishery is warranted.

Sand whiting: The size composition of commercial landings of sand whiting differed greatly between mesh and haul nets. Fish retained in haul nets were generally just above legal size with most in the range 25-30 cm FL, whereas those retained in mesh nets were considerably larger, the majority being between 30-35 cm FL. This pattern was consistent across estuaries and time periods. Several year classes contributed to the sand whiting fishery in each estuary, but the dominance of any particular age group varied between gear types and estuaries. Haul net landings generally contained fish between 2 and 5 years old, whereas those in mesh net landings were predominantly 3 to 7 years old. There was substantial variation in the size at age of sand whiting, and future age-based assessments of the fishery need to be stratified according to gear type.

Luderick: Commercial landings of luderick displayed relatively even sex ratios. There was considerable variation in the size composition of luderick catches, but this was not related to gear type or location. Several year classes contributed to commercial landings of luderick. For example, in the Clarence River in 1997 luderick landings included fish between 2 and 8 years old. There was considerable variation in the size at age of luderick, and fish length was a poor indicator of fish age.

The data presented for each of these species will aid the design of long-term resource assessments of all four species, as well as providing managers of the resource with initial assessments of the status of the stocks.

A voluntary logbook program collected daily catch and effort data from 40 fishers between September 1995 and December 1997. A computerised Optical Character Recognition (OCR) system using teleforms software was successfully implemented, making it very easy and cost-effective to enter the large volume of data directly into a database. Relationships between catch and effort were complex. For example, catches of bream, sand whiting and mullet were related to the length and drop of haul nets, and similarly to fishing time, mesh size, net length and drop of mesh nets. The complexity of catch and effort relationships in the estuarine finfish fishery need to be considered in developing future biomass dynamic models of the estuarine finfish stocks in NSW.

KEYWORDS: Estuarine fish, stock assessment, recruitment, size and age structure, log book, Sparidae, Sillaginidae, Platycephalidae, Girellidae

1. Introduction

1.1 Background

Fish have been harvested commercially from NSW estuaries since the early 1800's, and in recent years more than 1000 commercial fishers have operated annually in the estuary fishery, producing in 1995/96 over 4500 tonnes of finfish valued at over $12 million. Most of the important species of fish harvested commercially from estuaries in NSW are also highly sought after by recreational fishers, and in some estuaries the recreational catch is very large and exceeds that of the commercial sector (West and Gordon 1995). Despite the value of the commercial and recreational fisheries to the NSW economy, and the continuing conflict between the two user groups over the allocation of the estuarine resources, there has been little research aimed at assessing the status of these important fish stocks.

The commercial estuarine finfish fishery is the most complex multi-method and multi-species fishery in NSW, and typically, many fishers operate on a single basis and are adept at switching from one fishing method to another, and from targeting one suite of species to another. Moreover, many fishers also participate in other sectors of the fishing industry (e.g. ocean beach haul, estuary prawn fishery). The commercial estuarine finfish fishery in NSW is currently managed by a complex set of gear and fishing time specifications, areal and seasonal closures, and gear and minimum fish size restrictions. Commercial fishing is currently permitted in nearly all estuaries in NSW, the main exceptions being the Brunswick, Evans and Wooli Wooli Rivers, Brisbane Water, Port Hacking, Wagonga Inlet and many of the small intermittently open coastal lagoons. Access to the commercial estuarine fishery has now been restricted to fishers who have a specified level of catch history in the fishery.

Annual commercial production of finfish from NSW estuaries has increased over the past 40 years. From the mid 1950's to the late 1970's annual finfish production generally fluctuated between 3000 and 4000 tonnes, after which it increased to peak at about 5600 tonnes in 1986/87, but has since declined to about 4500 tonnes (Figure 1.1). Although the total commercial production of estuarine fish in NSW includes over 100 species, in 1995/96 the top 10 species contributed approximately 88% of total finfish landings from estuaries (Table 1.1). The principal species (by weight and monetary value) comprising the estuarine fishery are sea mullet (*Mugil cephalus*), yellowfin bream (*Acanthopagrus australis*), sand whiting (*Sillago ciliata*), dusky flathead (*Platycephalus fuscus*), luderick (*Girella tricuspidata*), silver biddy (*Gerres subfasciatus*) and river eels (*Anguilla* spp.) (Table 1.1).

Mesh nets, haul nets, traps and handlines are used to capture most species of finfish in estuaries, although mesh nets and haul nets have accounted for about 80% of the total effort (fisher days) in recent years (Table 1.2). Although commercial fishing is permitted in numerous estuaries, approximately 70% of landings are taken from the top 10 estuaries (Table 1.3).

Figure 1.1. Estimated total estuarine commercial finfish production from 1954/55 to 1996/97.

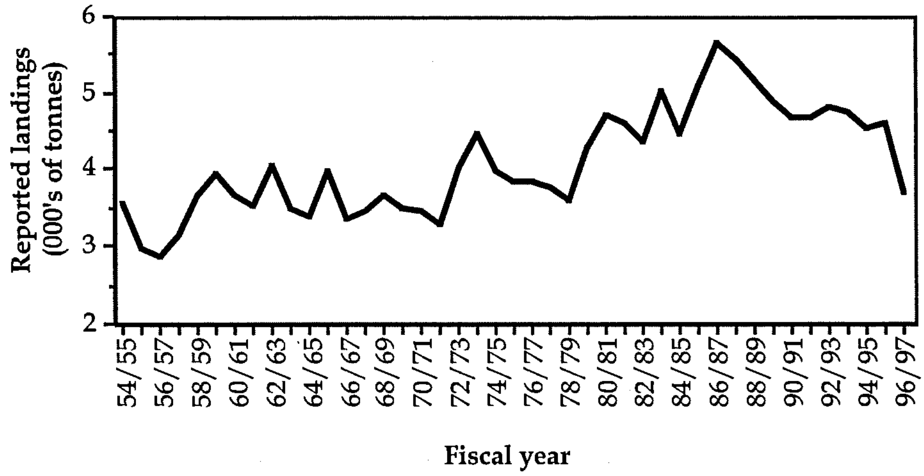


Table 1.1. Estimated commercial finfish production and value of the top 10 estuarine finfish species in 1995/96 in NSW.

Species	Production (tonnes)	Value ($)
Sea mullet	2164	3,268,337
Bream	440	3,240,867
Luderick	423	602,043
Eel	220	666,179
Sand whiting	180	1,669,783
Dusky flathead	168	634,348
Silver biddy	156	317,629
Flat-tail mullet	87	69,711
Tarwhine	66	249,436
Silver trevally	62	114,272
Trumpeter whiting	42	146,346
Mulloway	37	278,345
Other estuarine species	480	1,253,236
Total estuarine species	4,525	12,510,532

Table 1.2. Commercial fishing effort (days fished) using different gear-types in the estuarine finfish fishery in 1995/96.

Method	Days fished
Nets:	
Bait net	557
Bullringing (Garfish net)	1,009
Haul net, Beach haul	13,271
Mesh net, bottom set	9,439
Mesh net, flathead	4,080
Mesh net, splash	31,092
Mesh net, top set	6,673
Pound net (baulk/six)	251
Purse seine	81
Traps:	
Eel trap	8,696
Fish trap	5,662
Lines:	
Handline	2,007
Trotline	26
Total finfish methods	82,844

Table 1.3. Commercial finfish production of the top 10 estuaries in 1995/96.

Estuary	Production (tonnes)
Clarence River	691
Port Stephens	414
Hawkesbury River	393
Wallis Lake	332
Tuggerah Lake	310
Lake Macquarie	295
Lake Illawarra	200
Botany Bay	178
Myall Lakes	174
Port Jackson	150
Other estuaries	1,387
Total estuaries	4,525

The commercial production and fishing effort information collected by NSW Fisheries suggest that stocks of estuarine finfish have been relatively stable since the mid 1980's. However, these data are of limited use for assessing the status of stocks as the catch and effort information has traditionally been collected by a mandatory monthly catch return system, which provides estimates of total monthly production by species and area as well as a summary of fishing effort by method. Catch by species information has been recorded independently of fishing method information, and thus the data do not provide an accurate measure of catch per unit of effort by species. Biologically based assessments of the estuarine fish stocks are required for the future sustainable long-term management of stocks. The size and age composition of catches and changes in the abundance of different year classes can be very powerful tools for assessing the status of fish stocks (reviewed by Megrey 1989). Prior to the study reported herein, data suitable for this kind of analysis were not available for any of the important species of estuarine fish in NSW.

Several of the important fishes in the commercial estuarine fishery are also harvested in nearshore coastal waters, namely in the ocean haul, ocean trap and line, and ocean fish trawl fisheries, presumably at a different stage of their life cycle. The ocean production of some species (e.g. sea mullet, bream, luderick, tarwhine) is significant, and ocean catches of these species therefore need to be considered when assessing the status of these fish stocks.

1.2 Need

Prior to the current study, there was a need to develop methods to monitor and assess stocks of estuarine fish in NSW. No formal stock assessment studies had been conducted on any of the major species during the last 50 years, even though the resources supported commercial and recreational fisheries. There was little information on which to judge the status of stocks, apart from the NSW Fisheries annual production and fishing effort data. These data were limited, however, as traditionally they were collated on a monthly basis, with all catches of a particular gear type being pooled for each month. Consequently, there was a potential for relevant patterns to be masked, and thus there was a need to look at catch and effort data over finer, and perhaps more relevant, temporal scales.

The most powerful stock assessment procedures for finfish require accurate information on the size and age compositions of catches (see Megrey 1989). Knowledge of how these variables differ between different estuaries, estuarine and ocean waters, different gear types, and throughout time will provide beneficial information for designing long-term strategies for monitoring and assessing the stocks of fish in estuarine and coastal waters in NSW. Moreover, data on spatial and temporal changes in the relative abundances of different year classes can be extremely beneficial for managing fish stocks and for potentially forecasting future catch levels. An assessment of the potential for detecting changes in abundance of pre-recruits to the fishery as a means of forecasting future catch levels was warranted. This type of pertinent and important information necessary to design a scientifically sound long-term monitoring and assessment procedure for the important finfish species in NSW was unavailable for any species of estuarine finfish.

Prior to the implementation of any long-term monitoring program, appropriate strategies needed to be developed to ensure results are scientifically sound. Data on the magnitude of variability in the size, sex and age compositions of commercial catches from different locations, in different time periods and with different fishing gear was required to ensure the design of a long-term monitoring program is robust. It is acknowledged that initially, such data will only enable preliminary estimates on the status of stocks in selected locations, however this information was urgently needed by managers and industry to allow development of management plans for the fishery.

This study is an important first step in increasing our knowledge of the status of estuarine fish stocks in NSW, and will provide the necessary pilot work prior to the implementation of an ongoing monitoring program of the important estuarine fishes. The fish species targeted for detailed study were yellowfin bream, sand whiting, dusky flathead and luderick. The fishery for sea mullet was the subject of a separate FRDC funded study (FRDC 94/041)

1.3 Objectives

The objectives of this project as stated in the original funding application were:

1). To investigate standard methods for independently sampling fish stocks in estuaries.

2). To determine adequate sample sizes for providing the breakdown of the age and sex composition of the major estuarine fish species.

3). To determine variability in age, length at age and sex composition of commercial catches of the main estuarine fish species at the major landing locations along the NSW coast over a two year period.

4). At each location, to determine the variability in age and sex composition between ocean caught and estuarine caught fish.

5). In association with industry, to determine and begin implementation of an efficient logbook system to monitor daily catch and effort of individual fishers at these locations.

6). To advise industry on the means of assessing estuarine fish stocks through explanations of the data requirements and of how these data are used. This would involve regular visits to regional areas to show the results of data collection and analysis. The aim would be to make the process as transparent as possible and the data as useful as possible to industry. It is hoped that in the future industry will be encouraged to play a major role in supporting longer term stock assessment projects.

1.4 Achievement of objectives

Objective 1. A pilot study using different fishing gears identified that quantitatively sampling young newly-settled fishes with a small beach seine was the most cost-effective and appropriate method to assess recruitment variability of juvenile fishes in NSW estuaries. This approach has been used successfully to assess the recruitment patterns of young fishes elsewhere in southeastern Australia (Jenkins et al. 1997a, Fowler and Short 1997). Sampling of juvenile fishes across several estuaries throughout NSW identified latitudinal gradients in the timing of recruitment of young sand whiting, bream and luderick to different estuaries. Newly settled sand whiting occurred from January to April in the Clarence River (northern NSW), January to July in Wallis Lake, February to May in Lake Macquarie and January to August in St. Georges Basin (southern NSW). Newly settled bream occurred from July to December in northern NSW estuaries, but from April to September in southern NSW estuaries. Young luderick occurred from July to January in northern NSW estuaries, but from August to December and also March and April in southern NSW estuaries. Small dusky flathead were captured throughout winter in the Clarence River, but very few individuals were captured elsewhere. Because recruitment of most species was spread across several months, a state-wide sampling program to determine indices of recruitment may prove costly. The feasibility of sampling larger juveniles some months after initial settlement needs to be assessed.

Objectives 2, 3 and 4. Sampling of commercial landings of bream, sand whiting, dusky flathead and luderick identified spatial, temporal and gear-related differences in the size, sex and age compositions of commercial landings of estuarine fishes. These data will be beneficial to designing longer-term monitoring and assessment studies and will provide managers of the resource with initial assessments of the status of the stocks. The size compositions of landings were generally dependent on gear-type and patterns were relatively consistent in space and time. Commercial landings were predominantly comprised of fish close to legal length. However, the age structures of landings generally varied among locations and throughout time, depending on the species. The age data were used to ascertain the necessary sample sizes required to undertake future stock assessments of estuarine fish species.

Objective 5). The voluntary logbook program collected daily catch and effort data from 40 fishers between September 1995 and December 1997. A computerised Optical Character Recognition (OCR) system using teleforms software was successfully implemented, making it very easy and cost-effective to enter the large volume of data directly into a database. Relationships between catch and effort were complex. for example, catches of bream, sand whiting and mullet were related to the length and drop of haul nets, and similarly to fishing time, mesh size, net length and drop of mesh nets. Biomass dynamic models of the estuarine finfish stocks in NSW need to consider the complex relationships between catch and effort of mesh and haul nets.

Objective 6). In the ports where sampling took place fishers were provided with regular feedback regarding the study throughout the sampling program. Quarterly catch per unit of effort summaries were provided to fishers who participated in the voluntary logbook program. NSW Fisheries is currently advising industry via the relevant Management Advisory Committees on the results and implications of the current study. The implications of the data presented in this report for future assessments of the NSW estuarine finfish fishery and the role industry needs to play in such assessments is being highlighted. Follow up debriefings will be done throughout several regions of NSW and at meetings of the Estuary General and Ocean Haul Management Advisory Committees.

2. Spatial and temporal variation in recruitment and growth of juvenile estuarine fishes

2.1 Introduction

Most estuarine fish species have a dispersive larval phase, and consequently the recruitment of young-of-the-year can vary considerably at different temporal and spatial scales (Houde 1987, Campana et al. 1989, Fogerty et al. 1991, Fowler et al. 1992). There is increasing evidence that recruitment variability of young fishes can have long-term impacts on the demography of a population (Doherty and Fowler 1994). An understanding of recruitment variability and its relationships with stock size can, therefore, be highly valuable to fisheries scientists and managers as prior knowledge of the recruitment strength of a particular year class to a fishery and the level of year-to-year variability in general can be important tools for deciding future harvest options. The forecasting of future stock levels based on surveys of recruits some years prior to the fish entering a fishery has successfully been used in managing some crustacean fisheries, notably that of the Western Australian rock lobster (Caputi et al. 1996).

Before any type of sampling regime to quantify recruitment levels of estuarine fishes can be implemented, it is important to have an understanding of natural variability in the timing of recruitment and of the early life history characteristics (e.g. growth) of each species over relevant spatial and temporal scales. Previous studies in NSW have identified the magnitude of the small-scale spatial variability in the relative abundances of young estuarine fishes (e.g. Ferrell et al. 1993, Gray et al. 1996), but larger-scale latitudinal variations in the recruitment dynamics of these fishes have not been quantified. There is a general lack of understanding of the reproductive and early life history dynamics of most estuarine fishes in NSW.

The primary aim of this study was to identify the duration of the recruitment (settlement) period of young fishes to different estuaries throughout NSW, and to document spatial and temporal patterns in their early life history characteristics (primarily growth). The species of fish targeted in this study were: sand whiting, bream, luderick and dusky flathead. However, in the course of the study large numbers of young tarwhine (*Rhabdosargus sarba*) were caught and the results for this species are also presented here.

2.2 Methods

2.2.1 Development of sampling strategy

Previous reports on the early life history dynamics of the study species, and pilot sampling using several gear types conducted across several estuaries in northern NSW during the early stages (August to November 1994) of the project (Gray et al. 1995) indicated that it was most practical to sample young recently settled fishes in shallow waters prior to them dispersing to various other, and often less accessible, habitats.

Immediate post-settlement sand whiting inhabit shallow unvegetated sand habitats, whereas recently settled bream and luderick occur over shallow seagrass, particularly *Zostera capricorni* meadows, before they move to other habitats, including mangrove creeks, rocky walls and reefs, and deeper channels (Burchmore et al. 1988, Middleton et al. 1994, Gray et al. 1996). Therefore sampling for these species in this study was restricted to shallow sand and seagrass habitats. Very few dusky flathead were caught during the early survey (Gray et al. 1995), but it is generally considered that they frequent shallow unvegetated habitats during their early demersal period (SPCC 1981).

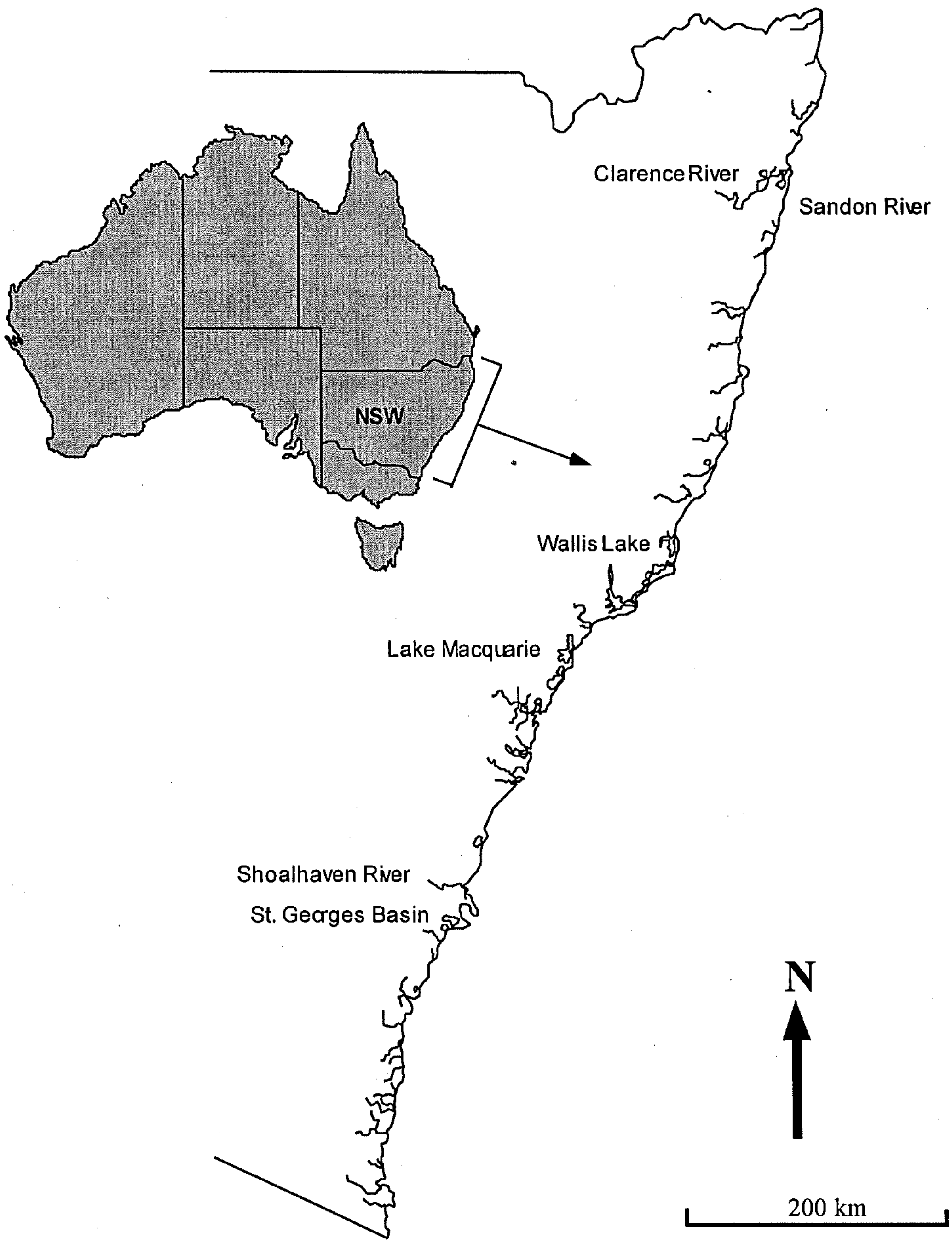
A small seine net was used to sample immediate post-settlement fishes from the shallow sand and seagrass habitats. The seine net was chosen over other commonly used methods such as otter and beam trawling, and poisoning, as it was safe, relatively quick and easy to use by two persons, it could be used to sample irregular shaped seagrass beds, and could be deployed out of a boat or from land. Further, similar sampling techniques for young fishes have been previously used successfully in NSW and elsewhere in southeastern Australia (e.g. Ferrell and Bell 1991, Connolly 1994, Gray et al. 1996, Jenkins et al. 1997a, b).

2.2.2 Study locations and sampling procedure

Sampling for juvenile fishes was conducted in selected estuaries between the Clarence River in northern NSW and St. Georges Basin in southern NSW, spanning a distance of approximately 600 km along the coast (Figure 2.1). The *Zostera capricorni* (hereafter referred to as *Zostera*) habitat was sampled in six estuaries (Clarence and Sandon Rivers, Wallis Lake, Lake Macquarie, Shoalhaven River and St. Georges Basin), whereas the sand habitat was sampled in four estuaries (Clarence River, Wallis Lake, Lake Macquarie and St. Georges Basin). Three distinct *Zostera* meadows were sampled in each estuary, whereas six separate sand habitats were sampled in each estuary. Sampling over *Zostera* was done monthly from April 1996 to December 1997, whereas sampling of the sand habitat was done monthly between April 1996 and April 1997, after which it was done bi-monthly until February 1998.

The seine net used to sample juvenile fishes was 10 m in length and 2 m deep with a stretched mesh of 6 mm. The area sampled by each haul of the net was approximately 25 m^2. Replicate hauls were made haphazardly over non-overlapping substratum in each habitat. Three replicate hauls of the net were made at each seagrass location, whereas four were made at each sand location. It usually took less than one hour to complete the replicate hauls at each location. Sampling of the seagrass habitats was done within 2 hours of low tide, whereas sampling of the sand habitat was done at various tidal stages. The depth of water at the time of sampling ranged from 0.5-1.5 m depending on the location and stage of the tide. All sampling was done during the day as pilot sampling identified that for each of the targeted species there were no diel differences in catchability and relative abundances of newly settled individuals (Gray et al. 1998).

Figure 2.1. Map of the NSW coast showing the locations of the study estuaries.



The fish species of interest were sorted from catches, identified, measured and when and where possible returned to the water. Some individuals were retained and preserved in 70 % alcohol for later analyses in the laboratory.

2.2.3 Analyses of data

Analysis of variance was used to test for spatial and temporal differences in the number of small sand whiting, bream, tarwhine and luderick captured. Data were transformed to log (x+1) prior to analysis to satisfy homogeneity of variances using Cochran's test. Because one of the primary aims of the study was to identify latitudinal variations in the timing of recruitment of each species, and because the numbers of some of the species captured in some estuaries were relatively low, the data for each estuary was pooled across locations to assess the latitudinal patterns. This was done despite the fact that most analyses identified significant small-scale (within estuary) variations in the relative abundances of young fishes.

2.3 Results

2.3.1 Sand whiting

The numbers of small (< 150 mm FL) sand whiting caught varied greatly between locations within each estuary, between estuaries and throughout time (Table 2.1, Figure 2.2). Although there was no consistent pattern as to when the greatest or least number of sand whiting occurred in any given estuary, abundances were high in samples taken in April 1996 and February 1998.

The temporal occurrence of young recently settled sand whiting (< 20 mm FL) also varied among individual locations within each estuary and between estuaries. Sand whiting < 20 mm FL were generally most abundant in January, February and April in the Clarence River, from January to July in Wallis Lake, February to May in Lake Macquarie and January to August in St. Georges Basin (Figure 2.3). This indicates that a temporal gradient of recruitment of sand whiting occurs along the NSW coast.

It was evident that more than one pulse of newly settled sand whiting contributed to the population in each estuary during each yearly recruitment period. For example, in St. Georges Basin one group of sand whiting < 20 mm was evident in January, and a second in May and June in 1997, and similarly in December 1997 and February 1998 in Lake Macquarie.

Analysis of the monthly size frequency data showed that small sand whiting increased from 2 to 10 cm FL in approximately 6 months, and that the rate of growth appeared to be greatest in the Clarence River and least in St. Georges Basin (Figure 2.4).

Table 2.1a. Summaries of analyses of variance of numbers of juvenile sand whiting caught across 6 locations within 4 estuaries between June 1997 and February 1998. Month and Estuary were considered fixed factors, while Location was random and nested in Estuary. df = degrees of freedom, SS = Sums of squares, p= probability, ns = p > 0.05. Raw data used, Cochrans test p < 0.05.

		Total sand whiting			Sand whiting < 20 mm		
	df	SS	F-ratio	p	SS	F-ratio	p
Month	16	8814.55	3.14	<0.001	1512.91	2.22	<0.001
Estuary	3	33675.13	3.21	<0.05	2077.05	1.64	ns
Location (Est)	20	10475.22	8.96	<0.001	1264.77	13.01	<0.001
M x E	48	3771.50	1.34	ns	765.31	1.12	ns
M x L(E)	320	2807.75	2.40	<0.001	682.19	7.02	<0.001
Residual	1224	1169.63			97.19		
Total	1631						

Table 2.1b. Summaries of analyses of variance of numbers of juvenile bream, tarwhine and luderick caught across 3 locations within 6 estuaries between August 1996 and December 1997. Month and Estuary were considered fixed factors while Location was random and nested in Estuary. df = degrees of freedom, SS = Sums of squares, p= probability, ns = p > 0.05. Raw data used, Cochrans test p < 0.05.

		Bream			Tarwhine			Luderick		
	df	SS	F-ratio	p	SS	F-ratio	p	SS	F-ratio	p
Month	17	90.55	1.08	ns	68.49	1.59	ns	219.49	1.79	<0.05
Estuary	5	428.60	1.15	ns	255.11	2.11	ns	1265.05	1.80	ns
Location (Est)	12	372.79	8.95	<0.001	120.70	7.96	<0.001	700.99	11.36	<0.001
M x E	85	80.63	0.96	ns	55.83	1.30	ns	187.79	1.53	<0.01
M x L(E)	204	83.76	2.01	<0.001	43.07	2.84	<0.001	122.38	1.98	<0.001
Residual	648	41.65			15.16			61.71		
Total	971									

Figure 2.2. Mean numbers of sand whiting < 150 mm caught in each estuary throughout the study. Data pooled across locations in each estuary.

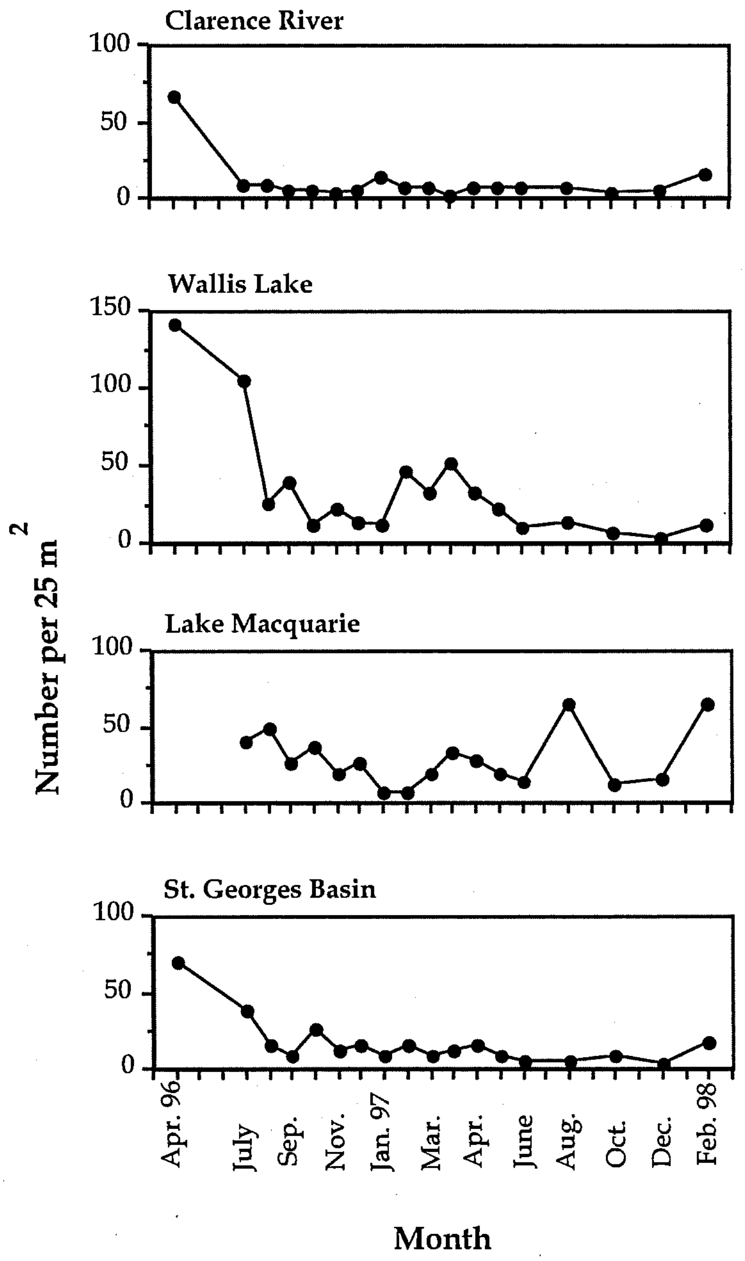


Figure 2.3. Mean numbers of sand whiting < 20 mm caught in each estuary throughout the study. Data pooled across locations in each estuary.

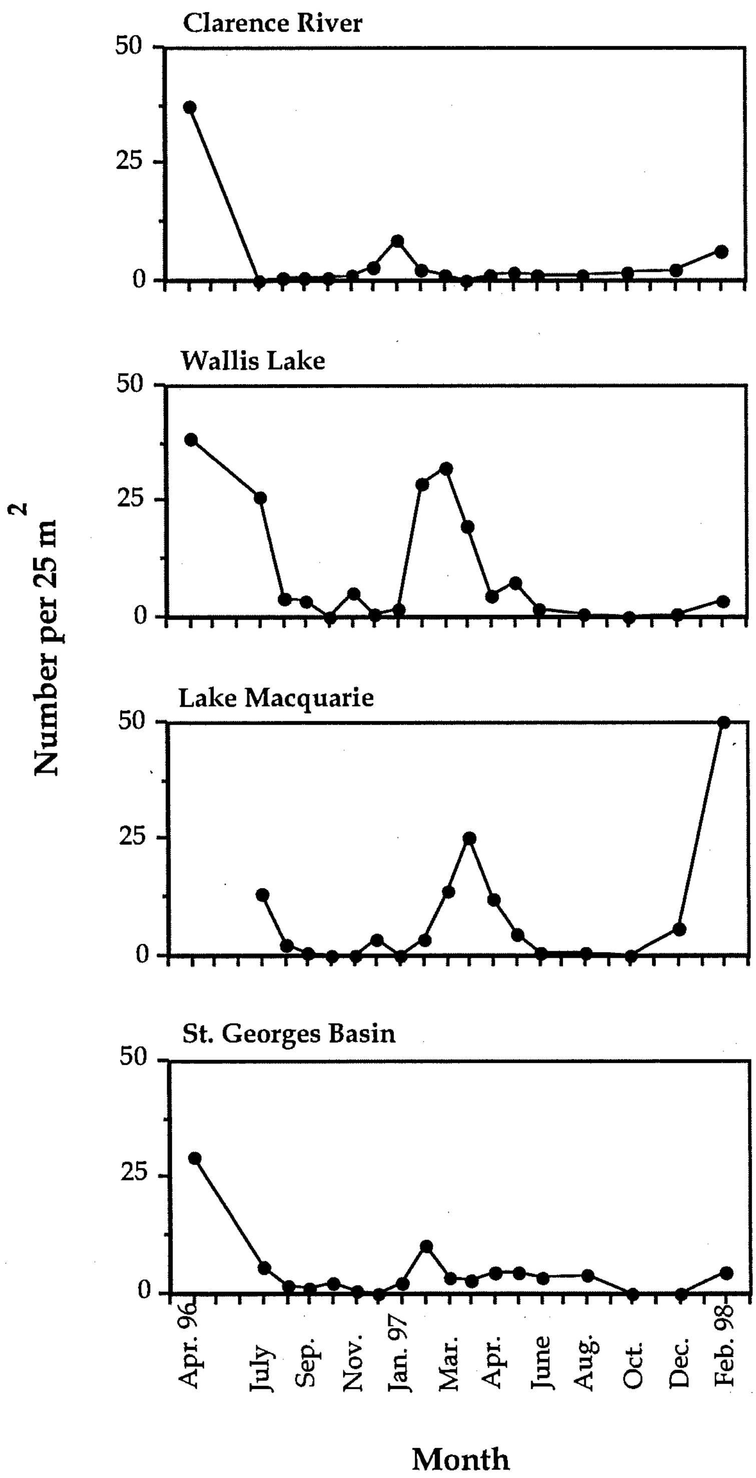


Figure 2.4. Size-frequency compositions of sand whiting captured in each estuary throughout the study period.

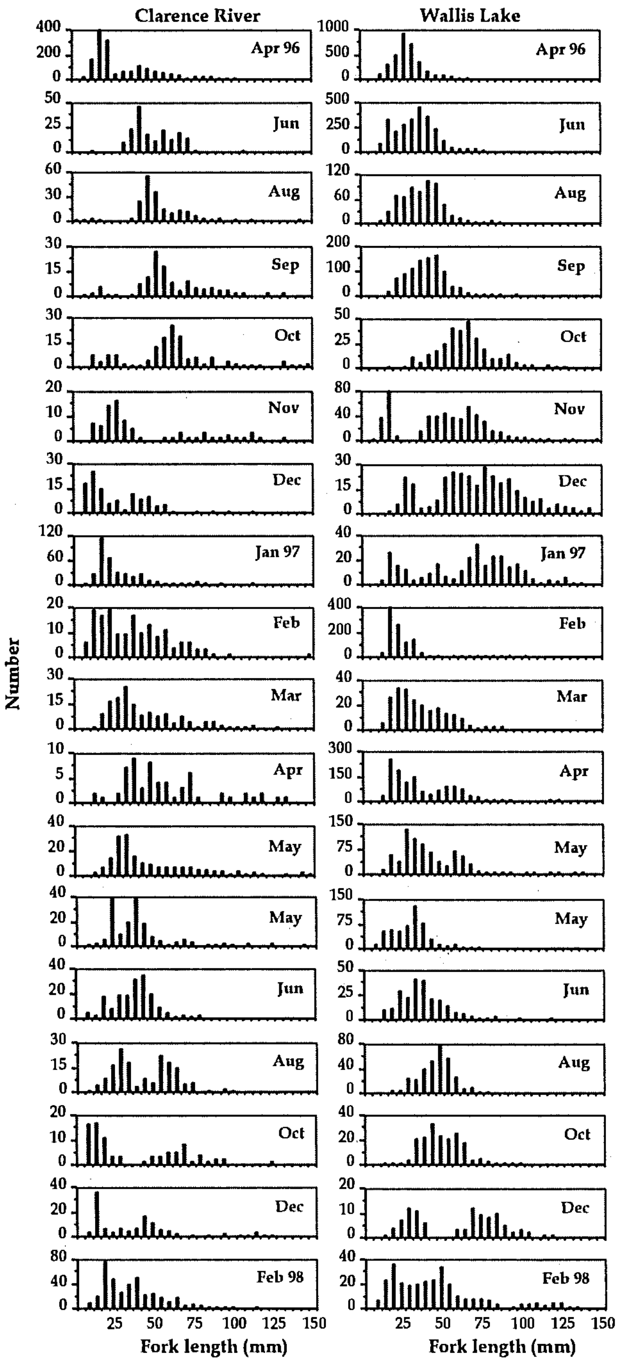
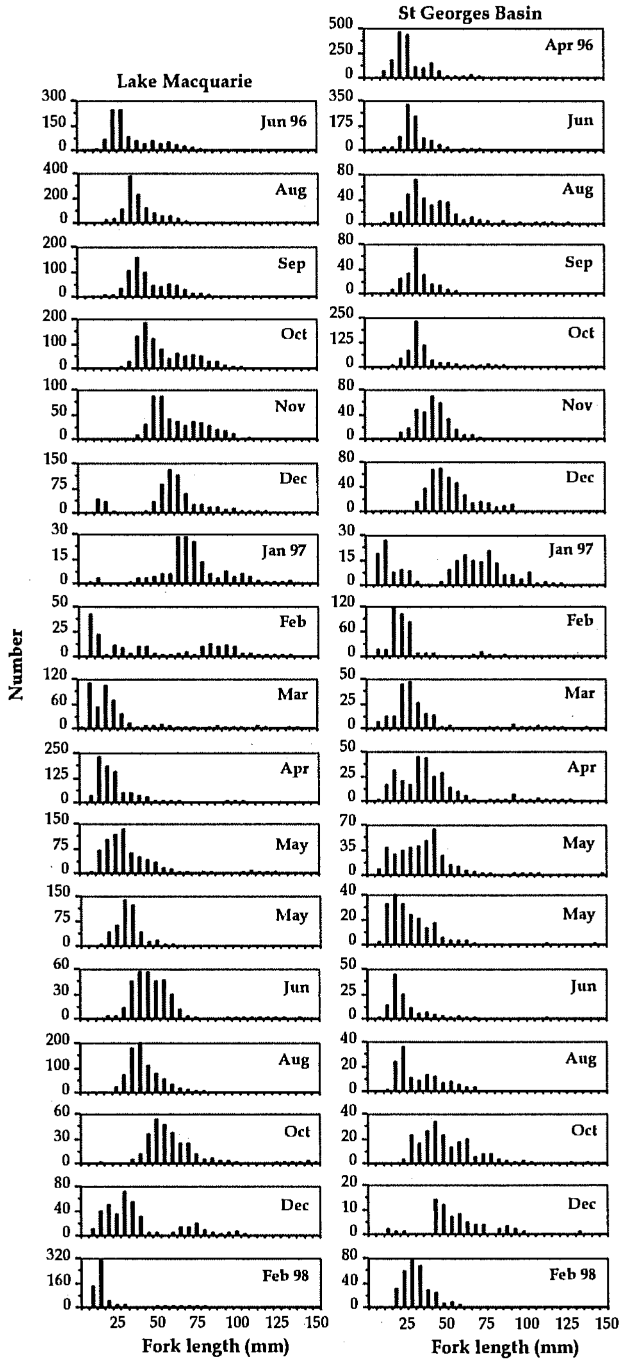


Figure 2.4. continued.



2.3.2 Dusky flathead

Very few juvenile dusky flathead were caught throughout sampling, and the majority of these were caught over sand flats in the Clarence River when they were most prevalent between June and October in each year (Figure 2.5). Because few flathead were caught no formal analyses were performed on the data.

Figure 2.5 shows the sizes of the juvenile dusky flathead caught in the Clarence River, but too few individuals were captured to accurately assess rates of growth from the size frequency data. Despite this, it appeared that dusky flathead increased from 30-70 mm TL in June to 70-120 mm TL in November 1996. The otoliths from these individuals have been retained to help validate the aging of older fish by determining: (1) whether a growth increment (annual mark) can be seen between the fish caught in May and June to those caught in August to December, and (2) the possibility of using daily growth rings to age juveniles.

2.3.3 Bream

The numbers of small (< 50 mm) bream caught varied among individual seagrass beds within each estuary, among estuaries and throughout time. Bream < 50 mm were primarily caught between July and October in the Clarence and Sandon Rivers, May and August in St. Georges Basin in 1997 (Figures 2.6 and 2.7).

Newly settled (< 15 mm) bream were most prevalent from July to December in the Clarence River and Sandon Rivers, April to September in St. Georges Basin, indicating that there may be a gradient in the timing of recruitment of bream to estuaries along the NSW coast. Unfortunately, very few newly settled bream were caught in the other estuaries to test this observation. The data indicated that more than one settlement event can occur in a particular estuary throughout each extended recruitment period. For example, bream 10 mm in length were present in July and again in October in 1997 in the Sandon River. The data also suggested that the number of recruits settling in seagrasses can vary between years and that this may not necessarily be concordant between estuaries. For example, more bream were captured in the Clarence and Sandon Rivers in 1996 than in 1997, but no such trend (albiet lower numbers) was evident in St Georges Basin. The general progression of the different cohorts sampled could be followed in the size frequency data (Figure 2.7).

2.3.4 Tarwhine

Small (< 80 mm FL) tarwhine were prevalent between July and December in all estuaries sampled except Wallis Lake, and also in May and June in St. Georges Basin (Figures 2.8 and 2.9). The numbers of tarwhine captured varied significantly among individual seagrass beds within each estuary, among estuaries and throughout time. Recently settled (<15 mm) tarwhine occurred over an extended period in all estuaries as

Figure 2.5. Size-frequency compositions of dusky flathead captured in the Clarence River throughout the study.

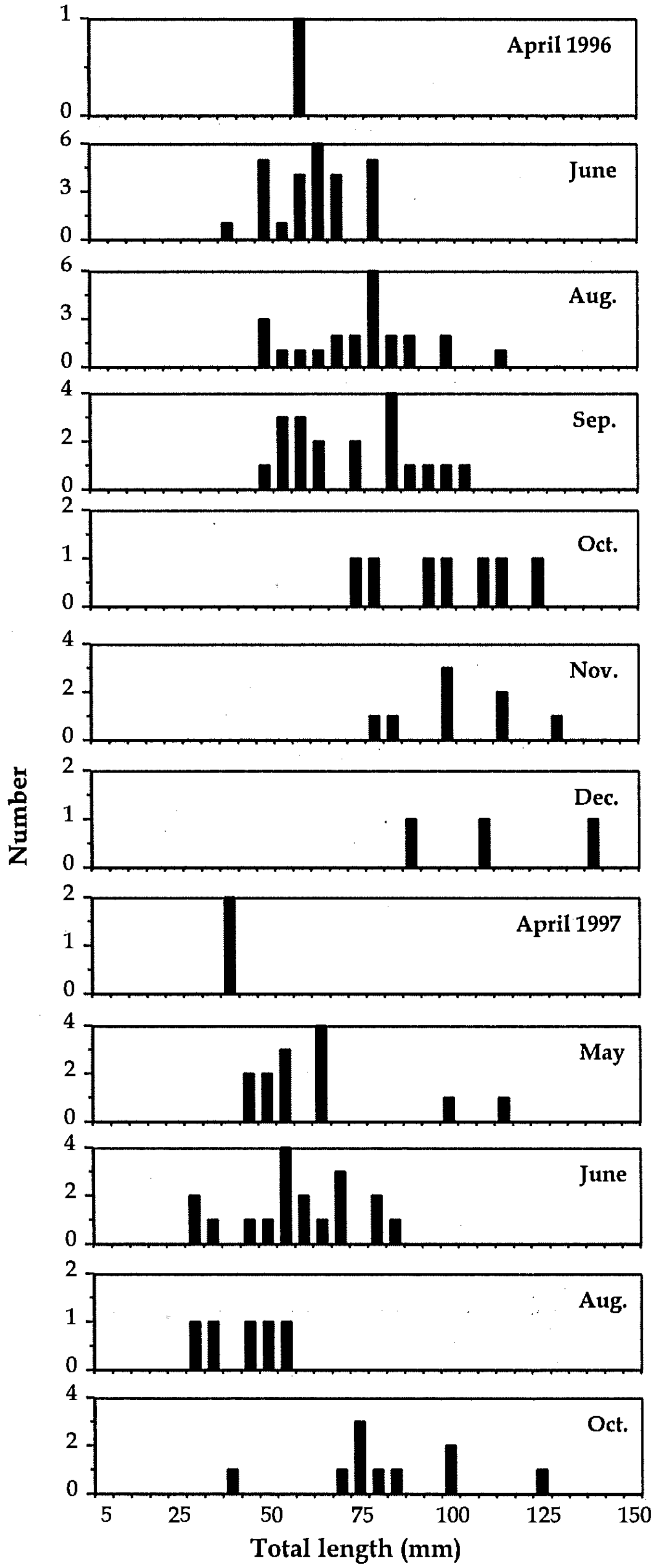


Figure 2.6 . Mean (± 1SE) numbers of bream < 50 mm TL captured in each estuary throughout the study. Data pooled across locations in each estuary.

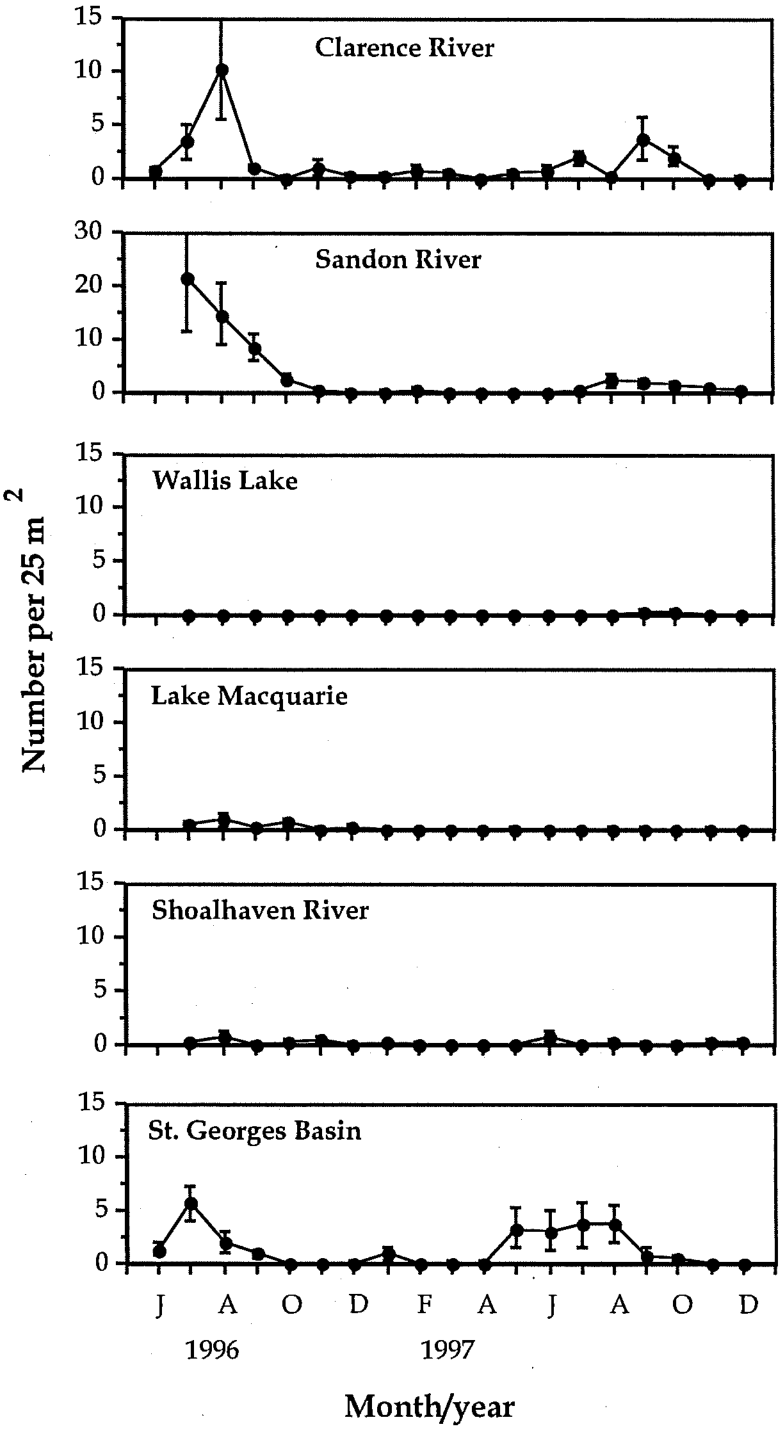


Figure 2.7. Size-frequency compositions of bream captured in each estuary throughout the study.

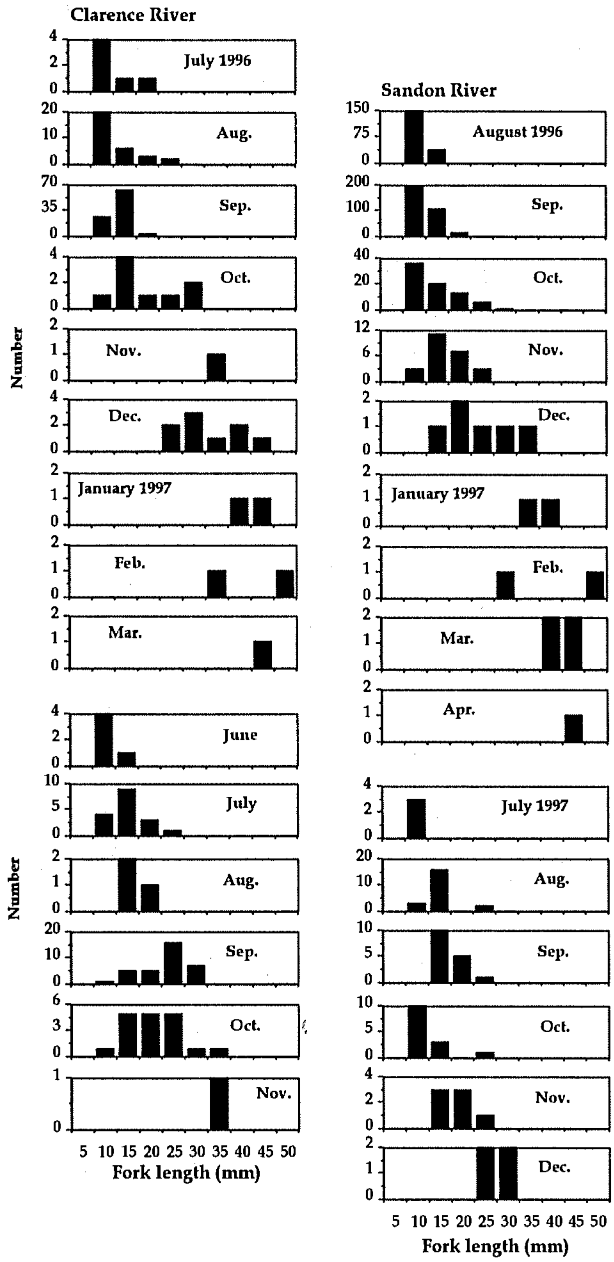


Figure 2.7. continued

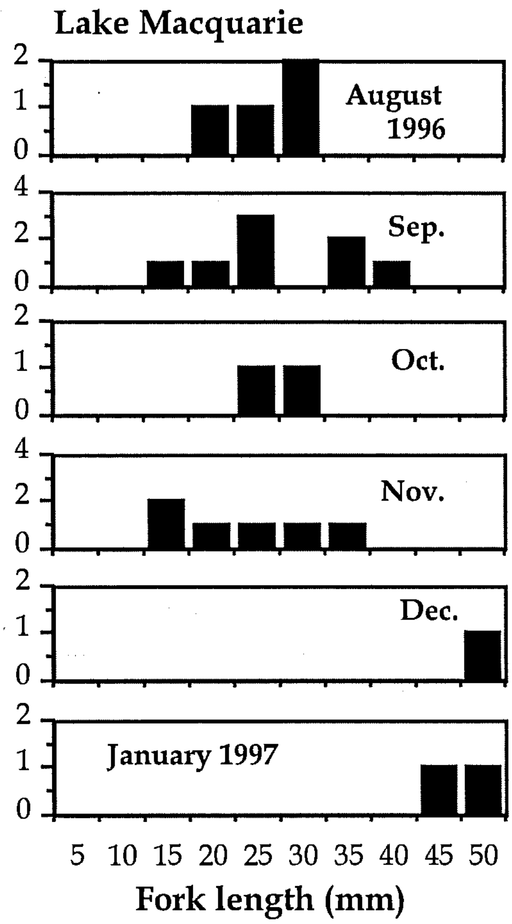
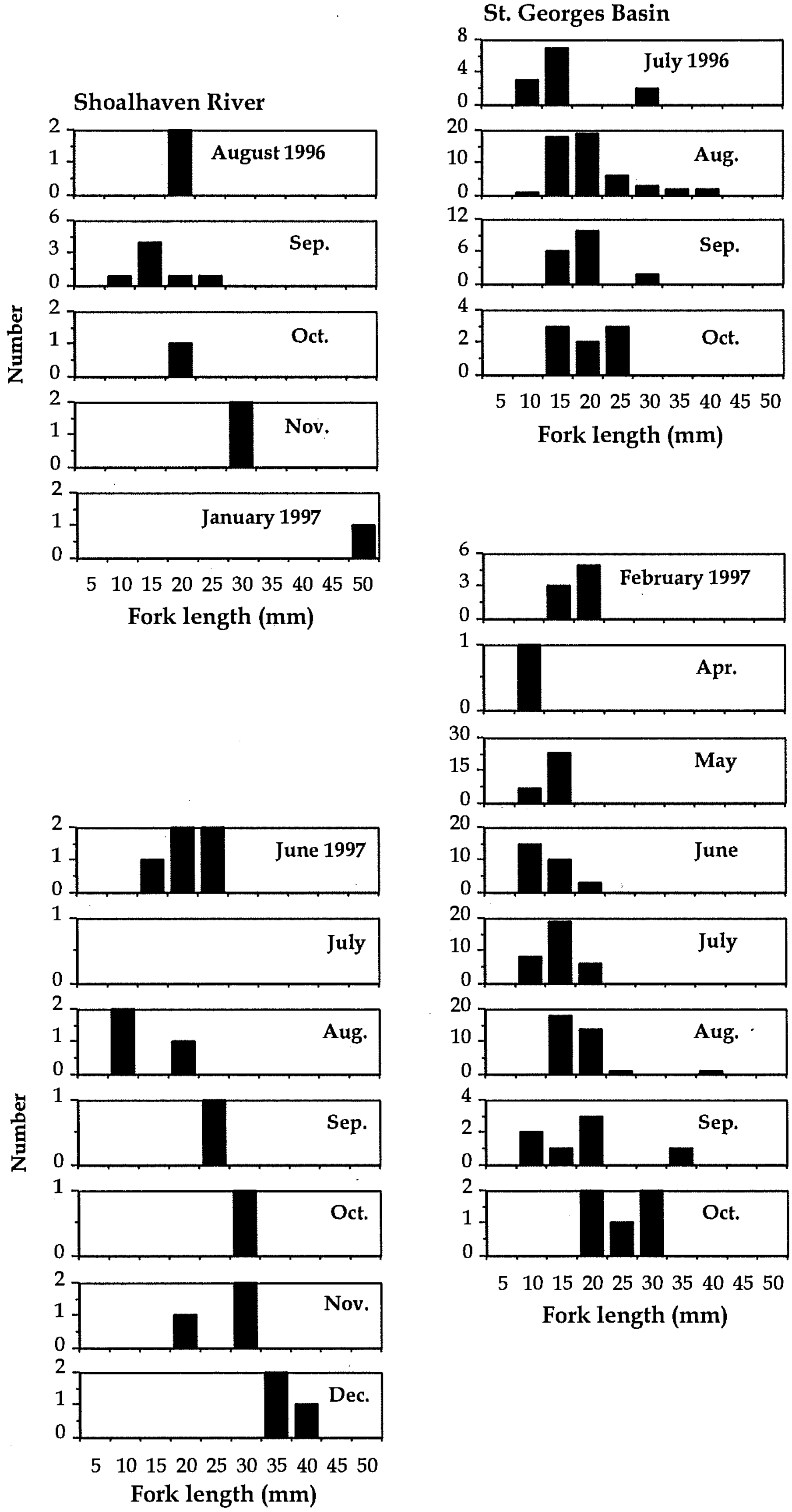


Figure 2.7. continued



they were generally present from July to November in the Clarence and Sandon Rivers, August to November in Lake Macquarie, October and November in the Shoalhaven River and June to October in St. Georges Basin. This indicates that there is significant overlap in the time that tarwhine recruit to estuaries along the NSW coast.

It was evident from the data that an extensive period of settlement of tarwhine occurred in each estuary in each year. For example, in the Sandon River 10 mm tarwhine were present in each month from August to November in 1996 and 1997.

The general increase in the size of young tarwhine could be observed in the size frequency figures. Although no formal analyses of growth were made here, the data suggest that in all estuaries tarwhine grow from 10 to 30-50 mm FL between August and December.

2.3.5 Luderick

Small (< 50 mm) luderick were generally more abundant in shallow *Zostera* beds from July to September in the Clarence River, August to December in the Sandon River, September to November in Lake Macquarie and the Shoalhaven River, and throughout most months of the year, except October/November and April/May in St. Georges Basin (Figures 2.10 and 2.11).

Newly settled (< 15 mm) luderick were present from July to October in the Clarence River, July to November in the Sandon River, September to December in Lake Macquarie, August to December and March to April in the Shoalhaven River, and June to April in St. Georges Basin. This indicates that the timing of settlement of young luderick into estuaries varies latitudinally throughout NSW. More than one recruitment event generally occurred in each estuary each year. For example, in St. Georges Basin 10 mm luderick were present in January, and again in April, June, September and December 1997. The general progression in the sizes of luderick captured can be followed in Figure 2.11.

2.4 Discussion

Considerable spatial and temporal variation in the relative abundance of small and recently settled sand whiting, bream, tarwhine and luderick was evident from the sampling program. This variation was generally considerable among locations within each estuary as well as between estuaries. The magnitude of this variation was not unexpected as large intra- and inter-estuary variation in the numbers of small fishes and crustaceans associated with shallow seagrass and bare sand has been reported previously (Gray 1991, Ferrell et al. 1993, Gray et al. 1996, Jenkins et al. 1996). Identifiable factors which influence such variations have been discussed in detail in the studies cited above and will not be reiterated in detail here. Briefly though, variations in the abundances of small fishes have primarily been accredited to interactions

Figure 2.8. Mean (± 1SE) numbers of tarwhine < 80 mm TL caught in each estuary throughout the study. Data pooled across locations in each estuary.

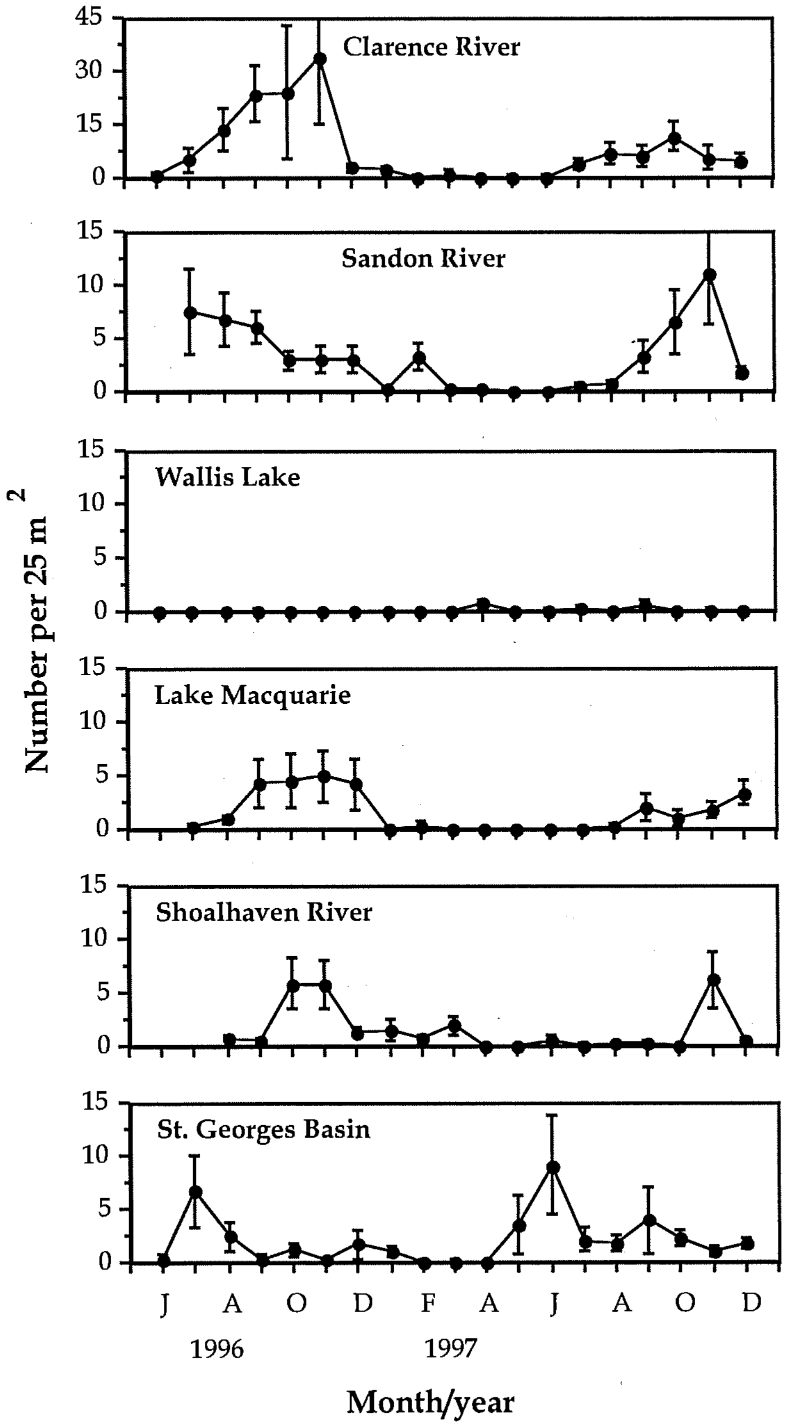


Figure 2.9. Size-frequency compositions of tarwhine captured in each estuary throughout the study.

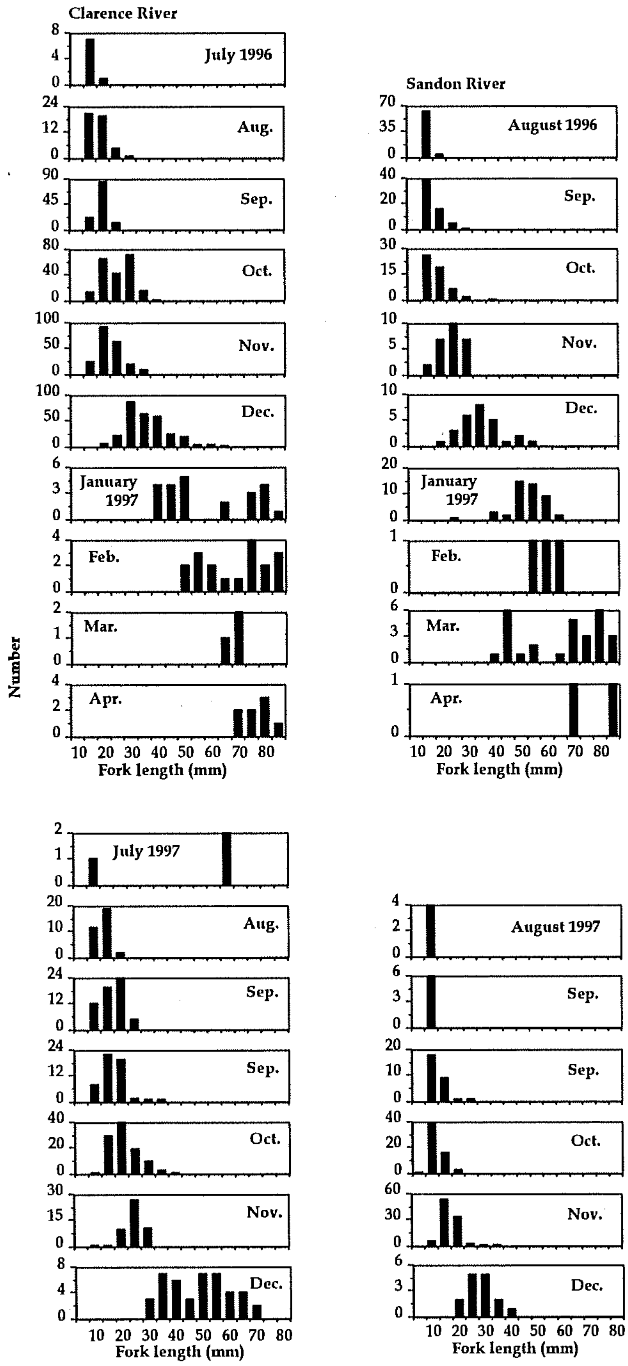
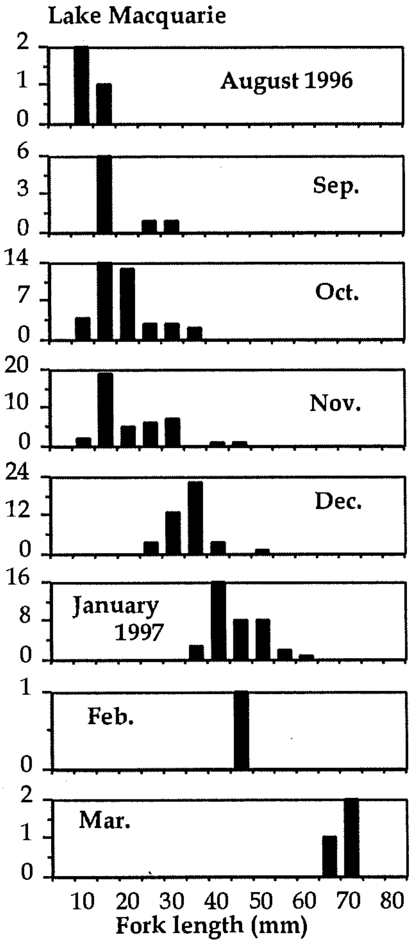


Figure 2.9. continued



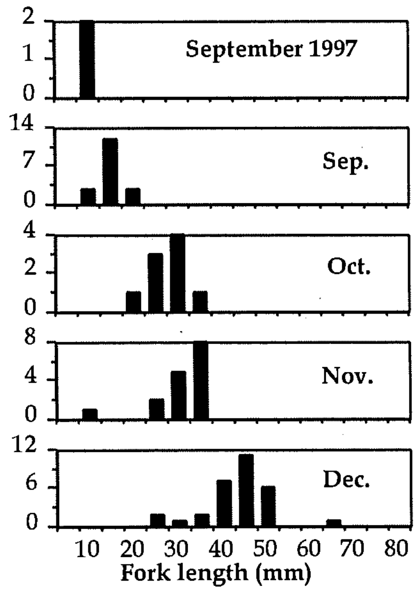


Figure 2.9. continued

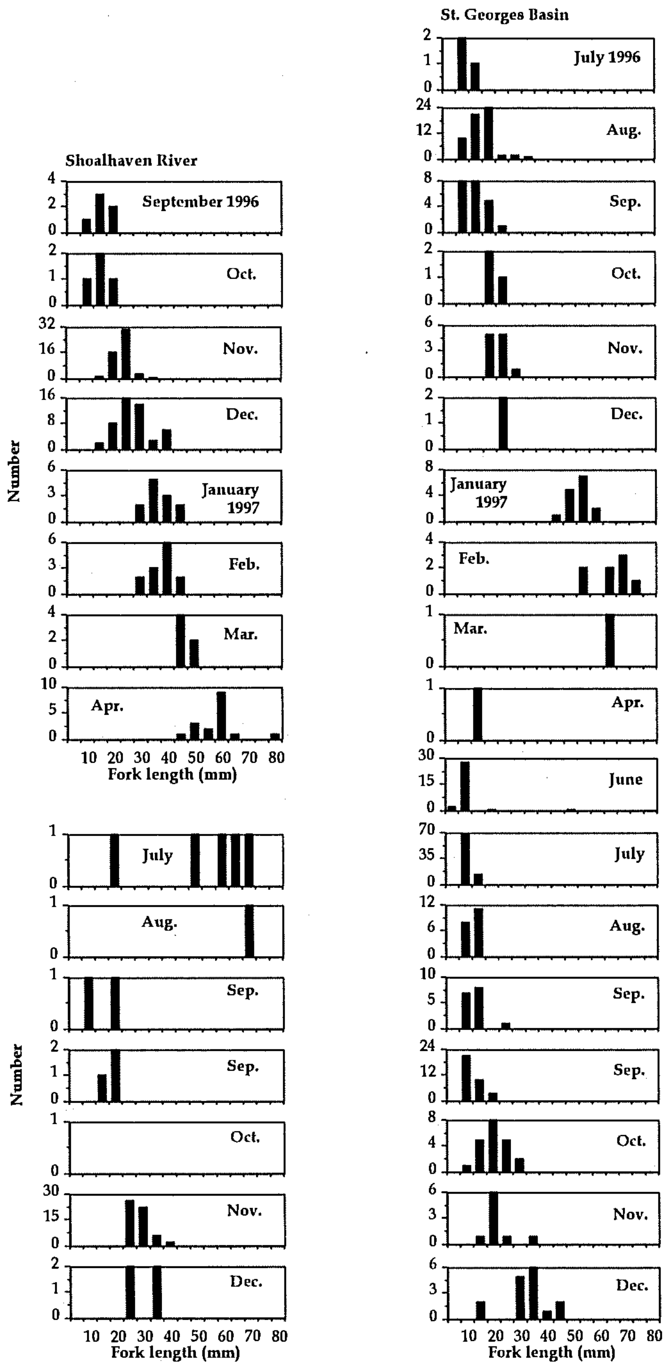


Figure 2.10. Mean(± 1SE) number of luderick < 50 mm caught in each estuary in each sampling period. Data pooled across locations in each estuary.

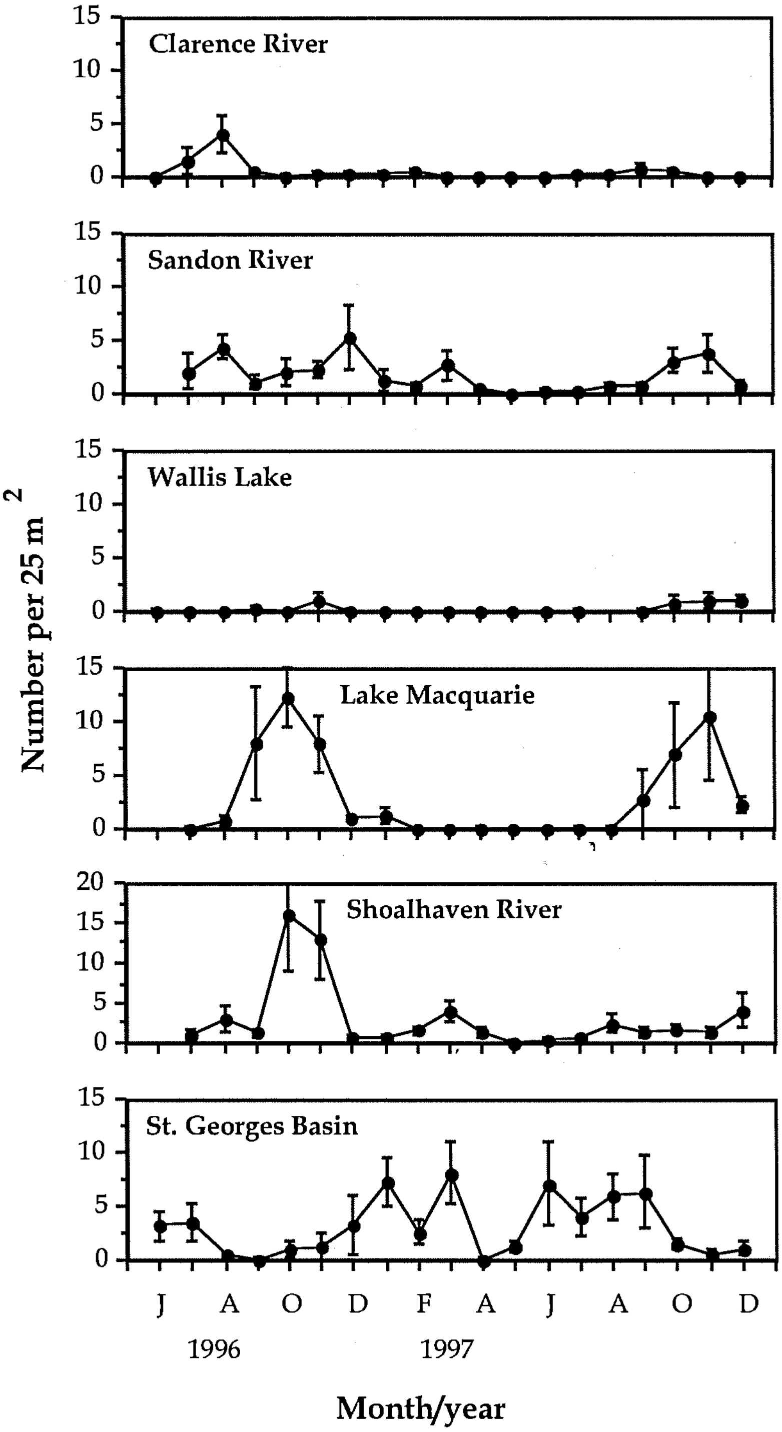


Figure 2.11. Size-frequency compositions of luderick captured in each estuary throughout the study.

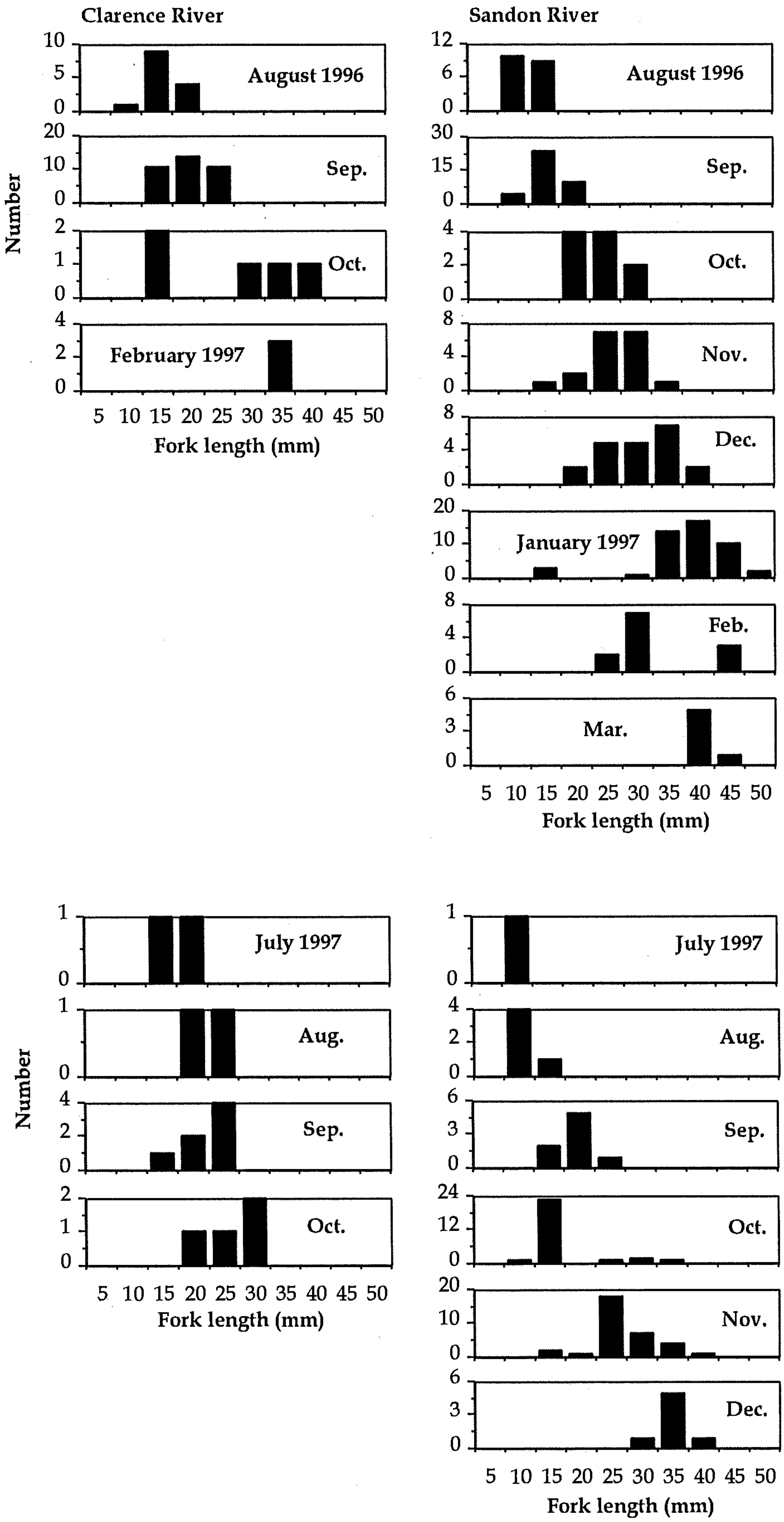


Figure 2.11. continued

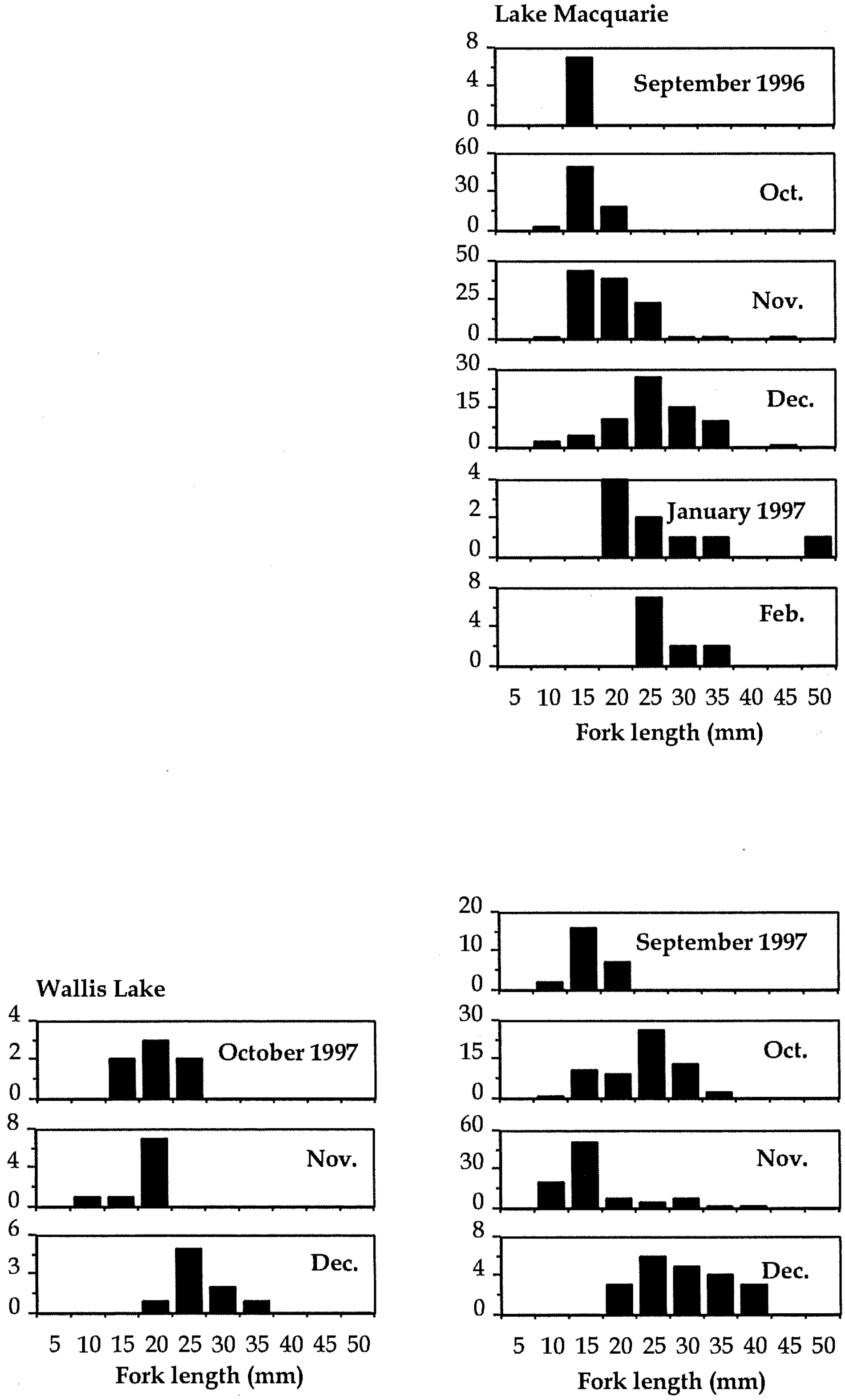


Figure 2.11. continued

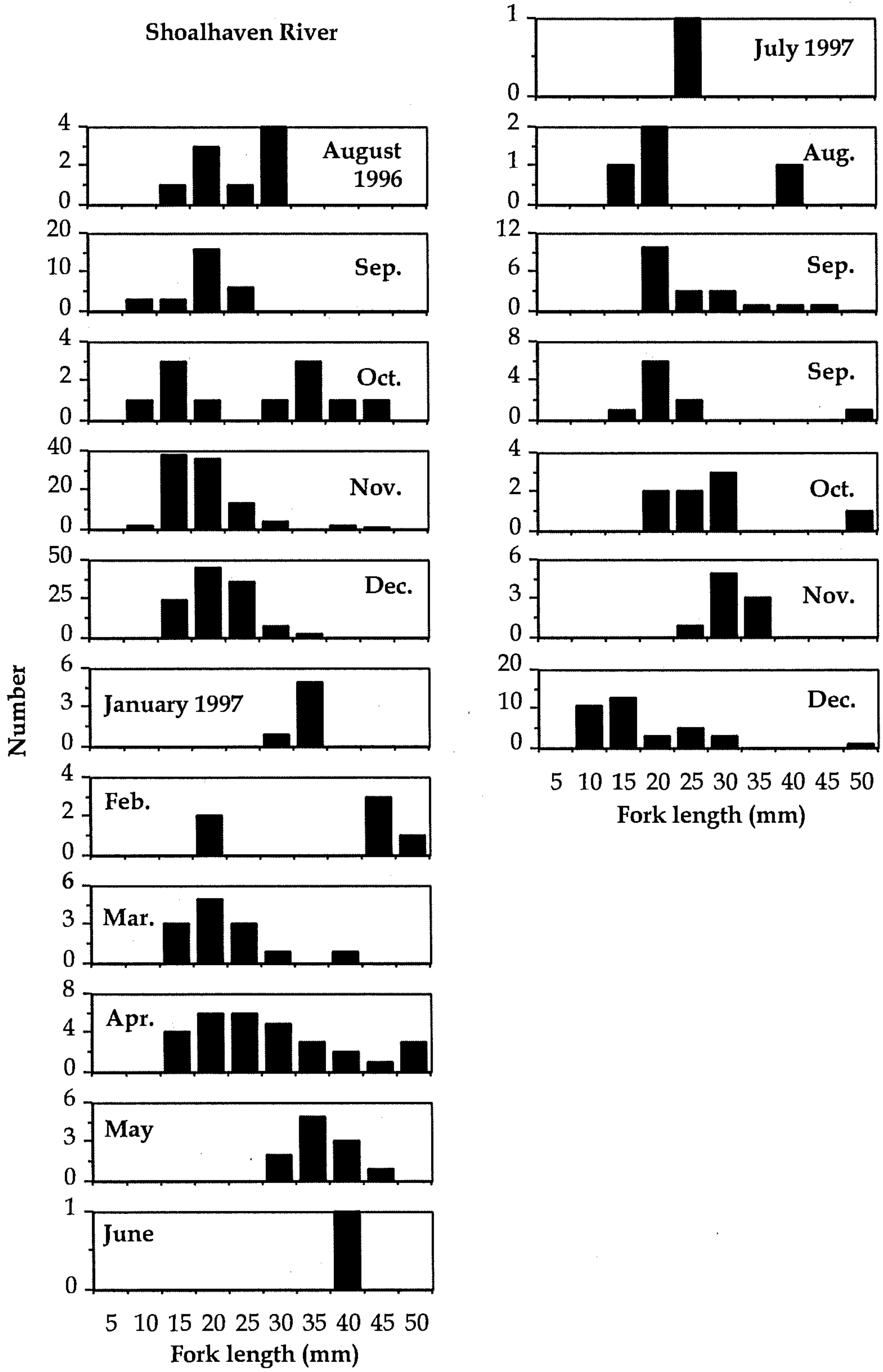
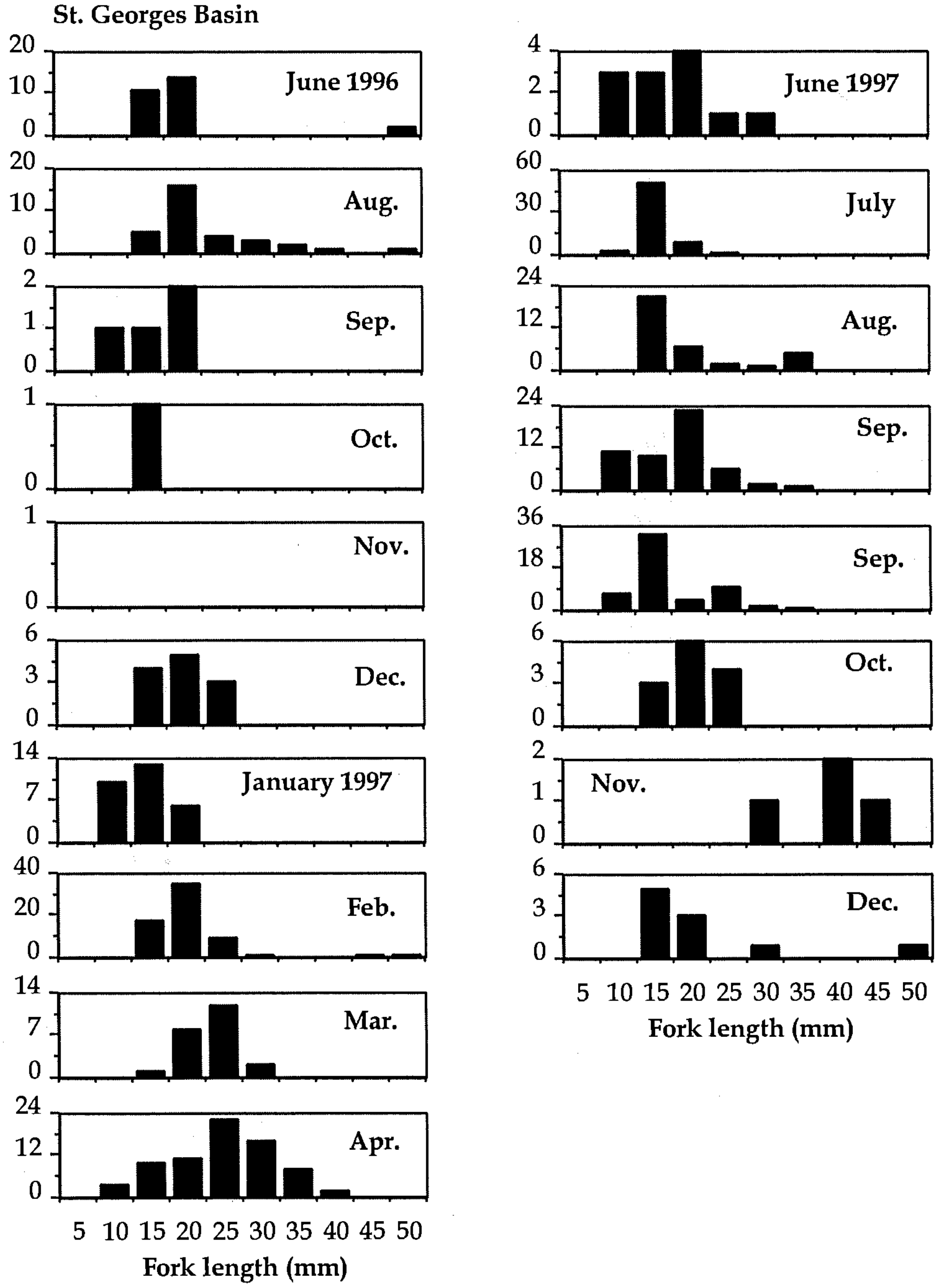


Figure 2.11. continued



between larval supply, the location and physical characteristics of the individual locations, and post-recruitment factors which affect mortality and emigration of small fish from these habitats. The primary purpose of the current study was to identify larger-scale latitudinal patterns in the recruitment dynamics of newly settled estuarine fishes, and consequently it was not an aim to determine the causative effects of the smaller-scale within estuary variations. Nevertheless, the small-scale variations in the abundances of young fish in these habitats needs to be considered in any future studies investigating recruitment of these fishes.

The data presented here suggest that there may be latitudinal gradients in the timing of settlement of sand whiting and luderick to estuaries along the NSW coast. Recruitment of sand whiting primarily occurred between September-February in the Clarence River, but December-May in St. Georges Basin. Luderick recruits were apparent between March-April and June-December in the southern estuaries but from July-January in the northern estuaries. This latter pattern may also occur for bream; Pollard (1991) reported that young (< 50 mm) bream were present in the Clarence River and Port Stephens primarily between August and September each year, but were also evident throughout autumn (April-May) in Lake Conjola and occurred year-round in some estuaries (e.g. Clyde River) on the NSW south coast. Latitudinal variations in recruitment probably reflect variations in the reproductive periods of each species along the coast, and interactions between pre-settlement staged fish and oceanography (e.g. Jenkins et al. 1997a)

Not all individuals of the one species settled concurrently to all locations within the one estuary, as several pulses or different cohorts of recruits occurred during each recruitment period. There are several possible explanations for these observations: (1) spawning of each species occurs over an extended period within each region, (2) recruits came from spawners located at varying distances from each estuary, (3) the pre-settlement period of these species may be highly flexible and may extend to relatively long periods (e.g. Jenkins and May 1994, Fowler and Short 1996). Knowledge of the age of these fish at settlement will shed some light on these possible scenarios.

The extended length of each recruitment period and the multiple pulses of recruits of each species within each estuary and also along the coast means that any future quantitative sampling of recruitment of these species to develop indices of abundance would be required to be done over several months. Depending on the numbers of locations sampled, this type of sampling would prove relatively costly. Because some fishes emigrate to other habitats throughout their early life it would not be viable to sample only at the end of each recruitment period.

Natural variations in the physical characteristics (e.g. seagrass density and height) of individual seagrass beds can influence abundances of small fishes (Bell et al. 1986a, b, Worthington et al. 1992a) and therefore confound comparisons of their relative abundances between locations. It may therefore be more appropriate to use artificial seagrass units (e.g. Bell et al. 1988, Jenkins et al. 1997a, Kenyon et al. in press), each of a standard size and characteristic (e.g. density, width and height of artificial leaves) as a standard sampling unit to estimate the relative abundance of young seagrass-associated fishes. This would minimise any impacts of sampling with small seine nets on natural seagrass beds and on other seagrass-associated fauna. Artificial collecting units have been used to successfully monitor the recruitment strength of young rock lobsters (Caputi et al. 1996).

The success of a research program to provide advice on future stock levels based on surveys of recruits some years prior to them entering the fishery relies on the assumption that there is a significant relationship between initial recruitment and future stock size. Although fluctuations in year class strength can be observed in the exploited stock of some species (e.g. bream, see Chapter 4), many years of data are required to test this assumption, and at present there are no robust estimates of adult biomass for any estuarine fishes in NSW. Such a relationship may be difficult to detect for the species studied here given: (1) the fisheries for these species are predominantly comprised of several year classes and that not all individuals from the one year class may enter the fishery concurrently, (2) the considerable mixing of fish between estuaries and coastal waters suggests that fish from different estuaries may mix substantially before they enter the fishery.

Although it was initially envisaged that the early growth and age of all four species would be investigated in this study, logistic and time constraints prevented this from being done. The general increases in the lengths of bream, tarwhine and luderick in the estuaries studied here were similar to that reported for the same species elsewhere in NSW (Worthington et al. 1992b, Hannan and Williams 1998). However, the ages of these fish were not determined, and the extent of variation in size at age of these fishes was not identified. Further research is therefore required to assess variations in the age of fish at settlement along the coast, and the potential interactions with oceanography (e.g. Jenkins et al. 1997a).

In conclusion, the cost of undertaking a state-wide sampling program to assess the relative abundances of newly settled estuarine fishes as a means to forecast future stock levels would be significant given that: (1) sampling would be required over an extended period, possibly year-round for some species; (2) many estuaries, individual locations and replicate samples would need to be taken in any given estuary. The feasibility of more extensive sampling of larger juveniles (using larger meshed seine nets) at the end of each recruitment period should be investigated. It may also be more cost-effective to examine whether variations in the strength of the earliest year class in the exploited stock can be used to forecast stock size (e.g. Fletcher et al. 1997).

3. General procedures and logistics of sampling fishes in the NSW estuarine commercial fishery

3.1 Introduction

Considerable research has documented that rates of recruitment and growth of fish can vary substantially over various spatial and temporal scales, and that such variations can have important subsequent implications for the demography of fish populations (Fogerty et al. 1991, Doherty and Fowler 1994). Given this, and the fact that commercial and recreational fishing effort and production varies greatly among estuaries and coastal locations throughout NSW, it is probable that the size and age compositions of fish populations may vary substantially between estuaries, estuarine and coastal waters, as well as between years. The magnitude of variations in demography between different estuaries depends on the amount of immigration and emigration of fish from an estuary. Large regional variations in the demography of fish populations could have significant implications for the design of sampling procedures for conducting stock assessments on these fishes, and on managing the stock. Consequently an investigation of variations in the demographic characteristics of fish stocks and their associated fisheries in NSW estuaries and coastal locations was warranted. The collection of size, sex and age structured data is fundamental to the assessment of many fisheries. Because of the multi-method nature of the commercial estuarine and coastal finfish fisheries, it was also necessary to investigate gear-related differences in the sex, size and age compositions of catches.

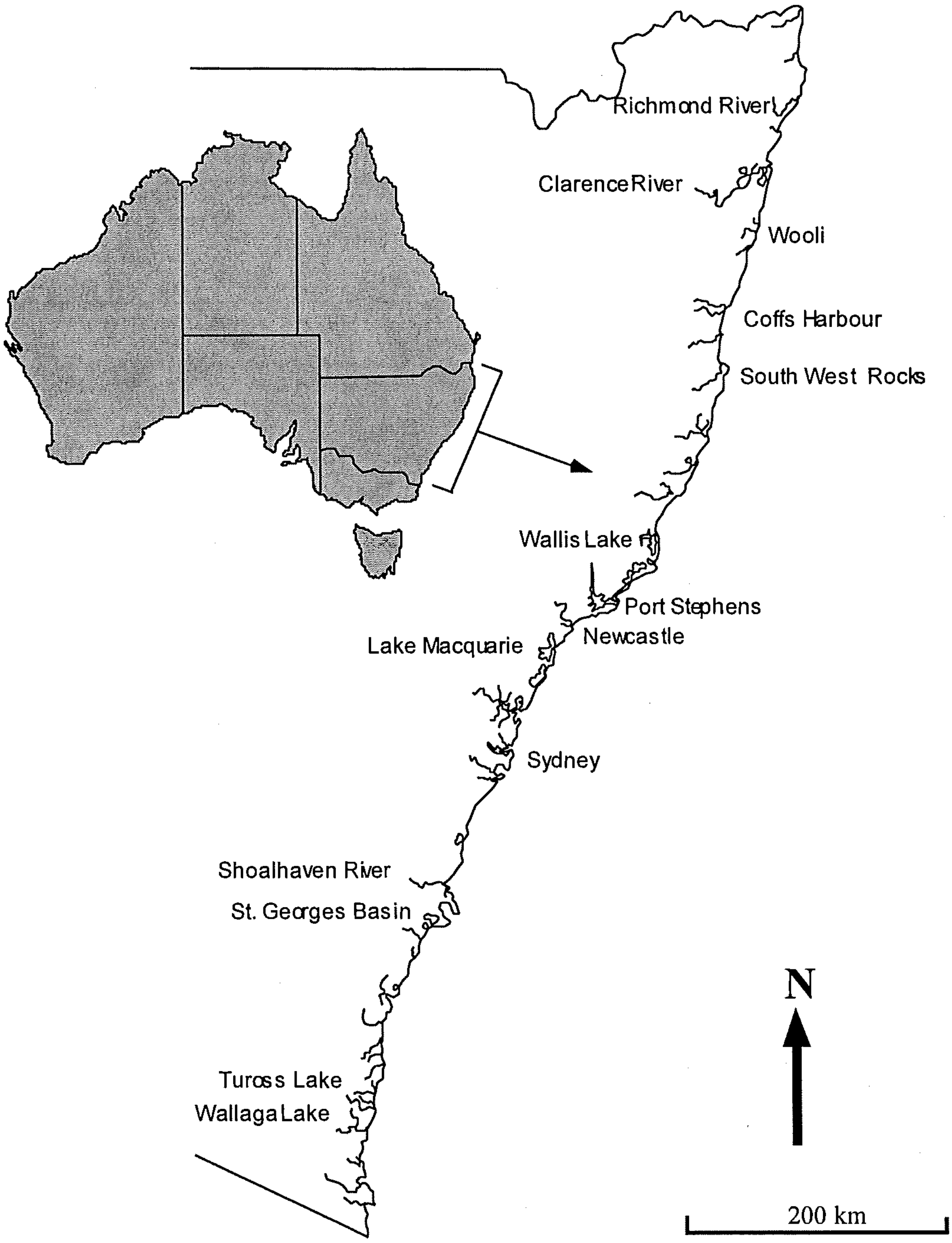
This chapter describes the sampling procedures used to determine variation in the sex, size and age compositions of the commercial fisheries for bream, sand whiting, dusky flathead and luderick in selected estuaries in NSW. The results and discussions of this work are presented separately for each species in the following four chapters.

3.2 Study locations and sampling rational

Throughout the course of this study, commercial catches of the four targeted species were examined from 9 estuaries (Richmond River, Clarence River, Wallis Lake, Port Stephens, Lake Macquarie, Shoalhaven River, St. Georges Basin, Tuross River and Wallaga Lake), and from 4 ocean areas (Brooms Head/Wooli, South West Rocks, Seal Rocks/Port Stephens and Wreck Bay) throughout NSW (Figure 3.1). Sampling of commercial catches took place between February 1995 and December 1997.

The estuaries and ocean areas sampled spanned the geographic range of the estuarine and ocean beach finfish fishery in NSW and included estuaries that varied greatly in size and those with fisheries of different

Figure 3.1. Map of NSW showing the locations of the estuaries and ocean areas sampled during this study.



stature (i.e. high and low commercial fishing effort and production). Some estuaries sampled had a central co-operative where most fishers landed their catches, whereas other estuaries had no co-operative and fishers had "consents" to sell their fish privately. It was considered that sampling of estuaries with different fisheries characteristics assessment studies on estuarine fishes in NSW. Sampling over a wide geographic spread of estuaries and ocean areas also permitted an assessment of latitudinal trends in growth and size at age of the study species.

3.3 Sampling for size and sex composition of commercial catches

Initially it was envisaged that the Sydney Fish Market could be used as a base to sample commercial catches for determining their sex, size and age composition, as this has been successful for researching other fisheries (e.g. gemfish in southeast trawl fishery). Unfortunately, after preliminary investigations this was not deemed suitable for all species and/or ports in the estuarine fisheries due to: 1) not all co-operatives send their fish to Sydney, and many fish are retained for local, interstate and overseas markets; 2) fish are often graded by size and specific sizes are retained for particular markets; 3) individual fishers are not always identified, and therefore the method of capture remained unknown; 4) in some areas, fishers had consents to sell their fish privately and did not always send their fish to markets. It was therefore decided that, where possible, sampling of commercial catches would be done at the points of landing, i.e. the local co-operatives and/or at local fishers premises. Several staff were therefore employed on a part-time casual basis to collect this information at the points of landing.

When possible, commercial catches were sampled for length and sex composition on a seasonal basis. Whole catches or random subsamples of whole catches were measured. Catches from as many different fishers as possible were sampled on any given day at each port. The gear-type(s) used to capture fish was obtained from fishers at the time the fish were being examined. Fish were measured to the nearest 0.5 cm below, i.e. a fish 23.8 cm was recorded as 23.5 cm. For presentation, however, fish were pooled into 1 cm size categories (e.g. 23.0 + 23.5 cm group). Assessing the sex and age composition of catches usually incurred a cost (see below), and therefore where practical, research staff worked with local processors (filleters and buyers) and were able to sex the frames of fish and extract otoliths (see below) at no or minimal cost.

3.4 Sampling of commercial catches for age composition

Sagittal otoliths were used to estimate the age of all four species of fish. Sagittae were collected from random subsamples of catches of all 4 target species from the various locations between February and May (estuary catches) and April and July (ocean catches) in each year. Otoliths were collected in proportion to the number of fish in each length category in the corresponding length composition of catches from each location. Between 200-600 otoliths were collected for each species at each location in each year. Otoliths from male and female fish were collected to assess sex-related differences in growth and age structures of the commercial landings. Otoliths were extracted, cleaned in freshwater, dried and stored in paper envelopes until preparation in the laboratory.

For comparative purposes it was important that all locations were sampled in the one time period. The autumn period was deemed best for this for several reasons:
(a) fishing effort and production of all four target species is generally high during autumn, meaning that the samples collected were representative of the predominant catches, and it ensured an adequate supply of samples. During winter, effort and production of fish is generally lowest whilst in spring and summer, many fishers engage in alternate fishing practices (predominantly prawning);
(b) Previous examination of sectioned sagittal otoliths suggested that they were most easily interpreted when collected in autumn as the previous growth increment was furthest from the otolith margin (see Appendix I). Further preliminary examinations of sectioned sagittal otoliths of all four species indicated that annuli/growth checks were deposited in winter, being first observed in spring, making it difficult to observe the newly formed increments on otoliths and to assign ages throughout the spring/summer period.
(c) the gonads of many estuarine fish are undeveloped during summer making it difficult to sex fish;

The collections of otoliths were made from a combination of the points of landing and from the Sydney Fish Market as the problems of sorting and grading fish as highlighted above did not affect the collection of otoliths. The sampling of otoliths and sexing of fish incurred a cost as all four target species are normally marketed whole, and the extraction of otoliths via a sub-cranial incision meant that some (though minimal) damage was done to the fish. Furthermore, the abdominal cavity of fish needed to be cut open to determine their sex. Because many fish generally had to be purchased at a time (often in 20-30 kg quantities), otoliths were collected in batches, although a maximum of 40 otoliths of any species was taken from any one catch. At the Sydney Fish Market, fish were pre-purchased prior to auction and subsequently resold at auction after the otoliths had been extracted, whereas at the regional co-operatives fish were purchased at a nominated price, dissected and subsequently sent to the Sydney Fish Market for auction. Elsewhere, individual fishers were reimbursed the difference in value between sampled and non-sampled fish. The costs of sampling varied depending on the species, the time of year and on the supply and demand of the market. For example, the cost of obtaining sex and age information on bream ranged from $0.20 to $4.00 per kilogram. Bream usually sell for between $4.00 to $12.00 per kilogram. The Sydney Fish Market also imposes a commission of 12% on all fish sold through the Sydney Fish Markets.

3.5 Determination of age and growth

3.5.1 Otolith preparation and reading

Whole and sectioned sagittal otoliths of all four species displayed alternate opaque and translucent zones that could be interpreted as annuli. Preliminary examinations suggested whole otoliths were more difficult to interpret than sectioned otoliths for all four species, and therefore sectioned otoliths were used to estimate the age of all four species of fish in this study.

Sagittae of all four species were cleaned, dried in an oven and examined for condition (perfect, chipped or broken) in the laboratory. Perfect intact otoliths were weighed to the nearest 0.001 mg on a electronic balance. One sagittae (or the part that included the core) from each fish was embedded in clear resin and sectioned (approximately 25-30 µm) in a transverse plane through the focus using a low speed saw fitted with two diamond blades. Both sides of the resulting thin section were then polished on 9 µm lapping film, after which the section was mounted on a standard glass slide and viewed under a binocular microscope (6-25 x magnification, depending on the species) with reflected light against a black background.

Most otolith sections displayed a clear pattern of narrow opaque (light) and broad translucent (dark) zones. Assignment of age was based on counts of completed opaque zones (i.e. number of opaque rings from the focus to the outer edge, usually along the line of the sulcus). Two readers examined and assigned ages (counts of opaque zones) to all sections, and these readings were considered independent as each reader assigned an age without the knowledge of the size or sex of the fish or of the interpretation of the slide by the other reader. On the few occasions when the assigned age of a otolith differed, the section was viewed a third time and where possible assigned a final age. When discrepancies could not be resolved or when otoliths were uninterpretable they were omitted from further analyses.

Although previous unpublished studies by NSW Fisheries confirmed that the otoliths of all four species displayed opaque and translucent zones that could be interpreted as annuli, if a structure is to be used for aging it is essential to know whether the structure continues to grow throughout the life of the fish, and whether the number of zones on the structure increase with its growth. Moreover, the number of zones on the structure must correspond to some regular time scale.

To determine whether the structure continued to grow throughout the life of a fish, otolith weight was regressed against the fork length of the fish. To determine whether the number of zones on each otolith increased with its growth, the otolith weight was regressed against age (number of opaque rings). Otolith weight was the average weight of the right and left otolith or the single weight of either the right or left otolith. Note that it was assumed there were no observed consistent differences in the weight or number of growth zones between the right and left otolith of a fish.

Otolith weight has successfully been used to estimate the age of several species of fish (e.g. Fletcher 1991), and it potentially may be a more economic way to estimate the age of a fish (Worthington et al. 1995a). Therefore, its applicability as a tool to estimate the age of the fish under study here was examined.

3.5.2 Determination of the age structure of commercial catches

The age structures of commercial catches for each species were calculated by applying age-length keys to the combined summer and autumn length frequency data for each estuary location, and for the entire size frequency data for each ocean catch. The numbers of male and female fish aged in each length class were proportional to the numbers of fish of that sex in each size class from the length frequency of landings. A different age-length key was used for each sex at each location and sampling period. The size frequency data for the summer/autumn period was used here as this was when the age samples were collected. The age structures for the males and females were combined in proportion to the sex ratio of each size class in the total population to get the total age structure of catches.

3.5.3 Estimation of growth models

Growth models for each species were derived using age estimates from sectioned otoliths using the procedures outlined in Schnute (1981). Schnute's model relates size to age by several parameters; a, b, y1 and y2. The parameters a and b describe the shape of the growth curve, notably the von Bertalanffy (a>0, b=1), Richards (a>0, b<0), logistic (a>0,b=-1), Gompertz (a>0,b=0). The parameters y1 and y2 represent the mean sizes at ages t1 and t2 respectively, where the value of t1 and t2 are chosen to be near the lower and upper end of the range of ages in the data set being modeled.

All growth models were calculated using additive error models because variation in size at age was similar across all ages of fish for each species. Initially, a two parameter model (y1 and y2) was fitted to the data, after which two types of three parameter model (a, y1, y2, and b, y1, y2) and a four parameter model were fitted to the data. To determine whether the addition of extra parameters significantly improved the fit of the model, significance tests based on the F-distribution were used (Schnute 1981). When comparing the three parameter models the model with the lowest residual sums of squares was selected as the best fit.

The parameters from the Schnute model were used to estimate the von Bertalanffy growth equation for each species. Separate analyses were done for each sex, but all growth modeling used data pooled across all locations and times.

4. Variations in size, sex and age compositions of commercial catches of yellowfin bream (*Acanthopagrus australis*) in NSW

4.1 Summary of relevant ecological literature

Yellowfin bream were originally thought to be endemic to the east coast of Australia, however they have also been identified from Japanese waters (Masuda et al. 1984). In Australia they inhabit estuarine and coastal waters between Townsville in Queensland and the Gippsland Lakes in Victoria (Rowland 1984). Although the stock structure of yellowfin bream is uncertain, unpublished preliminary results of tagging studies in NSW (West 1993 and unpublished data) suggest that it is most likely a single stock exists between southern Queensland and NSW, and possibly throughout the eastern Australian distribution.

The time of spawning of yellowfin bream has been reported to vary from April/May in southern NSW to July/August in southern Queensland (SPCC 1981, Pollock 1982a, 1995, Rowland 1984), and it is generally considered that yellowfin bream spawn in the coastal zone along open surf beaches and near the mouths of estuaries (Pollock 1982a, b). Reproductive studies in Queensland indicate that individual yellowfin bream spawn only once each season, and that an unquantified proportion undergo protandrous sex reversal (i.e. change sex from male to female) as reported for several species of sparids (Buxton 1993), apparently after their first spawning season (Pollock 1985, Suparta 1988). The proportion and extent of sex reversal in yellowfin bream throughout its distribution is unquantified. In southern Queensland bream reach sexual maturity at 20 - 21 cm FL (Pollock 1985), whereas in central NSW maturity occurs at about 24 cm FL (SPCC 1981). Yellowfin bream undertake pre-spawning migrations from estuarine to coastal waters and along the coast of NSW between April and July, although the extent of these specific migrations has not been quantified. In Moreton Bay (Queensland) spawning fish move up to 90 km (Pollock 1982b), but very few fish moved out of the bay. In contrast, tagging studies in NSW show that some bream move between estuaries, and that some individuals travel great distances along the coast (> 500 km) (West 1993 and NSW Fisheries unpublished data). Larval and pre-settlement juvenile bream enter estuaries where they settle in shallow, usually vegetated (e.g. seagrass) habitats, and after about 4 months move to other deeper estuarine habitats (SPCC 1981). It is not known whether some post-settlement juveniles spend their early demersal life in coastal and ocean waters.

Estimates of growth of yellowfin bream vary considerably (Table 4.1). Fish aged by scales in Tuggerah Lakes (Henry 1983) reached 9 cm FL at year 1, and 18 cm at year 3, whereas growth determinations by tagging and length frequency analysis in Moreton Bay, Queensland, (Pollock 1982a) reported size at year 1 to be 13 - 14 cm FL, and at age 3 to be 23 - 24 cm FL. Growth rate appears to be rapid until sexual maturity is reached, after which it declines. The oldest ages found for male and female yellowfin bream in NSW were 10 (30 cm FL) and 12 years (39 cm FL), respectively (Henry 1983). The largest yellowfin bream captured in NSW was 56 cm TL (4.5 kg), although specimens over 40 cm TL are rare.

Table 4.1. Comparisons of estimated mean fork length (cm) at age for yellowfin bream from various studies in NSW and Queensland (modified from West 1993).

	Age in years									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Kesteven & Serventy (1941)	11	23	35							
Munro (1945)	7	12	17	21						
Fairbridge (1946)	7	12	15	19						
Munro (1949)	7	11	15	18	20	23				
Dredge (1976)	8	12	16	18	20	22				
Pollock (1982a)	14	21	24							
Henry (1983)	9	13	18	23	24	26	27	29	30	
West (1993)	10	15	17	19	20	22	23	24	25	26

4.2 Overview of the NSW commercial fishery

Yellowfin bream are harvested by commercial and recreational fishers in estuarine and coastal NSW waters. Yellowfin and black bream are combined in the NSW commercial catch statistics, but the black bream only comprise a small (< 5%) component of the estuarine catches. Commercial estuarine production of bream in NSW in 1996/97 was approximately 361 tonnes, whereas the ocean catch was approximately 118 tonnes, with a combined total value to commercial fishers of approximately $ 3.2 million. Annual estuarine production of bream has generally increased over the past 40 years, fluctuating around 200 tonnes between 1954 and 1972, after which production increased to the present 350-450 tonnes (Figure 4.1). Ocean production fluctuated between 25 and 50 tonnes between 1954 and 1978, after which it increased to the present 100-200 tonnes (Figure 4.1). The increase in production in the ocean sector has generally been attributed to greater catches in fish trawls and in haul nets along ocean beaches. The inter-annual fluctuation in ocean production is probably due to inclement weather conditions affecting fishing effort.

Annual commercial production of bream varies greatly between estuaries and between coastal areas, with greatest estuarine and ocean production occurring in the central region of NSW. Port Stephens, Tuggerah Lakes, Lake Macquarie, Clarence River and Botany Bay have generally accounted for approximately 50% of the total estuarine commercial catch over the past 5 years (Figure 4.2). Most ocean caught bream are taken in zones 5 and 6 (Manning River to Botany Bay) (Figure 4.3). Commercial estuarine and ocean catches of yellowfin bream decline south of St. Georges Basin.

In most estuaries bream are primarily caught by mesh and haul nets, but in some estuaries (e.g. Clarence River) significant quantities are also caught in fish traps and by handlining. In Port Stephens

Figure 4.1 Annual commercial estuarine and ocean landings of bream from 1954/55 to 1996/97.

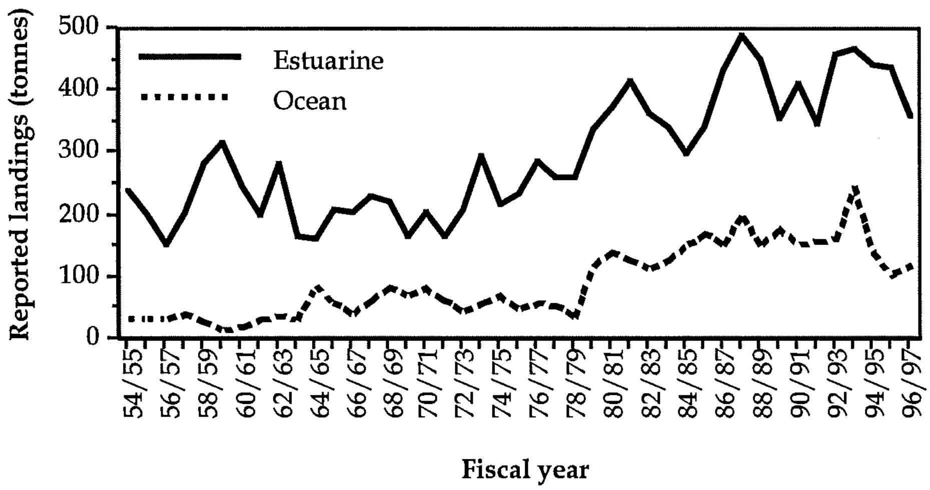


Figure 4.2 Average (+ 1se) commercial estuarine landings of bream in the top 20 estuaries in NSW for the period 1992/93 to 1996/97.

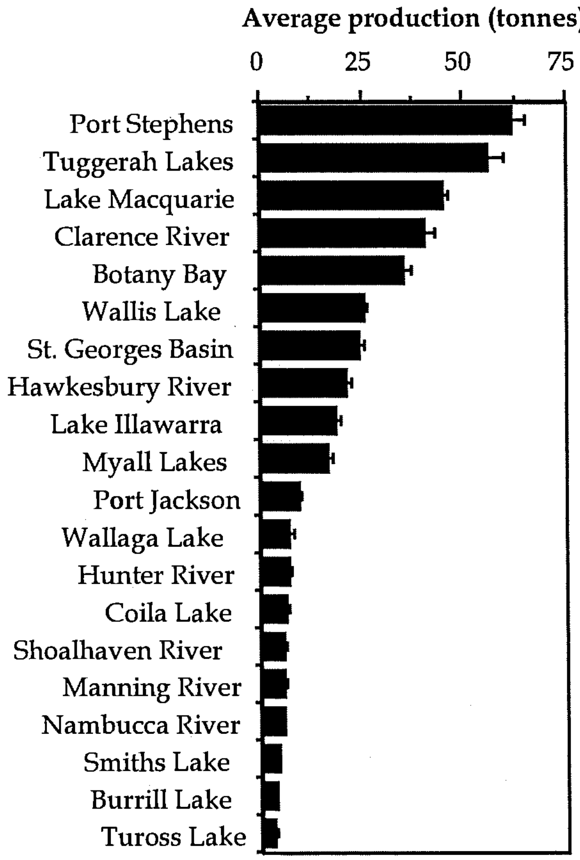


Figure 4.3 Average (+ 1se) commercial ocean landings of bream in each ocean zone in NSW for the period 1992/93 to 1996/97.

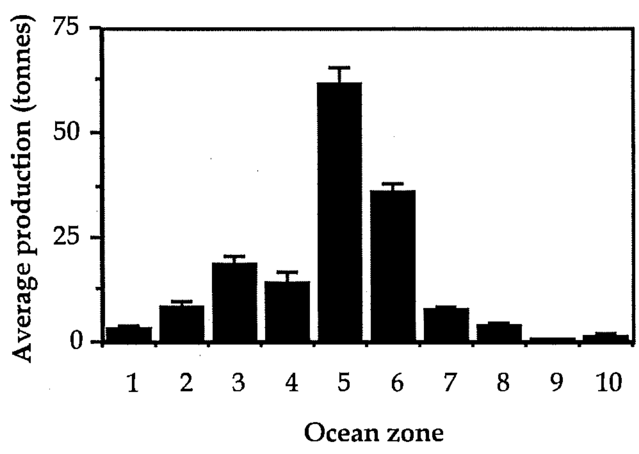
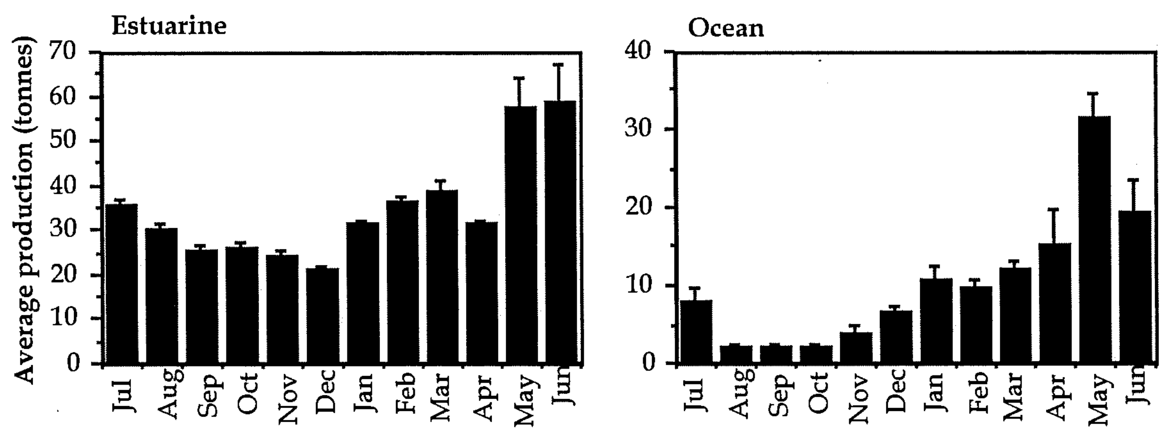


Figure 4.4 Average (+ 1se) monthly commercial estuarine and ocean landings of bream in NSW for the period 1992/93 to 1996/97.



a large quantity have also been taken in "pound nets", but this method of fishing is being phased out. Most ocean catches of bream are taken by haul nets in the ocean beach fishery, but significant catches are also made by fish trawling, trapping and in the Port Stephens area by an ocean located "pound net".

Although yellowfin bream are caught all year round, estuarine and ocean production is generally greatest in May and June (autumn) during the 'travelling' season, particularly on the ocean beaches (Figure 4.4). This same seasonal trend in commercial production occurs in southern Queensland (Brown et al. 1996).

No formal stock assessments of yellowfin bream in Australia have been published. However, Henry (1983) described the commercial estuarine fishery for bream in Tuggerah Lakes, and reported that haul and mesh net catches comprised fish between 22-30 cm FL, with the majority between 22-25 cm FL. Commercial catches of bream were dominated by 3-4^+ year old fish (based on scale readings). Henry (1983) estimated annual total mortality of bream in Tuggerah Lakes to be 65%.

The fishery for yellowfin bream in NSW is managed through a complex set of gear and fishing time restrictions, spatial and temporal closures, minimum net mesh sizes and minimum legal fish size regulations. Two regulations specifically relate to the management of bream in NSW, namely a minimum legal length limit of 25 cm TL (approximately 22 cm FL) which applies to commercial and recreational fishers, and a recreational bag limit of 20 fish per day per angler.

4.3 Aims of this chapter

This chapter describes spatial, temporal and gear-related variations in the sex composition, size and age structure of commercial estuarine and ocean landings of bream in NSW between 1995 and 1997. Relationships between age and length of bream and preliminary estimates of growth are presented and recommendations for future monitoring of bream landings in NSW are discussed.

4.4 Methods

Commercial catches of bream from 8 estuaries (Richmond River, Clarence River, Wallis Lake, Port Stephens, Lake Macquarie, St. Georges Basin, Tuross River and Wallaga Lake) and from 4 ocean areas (Brooms Head/Wooli, South West Rocks, Seal Rocks/Port Stephens and Wreck Bay) were sampled throughout the study.

The methods used in the field and laboratory followed the protocol detailed in Chapter 3.

4.5 Results

4.5.1 Variation in size and sex composition of commercial catches

The size compositions of bream retained in commercial estuarine catches were relatively similar across different gear types (mesh net, haul net and trap), estuaries, seasons and years (Figures 4.5-4.7, and 4.9). Bream retained in commercial operations ranged between 20-42 cm FL, but catches using all gear types were generally dominated by small fish (22-24 cm FL), immediately above the minimum legal length (22 cm FL). However, there were some notable exceptions to the general pattern. In the Clarence River, for example, catches from haul nets and traps generally had a greater proportion of fish > 25 cm FL than mesh net catches (Figures 4.5- 4.7). Few fish > 30 cm FL were taken in mesh nets, probably because of the selectivity of the gear. Some inter-estuary variations in the size composition of catches were evident; notably bream > 25 cm were less abundant in haul net catches from Lake Macquarie compared with other locations. No distinct seasonal or annual patterns of change in the size structures of bream landings were evident across any estuaries or gear types.

Bream retained in ocean haul catches from surf beaches and from pound nets in the Port Stephens area ranged between 20-42 cm FL, but as in the estuaries, catches were dominated by fish between 22-25 cm FL (Figure 4.8). The mean size of fish taken in this sector of the fishery, particularly the pound nets, was slightly larger than that in estuaries (Figure 4.9).

The sex composition of commercial landings of bream generally comprised a higher proportion of females, the main exceptions being the fish trap catches in the Clarence River and the pound net catches in 1996 (Figure 4.10). The size composition of landings also varied between sexes, with females generally being larger than males (Figure 4.11). Females generally displayed a larger size range than males, the main exception being for fish from Lake Macquarie.

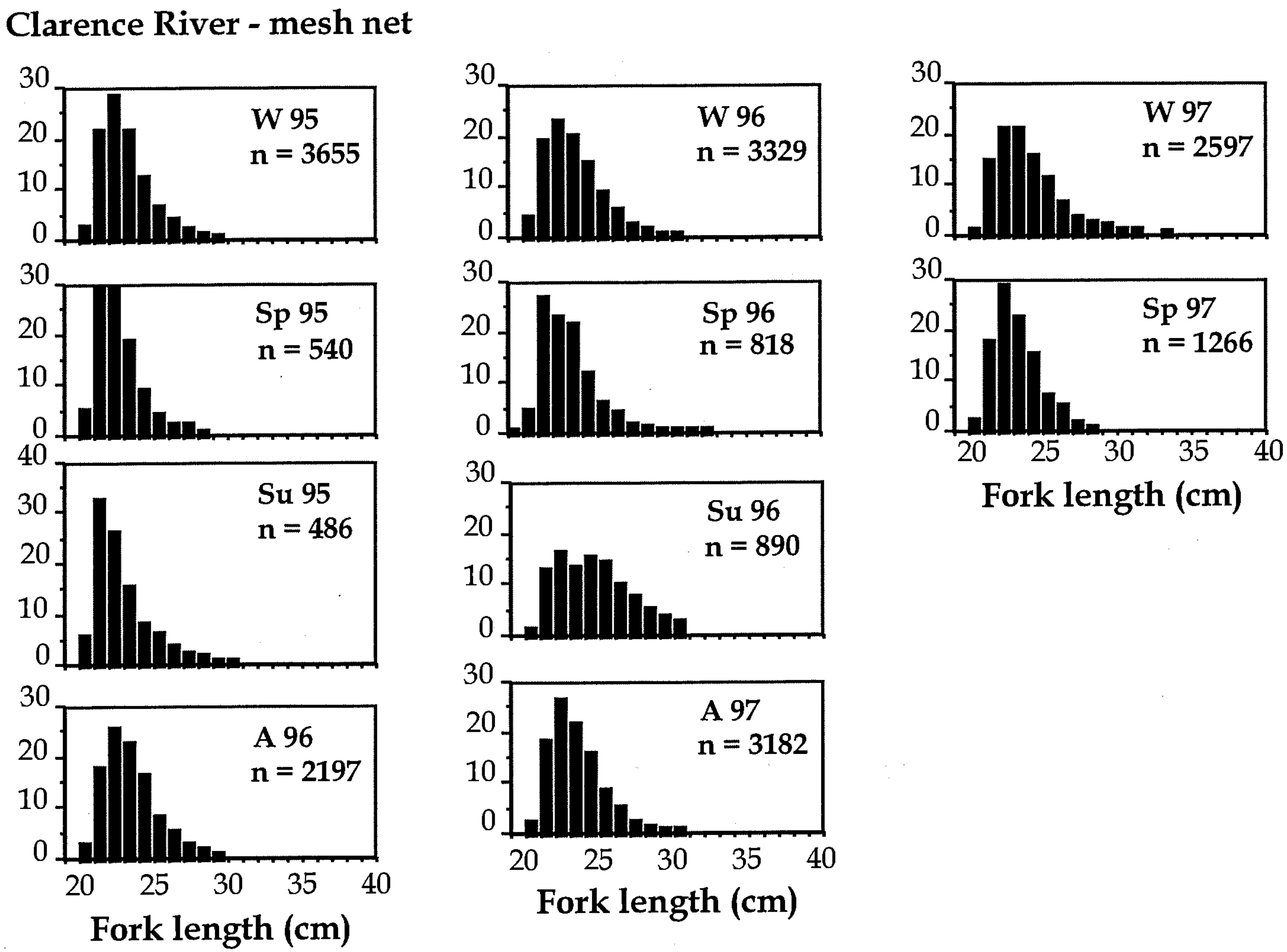
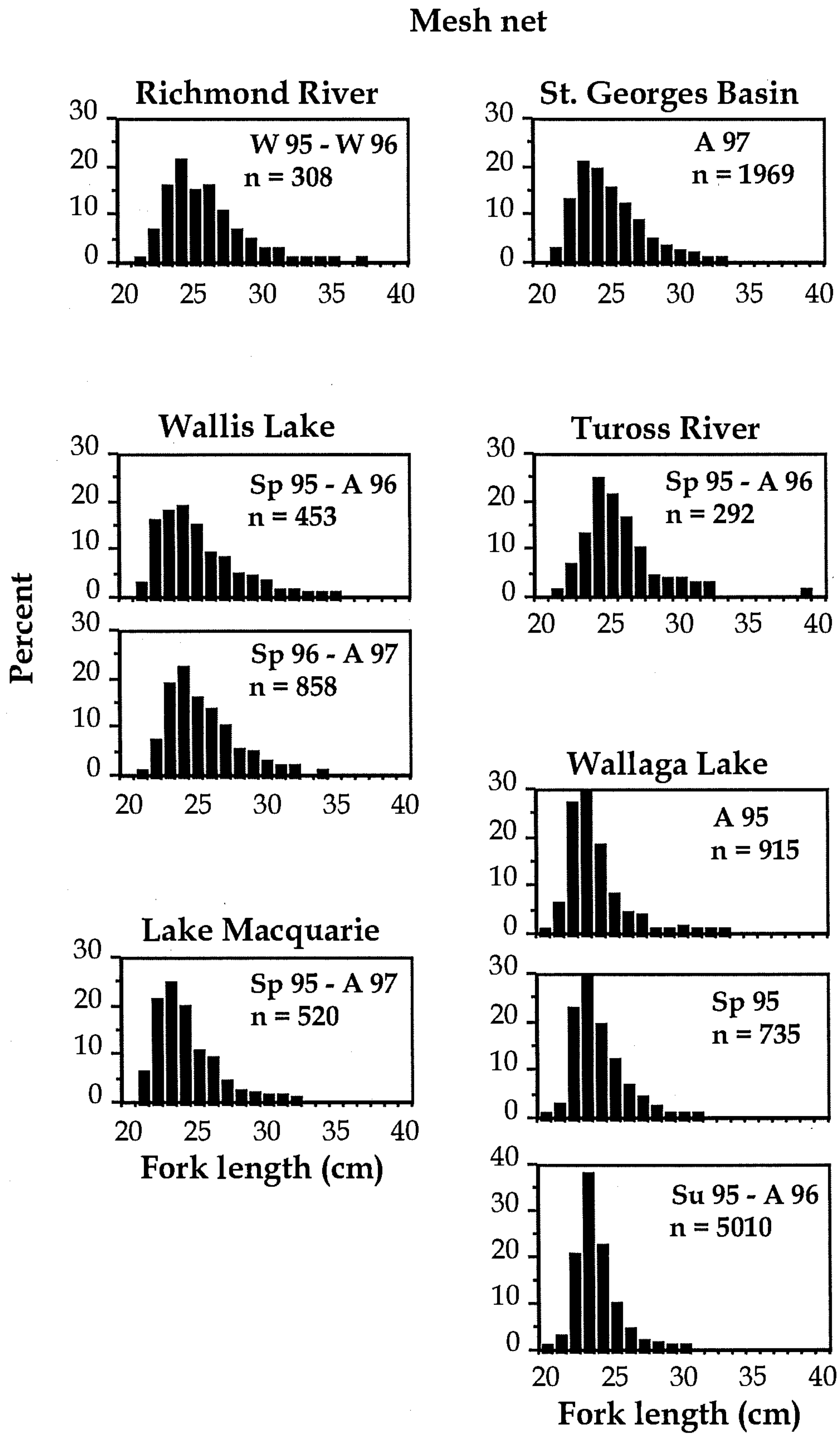


Figure 4.5. Size-frequency distributions of commercial estuarine mesh net landings of bream.

Figure 4.5. continued.



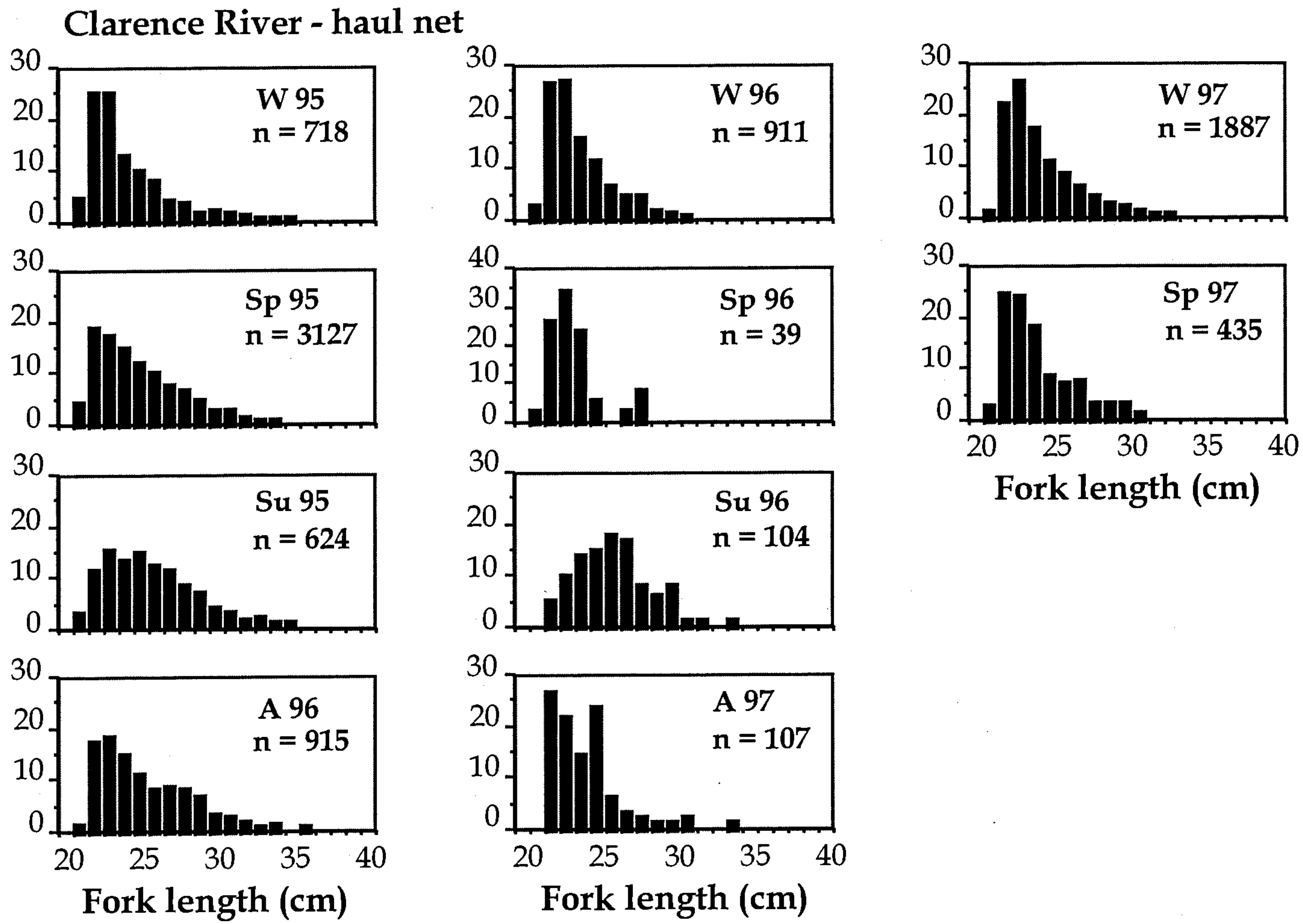


Figure 4.6. Size-frequency distributions of commercial estuarine haul net landings of bream.

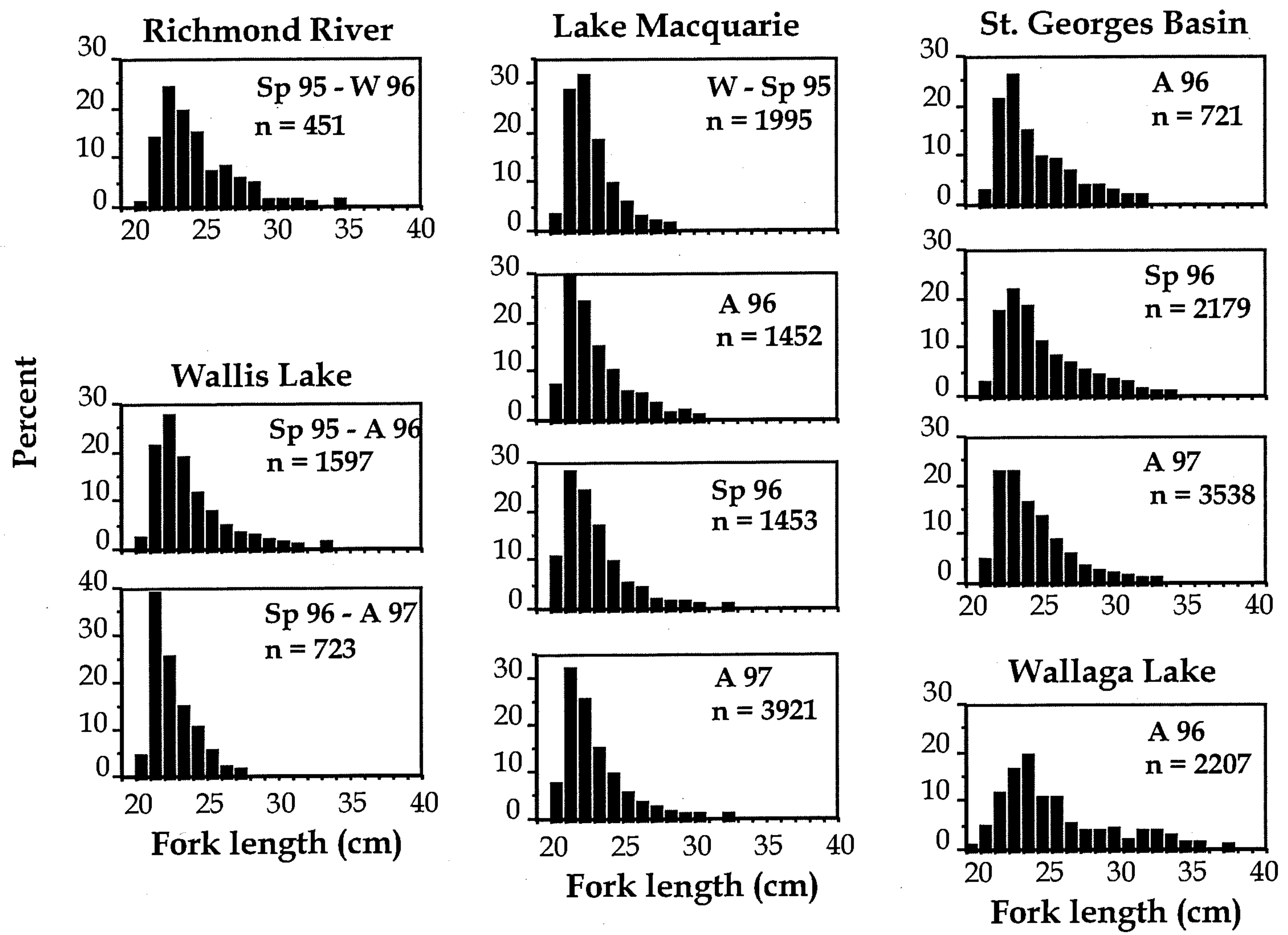


Figure 4.6. continued.

Figure 4.7. Size-frequency distributions of commercial trap landings of bream from the Clarence River.

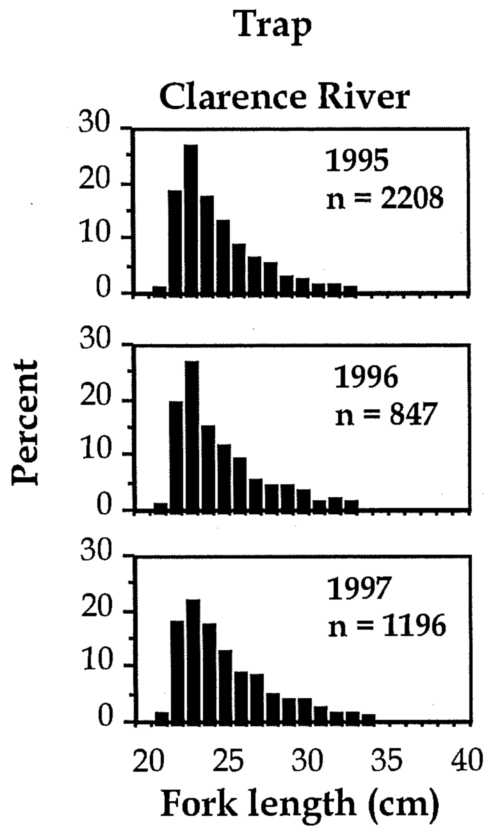


Figure 4.8. Size-frequency distributions of commercial landings of bream from pound nets in Port Stephens and from ocean haul nets.

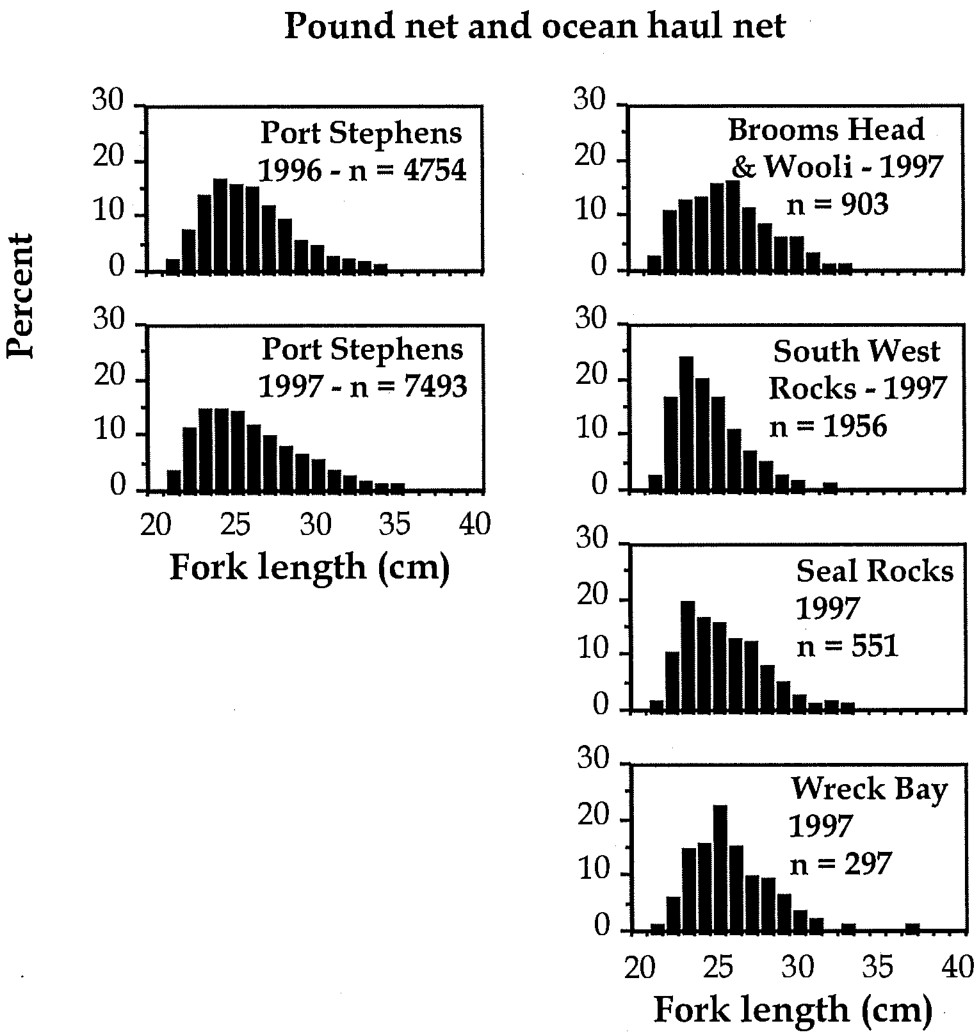


Figure 4.9. Total size-frequency distributions of commercial mesh, haul and pound net, and trap landings of bream.

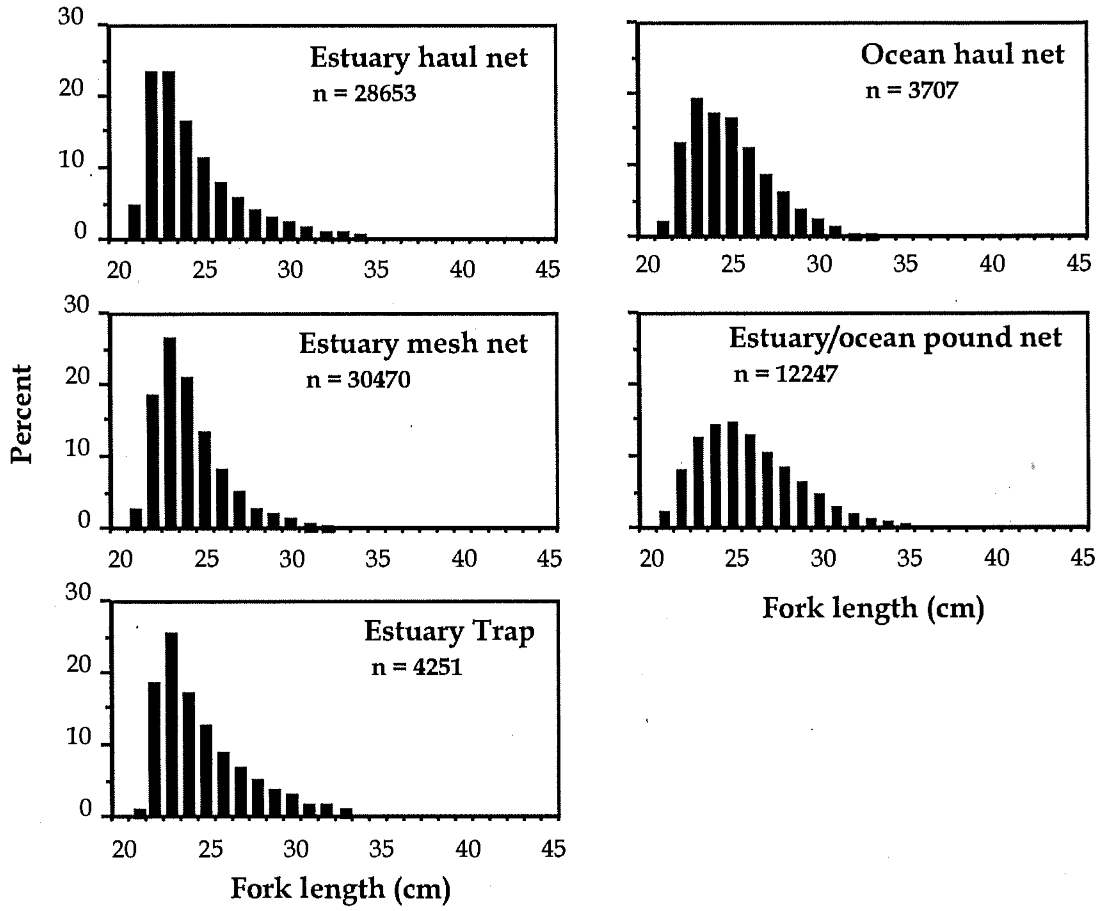
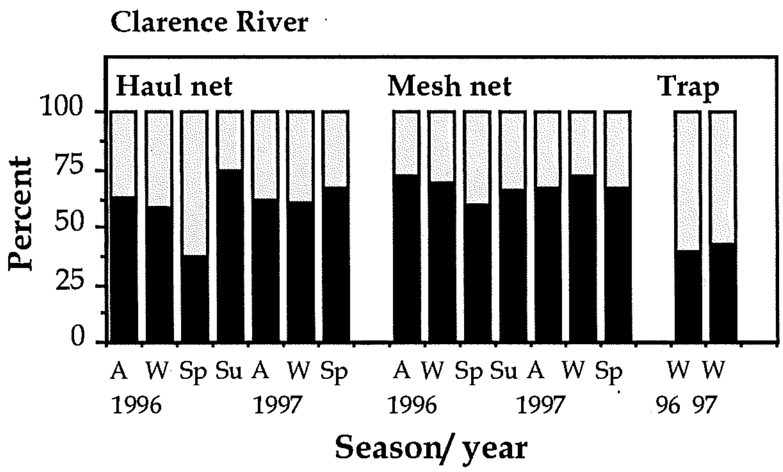
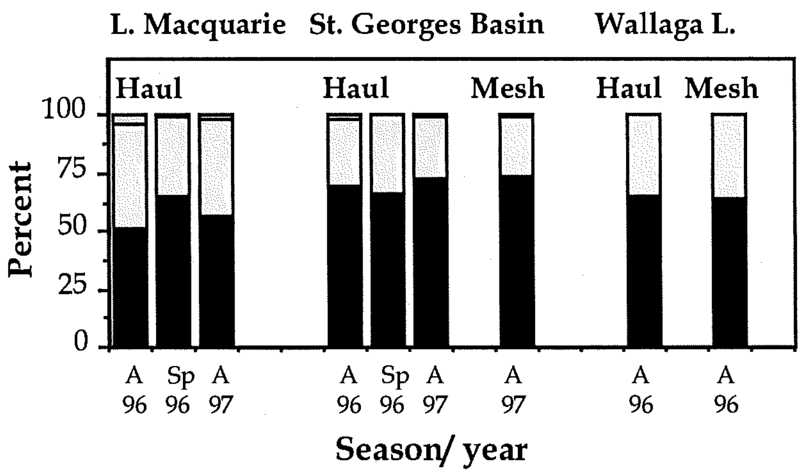


Figure 4.10. Sex ratio of commercial estuarine and ocean landings of bream. N = combined Brooms Head, Wooli and South West Rocks haul net catches; M = combined Port Stephens pound net and Seal Rocks haul net catches; S = Wreck Bay haul net catches.





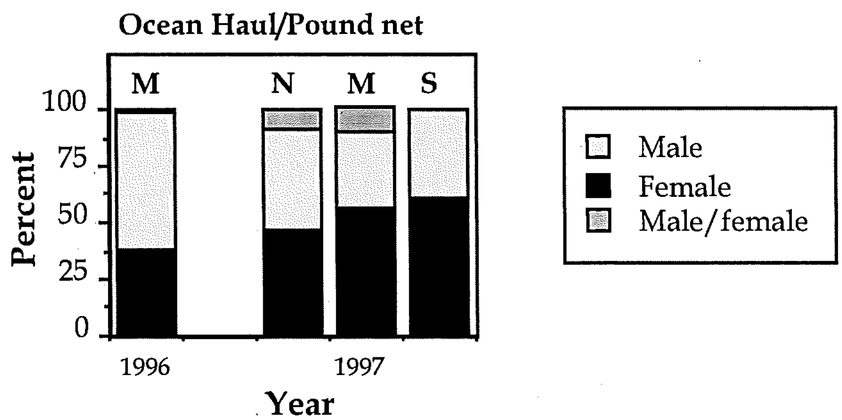
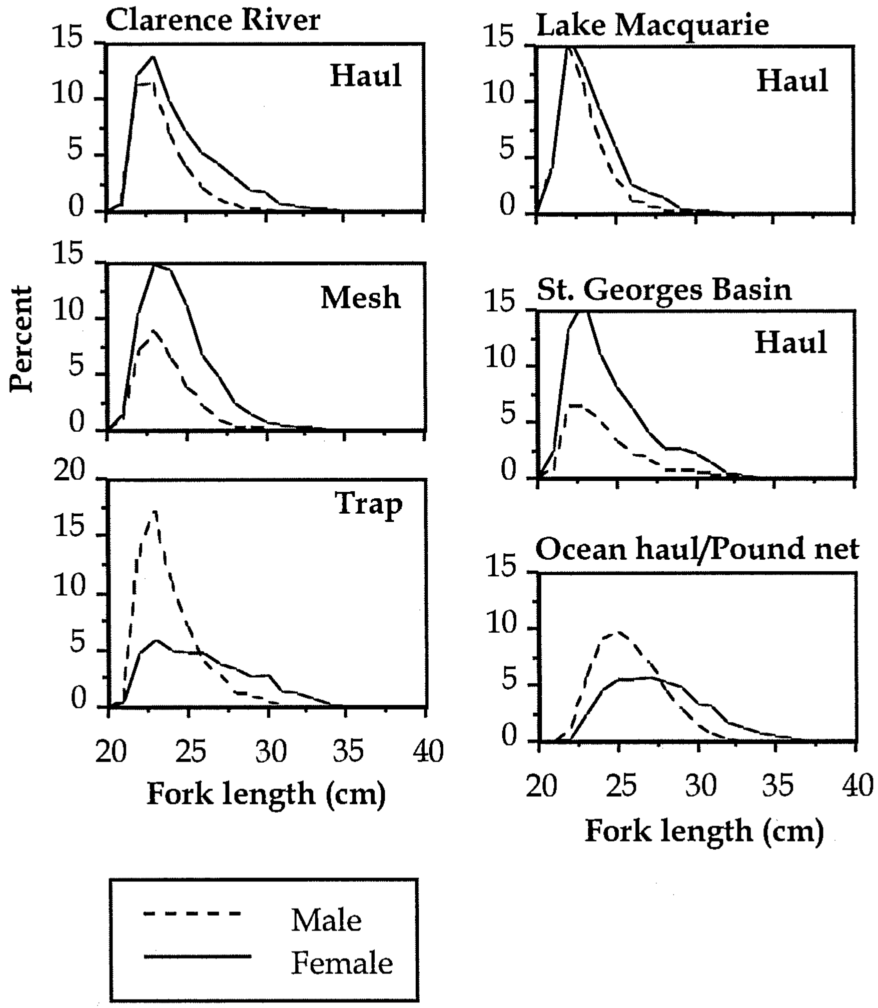


Figure 4.11. Total size-frequency distributions of male and female commercial landings of bream.



4.5.2 Age determination

Both whole and sectioned sagittal otoliths of bream displayed alternate narrow opaque and wide translucent zones (rings) that could be interpreted as annuli (Figure 4.12). However, preliminary investigations identified that the rings were more easily interpretable in sections than whole otoliths, particularly for older fish, and thus sectioned otoliths were used in this study to estimate the age of bream.

There was strong agreement (82-96%) between the two independent readers in assigning ages to sectioned otoliths of bream, and there was no obvious spatial (latitudinal) trend in the agreement of assigning ages to bream (Table 4.2).

The relationship between age and fork length was weak for male and female bream, as there was a large spread in the length of bream at any given age (Figure 4.13), indicating that length is a poor indicator of age of bream above the minimum legal limit. Logarithmic equations best described the relationships between age and fork length of male and female bream. Otolith weight generally increased with increasing size and age of bream, suggesting that they continued to grow throughout the life of the fish, and are therefore potentially a suitable structure for estimating the age of bream. Linear equations best described relationships between otolith weight and fork length, and otolith weight and age, although the relationships were relatively weak (Figure 4.13).

Table 4.2. Replication of age interpretation of bream otoliths by two independent readers. Note that there was no apparent bias over any particular age group.

Location	No. otoliths examined	% agree	% differ > 1yr
Clarence River 1995	438	85.1	2.5
Clarence River 1996	316	81.6	0.9
Clarence River 1997	540	90.5	1.1
Lake Macquarie 1996	278	95.4	0.4
Lake Macquarie 1997	468	94.3	0.4
St. Georges Basin 1996	406	84.2	0.2
St. Georges Basin 1997	608	82.2	1.6
Wallaga Lake 1996	350	88.8	0
Port Stephens 1996	719	94.6	0.3
Port Stephens 1997	541	96.2	0
South West Rocks 1997	200	95.5	0

Figure 4.12. Photos of sectioned yellowfin bream otoliths showing the alternate narrow opaque zones and wider translucent zones across the section.

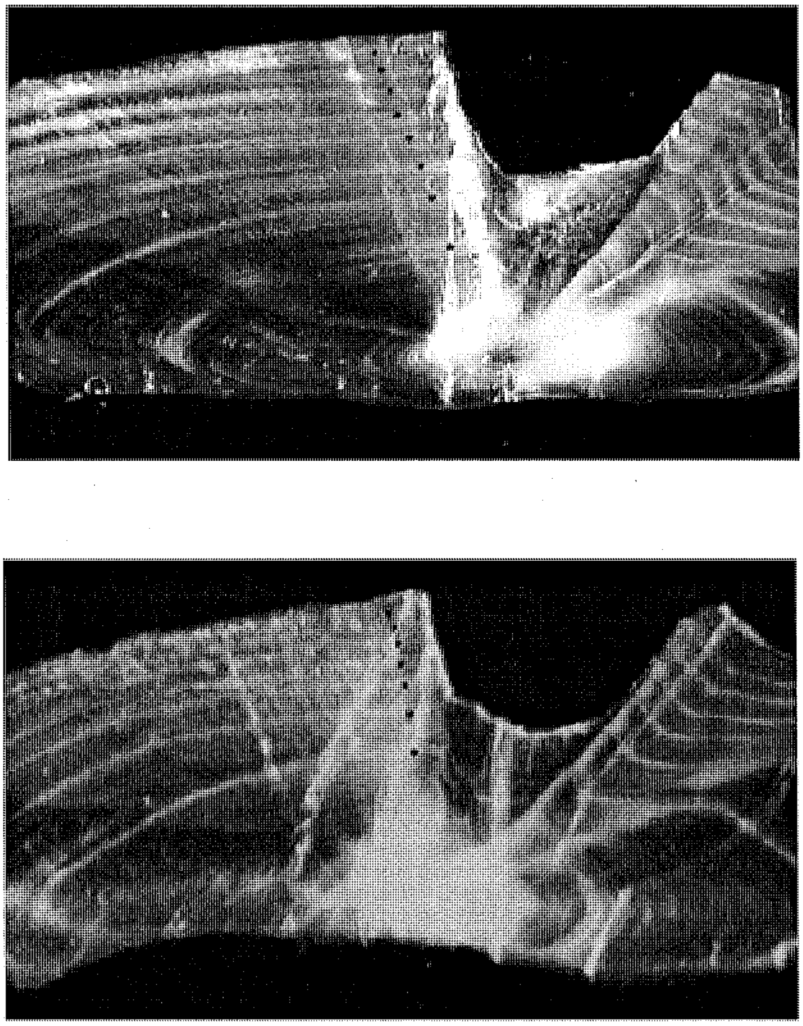
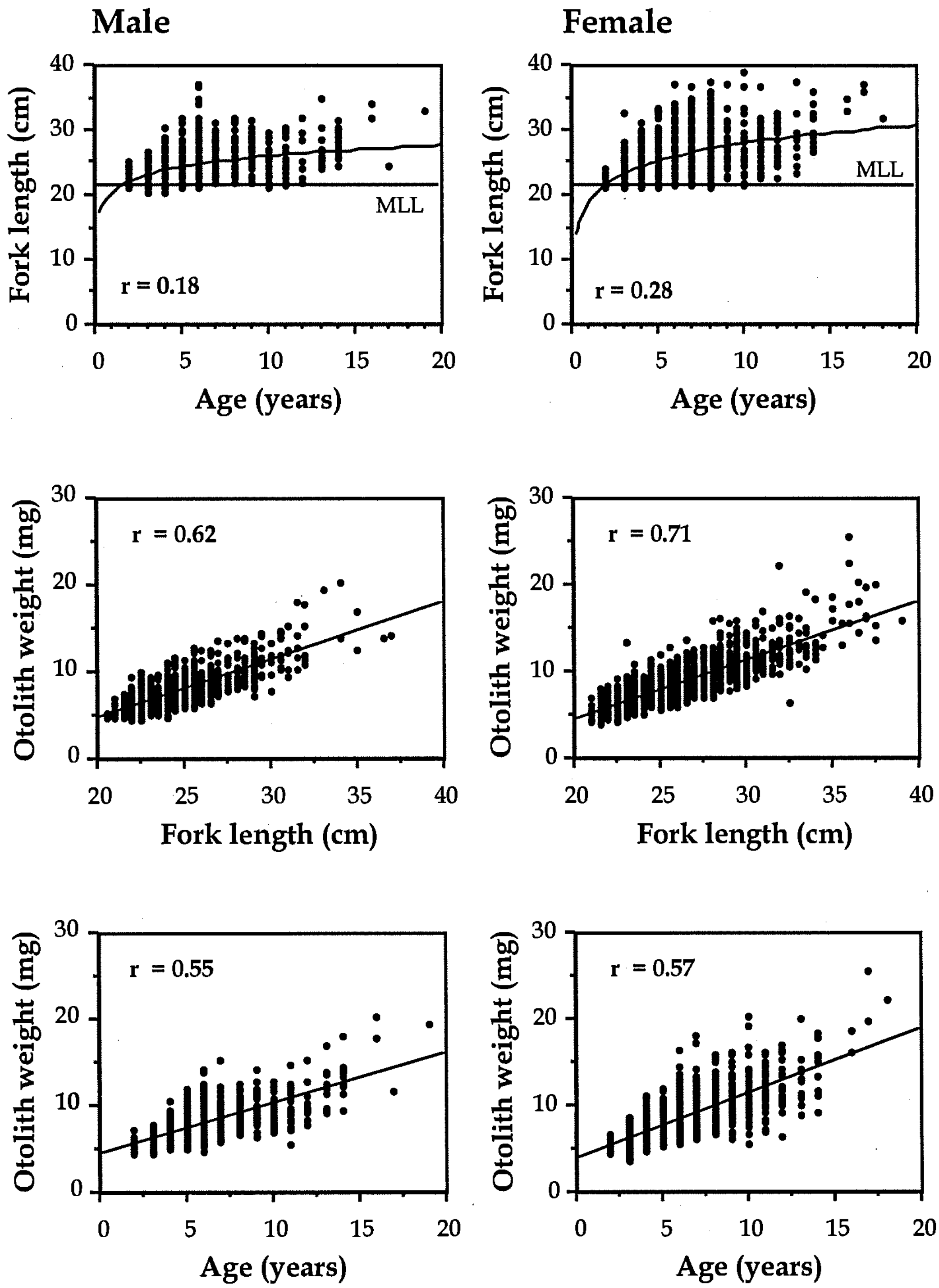


Figure 4.13. Relationships between estimated age, fork length and otolith weight for male and female bream. MLL = minimum legal limit.



4.5.3 Variation in age structure of commercial catches

Although there was a consistent difference in the size composition of male and female fish, the age structure of the male and female components of commercial estuarine and ocean catches was generally similar for each sample (Figure 4.14). Thus further analyses on variations of the age structure of catches were made using data pooled for males and females. Commercial estuarine and ocean catches of bream sampled in this study contained fish aged from 2-19$^+$ years, although catches primarily comprised fish aged between 3-8$^+$ years (Figures 4.15 and 4.16).

There was considerable variation between estuaries in the age structure of bream catches, with the dominance of any particular year class(es) and the average age of fish harvested varying between estuaries (Figure 4.15). For example, in 1997 catches in the Clarence River were dominated by fish aged 6-8$^+$, in Lake Macquarie by fish 4-5$^+$, and in St. Georges Basin by fish 3-4$^+$, indicating that there may be a latitudinal gradient in the age structures of bream populations along the coast. These data also indicate that there are strong variations in year class strength between estuaries. These differences in age structure occurred even though the size composition of catches within each estuary was fairly similar (see Figures 4.6 and 4.7). In contrast, the age structure of the pound net and ocean beach catches in 1997 were similar, with 4-5$^+$ fish dominating. The average age of bream landings ranged between 4.4 and 6.3 years and with the exception of the Clarence River, very few fish aged > 8$^+$ were caught (Figures 4.15 and 4.16).

The progression of certain year classes (strong or weak) could be followed in some locations. For example, the relatively strong 6$^+$ and weak 7$^+$ cohorts in the Clarence River in 1995 could be followed to 1996. Likewise, the relatively weak 5$^+$ cohort in the pound net catches in 1996 could be followed through to 1997 as the weak 6$^+$ cohort (Figures 4.15 and 4.16).

Figure 4.14. Estimated age structures of male and female commercial landings of bream.

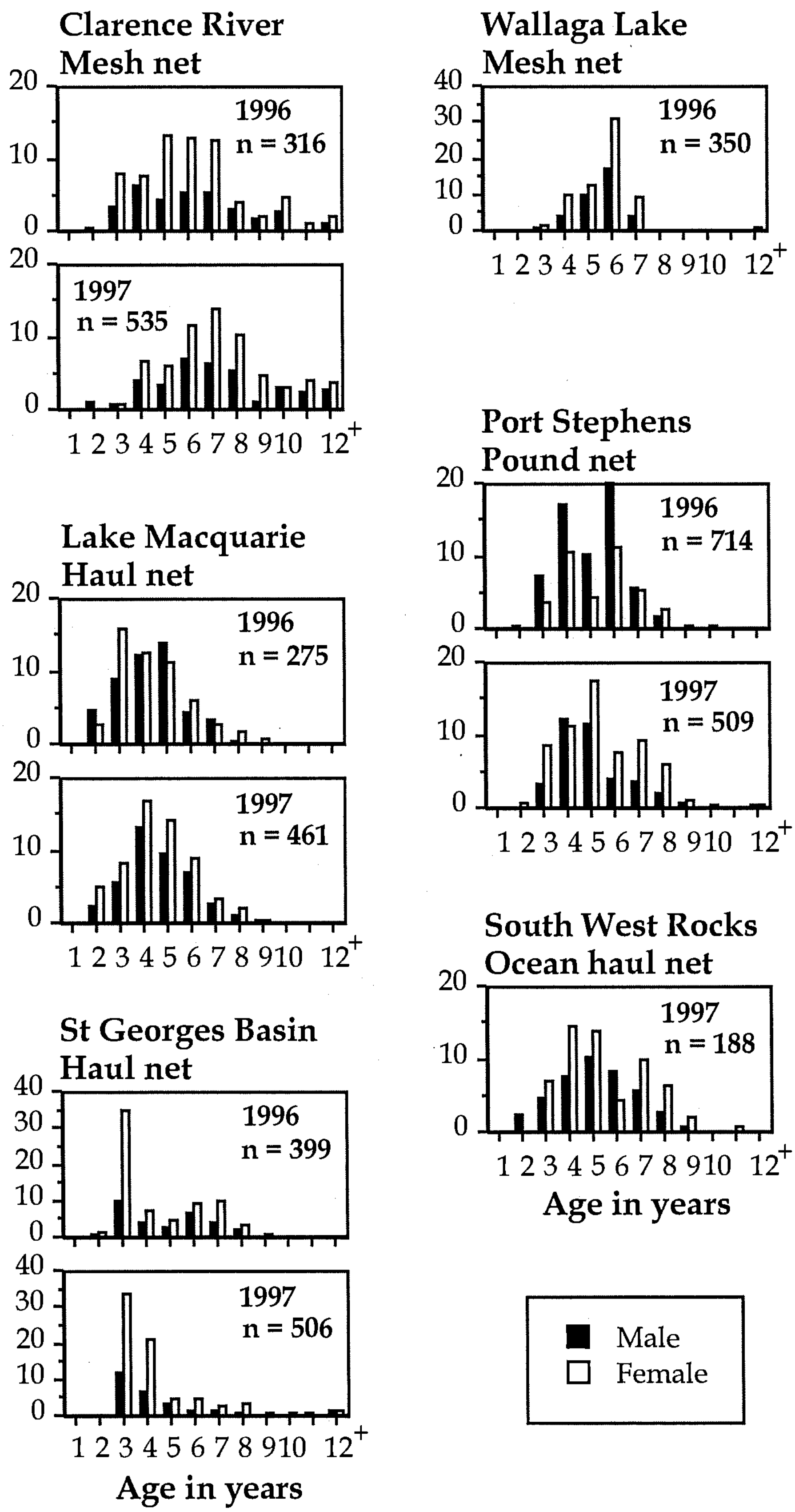
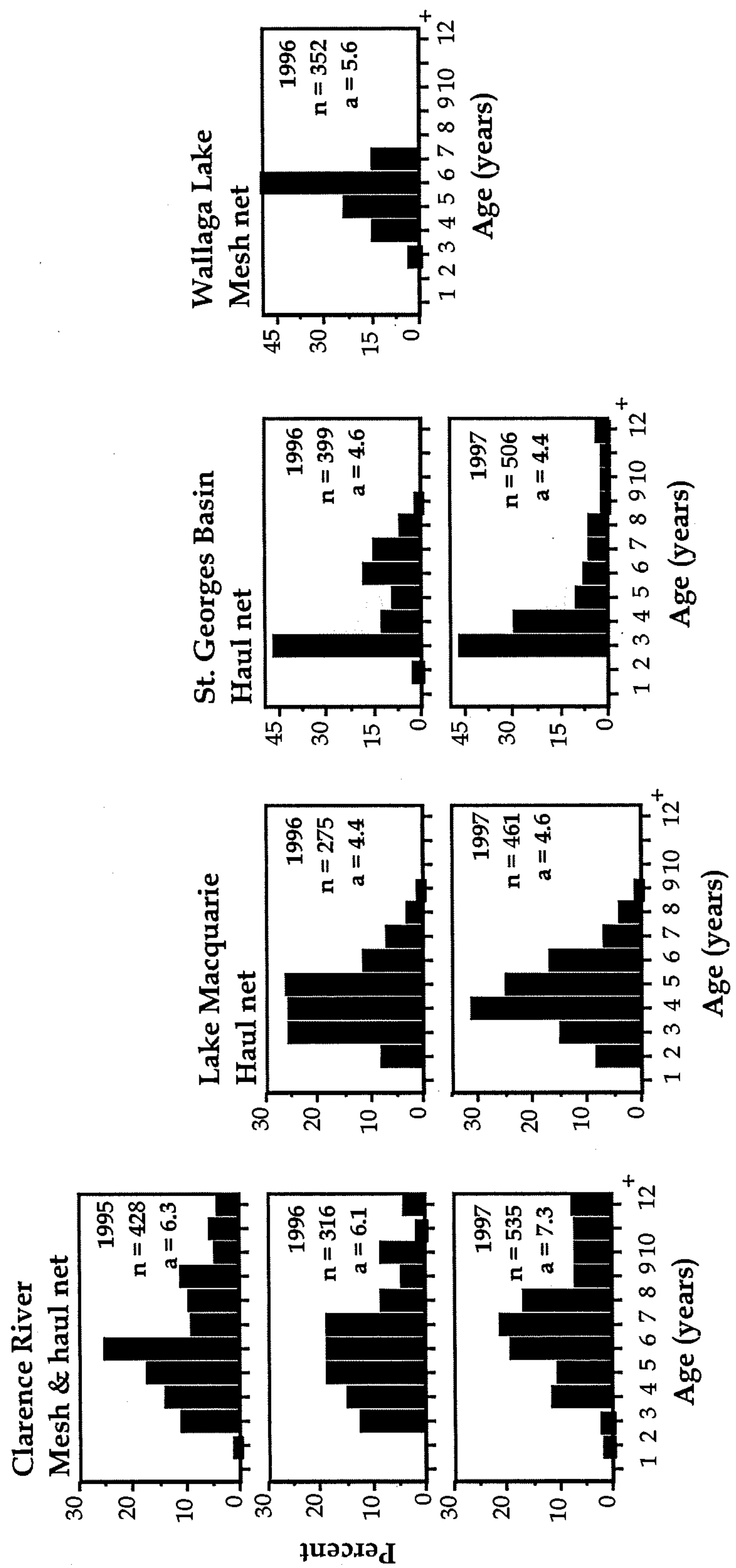


Figure 4.15. Estimated age structures of commercial estuarine landings of bream. n = no. otoliths; a = mean age in years.



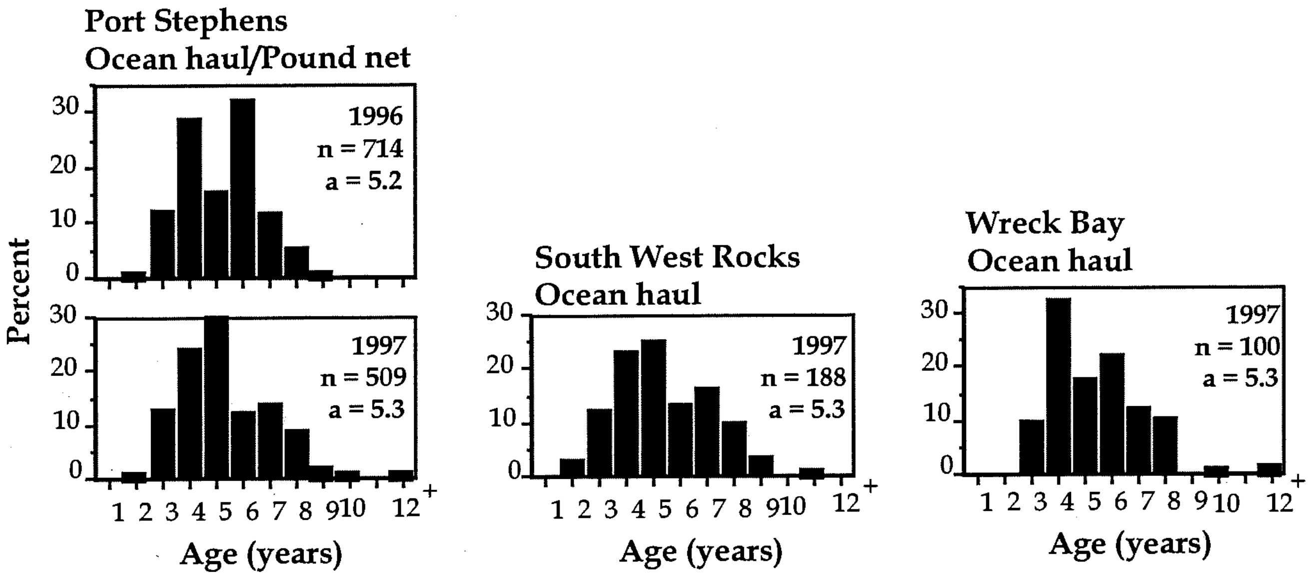


Figure 4.16. Estimated age structures of commercial ocean and pound net landings of bream.

4.5.4 Variation in size at age relationships and growth

There was considerable variation in the lengths of male and female bream at any given age (Figure 4.13), which was evident across all locations. There appeared to be some differences between locations in the mean length of bream at age, in particular the older age classes at Port Stephens tended to have a larger mean length at age than elsewhere (Figure 4.17). Estimates of the growth of bream in NSW were performed on data pooled across all locations using Schnute's (1981) growth model and the von Bertalanffy growth function.

Growth of male and female bream were best described by 4 parameter models (case 1 in Schnute 1981). The average length of male and female bream at age 3 was 23.09 and 23.28 cm FL, and at age 7 was 25.06 and 26.43 cm FL, respectively. The von Bertalanffy growth function gave estimates of L_∞ of 31.16 and 34.56 cm FL for male and female bream, respectively. Estimates of growth using both types of analyses do not describe the growth of young fish because of the truncation of the data at fish of 22 cm FL (i.e. undersized fish were not sampled).

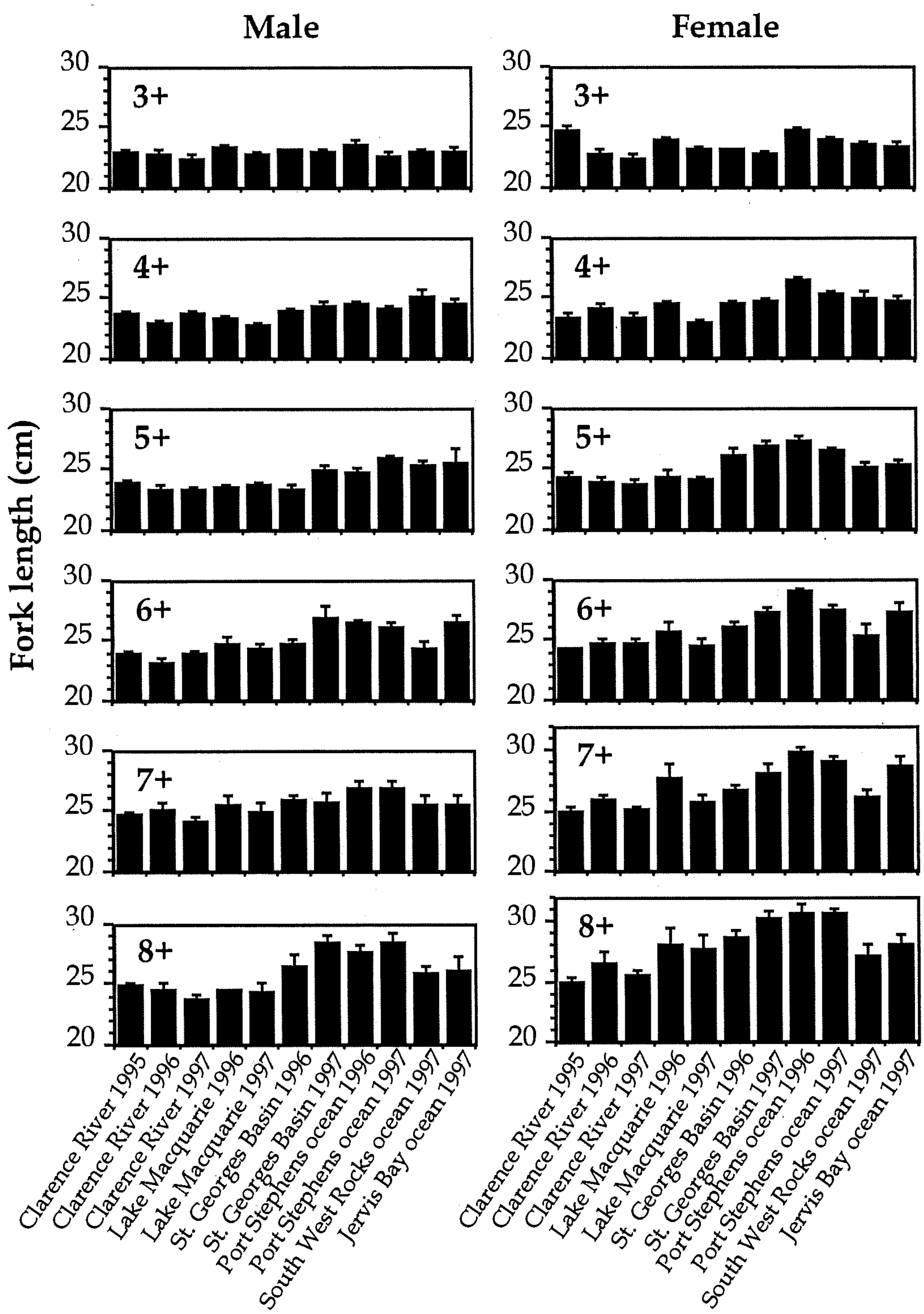
The oldest male and female bream aged in this study were 19^+ (33 cm FL) and 22^+ (36 cm FL), respectively. Both these fish were captured in the Clarence River. The largest male and female bream sampled were 35 cm FL (age 13) and 42 cm FL (age 10), respectively.

4.6 Discussion

4.6.1 Age determination

It is essential that aging techniques using growth zones on otoliths be validated (Beamish and McFarlane 1983). Legal-sized bream were marked with oxytetracycline and released into the wild in southern NSW estuaries. Subsequent recaptures showed that most individuals deposited one growth zone on their otoliths annually (Appendix I). Although this mark and recapture study was done only for legal sized fish (> 25 cm TL) in southern NSW, it is likely this pattern holds true for juvenile (sub-legal) fish and for fish in northern NSW. This is supported by Dredge (1976) and Henry (1983) who both documented that the observed growth increments on the otoliths and scales of bream respectively, were annuli. In the present study it was also possible to follow the progression of the stronger 6 and 7^+ age classes of bream in the Clarence River in 1995 to the 8 and 9^+ age classes in 1997, indicating that the zones aged were likely to be annuli. These results support the validity of the method of ageing bream used here. Despite this, the ages of bream reported here can only be described as preliminary even though sectioned otoliths proved relatively easy to read and there was very good agreement between readers in assigning ages to fish, as the age and timing of deposition of the first growth increment (opaque ring) on bream otoliths has not been quantified. The

Figure 4.17. Mean (± 1SE) fork length at age of male and female bream.



distance between the core and the first ring varied greatly among fish, and may be related to differences in the timing of spawning and subsequent recruitment of fish along the coast.

Cheaper options than using sectioned otoliths for assessing the age of bream are not promising. Fish length was a very poor indicator of fish age; otolith weight was better but was more related to fish length than age. Whole otoliths proved harder to read than thin sections, particularly for older fish because of the stacking of growth zones near the otolith margin, a feature common to Sparids elsewhere (Smale and Punt 1991, Buxton 1993), and therefore were less reliable to age than sectioned otoliths.

4.6.2 Variations in size at age and growth

The large variation in size at age of bream across all study locations precluded any analysis of spatial and temporal variations in growth. Realistic growth curves for bream (pooled across all locations) could not be generated, because of the lack of small fish in the analyses. However, the results showed that females grew faster and attained a greater maximum length (and age) than males. Bream at the size of recruitment to the fishery (approx. 22 cm FL) ranged from 2 to 10^+ years. Because the data collected here were limited to legal sized fish, the estimates of mean size at age for fish 2-6^+ were probably over estimates. It is probable that there would be significant variation in the size at age of small fish. Further studies are being conducted using small fish discarded from commercial estuarine haul nets and this data will be used to generate more realistic growth curves for the species in NSW.

The maximum age of bream reported in this study (22^+ years) was greater than that previously reported in NSW of 12 (Henry 1983) and in Queensland of 10 years (Pollock 1982a). The recorded maximum ages of estuarine/coastal species of sparids elsewhere exceed 40 years (Horn 1986, Buxton and Garrett 1990). A black bream, *Acanthopagrus butcheri*, measuring 36 cm FL captured in this study from Curunna Lake in southern NSW was aged at 26^+ years.

4.6.3 Variations in size, sex and age compositions of commercial catches

The results document that the size compositions of commercially harvested bream were relatively similar across estuaries, gear types and throughout the period sampled. The majority of fish landed were very close to the minimum legal size (between 22-25 cm FL), and few fish > 30 cm were included in catches. The general pattern in the size composition of estuarine and ocean beach bream catches detailed here was similar to that documented previously for the Clarence River in 1991, Tuggerah Lakes in 1987 (Henry 1988), and in ocean fish trawls between 1993-95 (Liggins 1996) (see Figure 4.18). It is therefore likely that: (1) similar patterns in the size structure of commercial catches of bream would also be observed in other estuarine and coastal locations throughout NSW; (2) the size structure of the commercial catches of bream throughout

NSW has remained relatively stable throughout the past decade given that the minimum legal size has remained the same.

Female bream were relatively more abundant in commercial catches than males (generally about 60%), the main exception being the trap catches in the Clarence River. From the reported sizes at maturity, it appears that most bream taken by commercial fishers have reached sexual maturity. Despite the differences in the lengths of male and female fish landed, the age structure of both sexes at each location was generally similar. Future sampling of commercial catches to obtain age structured data, therefore, does not need to be stratified by sex.

The commercial fishery for bream in NSW is based on several year classes. Although the size compositions of commercial catches of bream were relatively similar, the corresponding age structures of catches differed, and the dominance of any particular year class(es) varied among estuaries, and years. The data presented here indicates that there is significant spatial variation in the relative abundance of different year classes of bream throughout NSW, suggesting that recruitment of bream to the fishery varies substantially along the coast and through time. The independent sampling of newly settled juveniles (see Chapter 2) supports the hypothesis that recruitment is variable, however it is acknowledged that variation in mortality of pre-recruits and immigration and emigration patterns may have also contributed to the observed patterns in commercial catches.

It could be argued that differences in age structures of commercial landings between estuaries reflects differences in fishing mortality between these places. However, the data does not support this hypothesis. For example, older fish were most prevalent in the Clarence River, which has a greater annual production of bream than St. Georges Basin, where the fishery was dominated by young fish. However, the quantity of the recreational catch needs to be considered in any future work investigating such relationships.

The observed variation in age structure of commercial catches of bream among estuaries further supports to the observed trends obtained from tagging studies of a northerly movement of bream along the coast. Catches in St. Georges Basin (southern NSW) were dominated by young fish, whereas catches in the Clarence River (northern NSW) contained a higher proportion of older fish, indicating that fish may tend to move north with age. The ocean beach catches comprised fish of various age groups (mostly 3-6$^+$), and these fish are generally regarded to be undertaking pre-spawning migrations in a northerly direction. Although older fish (5-6$^+$) occurred in Wallaga Lake (southern NSW) in 1996, this lake was closed to the sea between 1993-96, and thus these fish were not able to leave the estuary. Similarly, the recruitment of young fish to the fishery, as observed in St. Georges Basin in 1996 was also not possible. The hypothesis of young fish predominating in south coast estuaries with a progressive shift in age structure towards the north needs further investigation. Age structured assessment of bream populations in other estuaries within the northern, central and southern region of NSW needs to be undertaken to test this hypothesis. This would also ascertain whether populations in nearby estuaries display more similar age structures than distant estuaries. Such knowledge would prove beneficial to designing future monitoring strategies of the bream fishery in NSW.

Tagging studies indicate that there is considerable mixing of bream between estuaries, and therefore future research needs to consider the bream stock as a single unit for assessment purposes. The spatial variation in the age structure of commercial catches of bream documented here needs to be considered in the design of any future monitoring studies of the commercial fishery in NSW.

4.6.4 Consequences for future monitoring programs of the commercial fishery

The data presented here have several implications for further monitoring of commercial catches and for the stock assessment of bream in NSW.

1). The large variation in the length of bream at any given age documents that length is a poor indicator of age, and thus it would be unwise to base a monitoring program of the fishery on length alone, because this would provide little information on the demographic status (age) of stocks. There was considerable spatial and temporal variation in the age structures of catches even though the size compositions were relatively similar. Thus changes in the demography of catches may not be detected using length alone.

2). The large degree of variation in the age structure of catches observed here indicates that the age structure of catches in other estuaries may differ, and thus monitoring of only 1 or 2 locations as indicators of the stock would not be beneficial. It would be useful to know whether or not bream in adjacent (nearby) estuaries display more similar age structures compared to distant estuaries. If nearby estuaries were most similar then it may be possible to sample representative estuaries to give an overview of the stock within a region.

3). Because of the mixing of fish along the coast the stock needs to be treated as a single unit for assessment and management purposes. It would not be feasible, however, to sample the commercial fishery in every estuary in NSW, and thus future sampling to assess the bream stock in NSW should be stratified according to expected catch (based on immediate past history) and age samples should be collected on a random basis in proportion to expected landings from a given proportion of the major ports of landings. For example, the top 10 ports which make up approx. 50% of the bream catch could be sampled and this could be used as the basis for stock assessment.

4). Future sampling of the age structure of commercial catches need not be stratified according to sex, as male and female bream showed similar age structures within a particular location.

5). The logistics encountered in this study identified that it was most beneficial to sample the size structure of bream catches at each port of landing because fish are commonly graded and retained for local and interstate markets. The collection of otoliths could still be based at the SFM. The sampling of fish in the field will also ensure a high profile of any monitoring program will be maintained with industry, and therefore provide industry with better ownership of research and belief in results. Our sampling also showed

that it was more costly to sample catches where there is no central co-operative, indicating that if the market becomes de-regulated then the costs of stock assessments on bream could be considerable.
6). The data presented here indicate that the fishery for bream in NSW is based on a broad range of age classes. However, the cohort strength appears to differ among years and estuaries and thus further monitoring needs to be done on a regular basis in order to develop population models.
7). Discards need to be aged to better describe growth.

4.6.5 Conclusions and stock assessment considerations

An overview of the commercial fishery has been presented which documents that the size compositions of bream landed did not vary greatly between locations, fishing methods and different sectors of the industry. However, an unquantified amount of small bream are captured and subsequently discarded from normal commercial fishing operations. Depending on mortality levels, this discarded component needs to be incorporated into stock assessment models. Research on the discarded component of estuarine haul nets is currently underway. The age of bream at the time the first (annual) growth ring is formed and its relationships with latitude needs to be determined.

Although an overview of the commercial fishery has been presented, there is little comparable information on the recreational fishery for bream in NSW. The few studies that have been done indicate that the recreational harvest is at least equal to, if not more, than the commercial catch (West and Gordon 1995). Clearly, for stock assessment purposes the quantity, size and age structure of the recreational harvest in NSW, and how this varies spatially and temporally, needs to be quantified.

5. Variations in size, sex and age compositions of commercial catches of sand whiting (*Sillago ciliata*) in NSW

5.1 Summary of relevant ecological literature

Sand whiting inhabit estuaries, coastal embayments and nearshore waters along the east coast of Australia from Cape York to eastern Victoria and to north east Tasmania. They also occur around Lord Howe Island, New Caledonia and south-eastern Papua New Guinea (McKay 1985). The stock structure of sand whiting is uncertain, although tagging studies in NSW show that some individuals travel between estuaries (> 150 km) (NSW Fisheries unpublished data), and it is therefore likely tat a single stock of sand whiting exists along eastern Australia (see also Dixon et al. 1987).

Growth of sand whiting has been studied in several regions, and has been reported to be relatively rapid, with fish reaching 15-17 cm FL in 1 year and 28 cm in 3 years (Dredge 1976, Burchmore et al. 1988). Sand whiting have been reported to reach a maximum length of 51 cm TL and an age of 22^+ years (Cleland 1947). Size at attainment of sexual maturity has been reported to vary between 19-26 cm FL, at a age of 2-3 years (Dredge 1976, Moreton 1985a, Burchmore et al. 1988). Sand whiting spawn in the lower reaches of estuaries and in nearshore coastal waters (Morton 1985b, Burchmore et al. 1988) with reported spawning times varying throughout the species distribution, from September to March in central Queensland, and December to April in central NSW (Morton 1985a, Burchmore et al. 1988). Larval sand whiting have been collected between September and May in estuarine and coastal waters of central NSW (Miskiewicz 1987, Gray 1995). There is some evidence indicating sand whiting may spawn more than once during each extended spawning period (Cleland 1947, Morton 1985a). Juvenile whiting occur over shallow sand and sparse seagrass beds in estuaries (Burchmore et al. 1988, Gray et al. 1996) and in the surf zones of coastal beaches (J. Leis unpublished data).

Although sand whiting are highly sought by commercial and recreational fishers throughout its distribution, the status of stocks is unknown, and no formal stock assessments have been done on the species in eastern Australia.

5.2 Overview of the NSW commercial fishery

The bulk of the commercial catch of sand whiting in NSW is taken in estuaries (Figure 5.1), with catches from the Clarence River, Wallis Lake, Port Stephens, Botany Bay and Tuggerah Lakes generally accounting for about 50% of commercial estuarine production over the past 5 years (Figure 5.2). Commercial estuarine production of sand whiting in NSW has generally increased from less than 40 tonnes in 1954/55 to its present level around 130-180 tonnes. In contrast, ocean production has remained relatively stable, less than 25 tonnes throughout this time period (Figure 5.1). The majority of the ocean catch is taken in the ocean trawl and beach haul fisheries, with zones 5, 7 and 8 contributing greatest catches over the past 5 years (Figure 5.3).

Figure 5.1. Annual NSW commercial estuarine and ocean landings of sand whiting from 1954/55 to 1996/97.

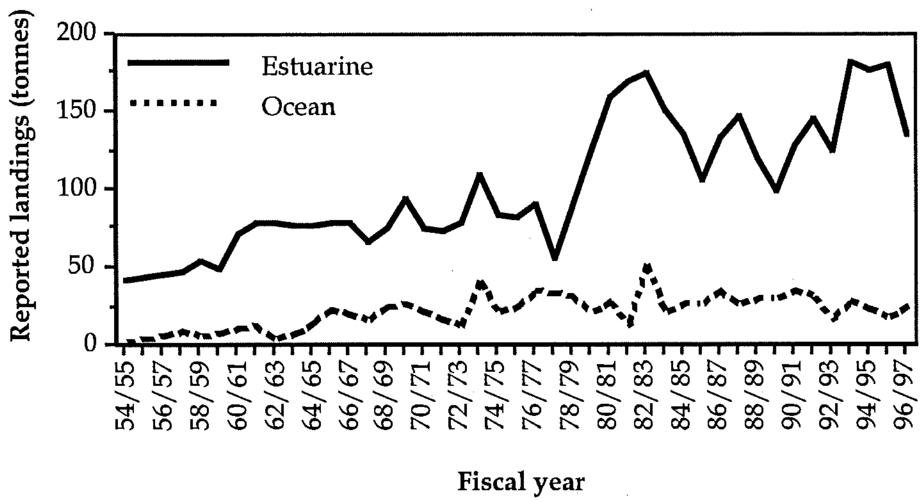


Figure 5.2. Average (+ 1se) commercial estuarine landings of sand whiting in the top 20 estuaries in NSW for the period 1992/93 to 1996/97.

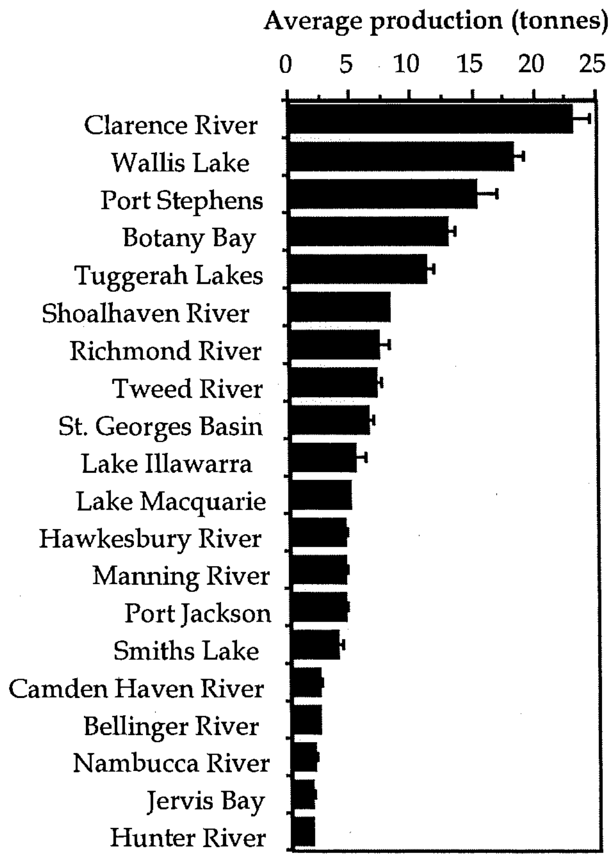


Figure 5.3. Average (+ 1 se) monthly commercial ocean landings of sand whiting in each ocean zone for the period 1992/93 to 1996/97.

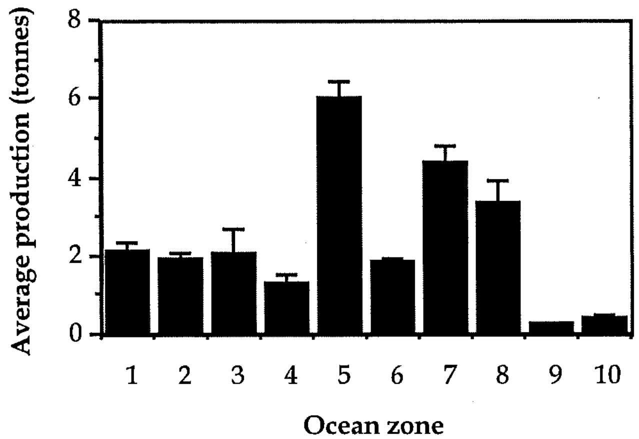
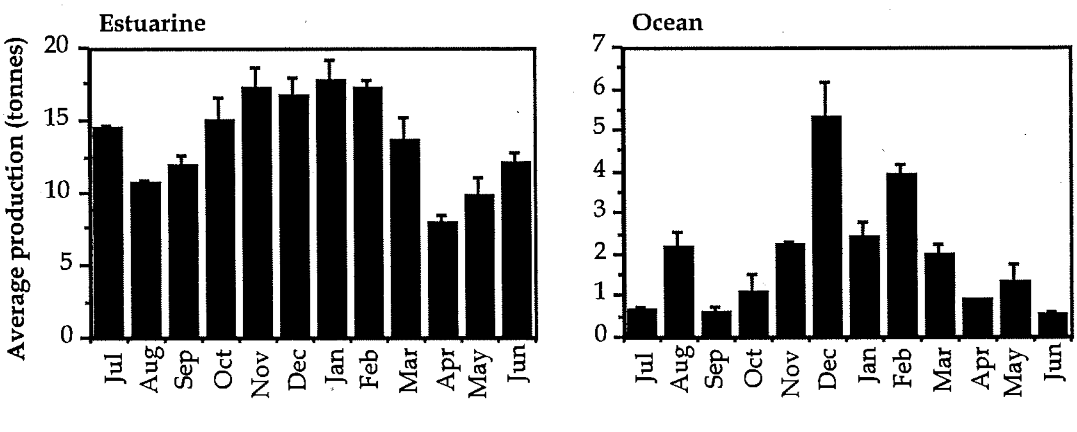


Figure 5.4. Average (+ 1 se) monthly commercial estuarine and ocean landings of sand whiting in NSW for the period 1992/93 to 1996/97.



In 1995/96 the total commercial sand whiting catch in NSW was 160 tonnes, valued at approximately $1.5 million to commercial fishers. Most recently a lucrative export market has been developed for sand whiting, and a large proportion of the NSW commercial catch is now exported. Many commercial fishers ice slurry catches to obtain maximum prices.

In estuaries, sand whiting are predominantly caught in haul nets over sand banks, although significant quantities are also caught in mesh nets. The estuarine fishery for sand whiting occurs year round, but greatest catches are generally taken in summer (Figure 5.3). This same seasonal trend is also evident in ocean catches (Figure 5.4).

The fishery for sand whiting in NSW is managed through gear restrictions, areal and temporal closures and a minimum legal size limit. Two regulations specifically relate to the management of sand whiting in NSW, namely a minimum legal length limit of 27 cm TL (approximately 25 cm FL), which applies to commercial and recreational fishers, and a recreational bag limit of 20 fish per day per angler.

5.3 Aims of this chapter

This chapter describes spatial, temporal and gear-related variations in the size, sex and age compositions of estuarine commercial catches of sand whiting in NSW between 1995 and 1997. Relationships between the age and length of sand whiting and preliminary estimates of growth are presented and recommendations for future assessment of the fishery for sand whiting in NSW are discussed.

5.4 Methods

Commercial catches of sand whiting were sampled for size and age composition in the Richmond, Clarence and Shoalhaven Rivers, Wallis, Macquarie, Tuross and Wallaga Lakes and St Georges Basin. The general protocol for obtaining the length distributions, sex and age compositions from commercial catches, the laboratory techniques and the analyses of data generally followed that outlined in Chapter 3.

5.5 Results

5.5.1 Variation in size and sex composition of commercial catches

Sand whiting retained in commercial catches ranged from 24 to 42 cm FL. There were strong gear-related differences in the size and sex composition of commercial catches of sand whiting, and these differences were relatively consistent across estuaries (Richmond River, Clarence River and Wallis Lake) and time periods. The majority of fish retained in haul nets were in the size range 25-30 cm FL (i.e. just above the

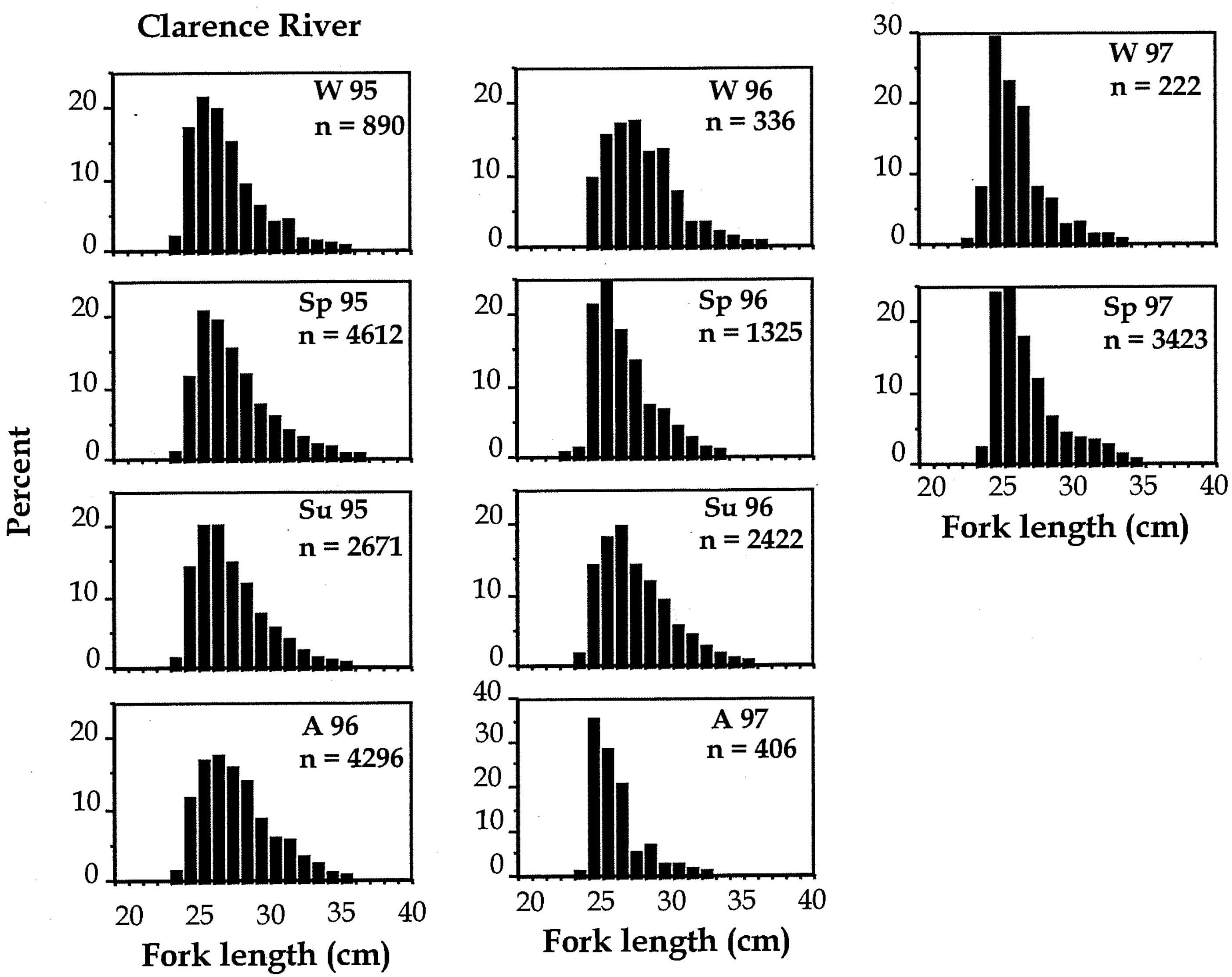


Figure 5.5. Size-frequencies of commercial estuarine haul net landings of sand whiting.

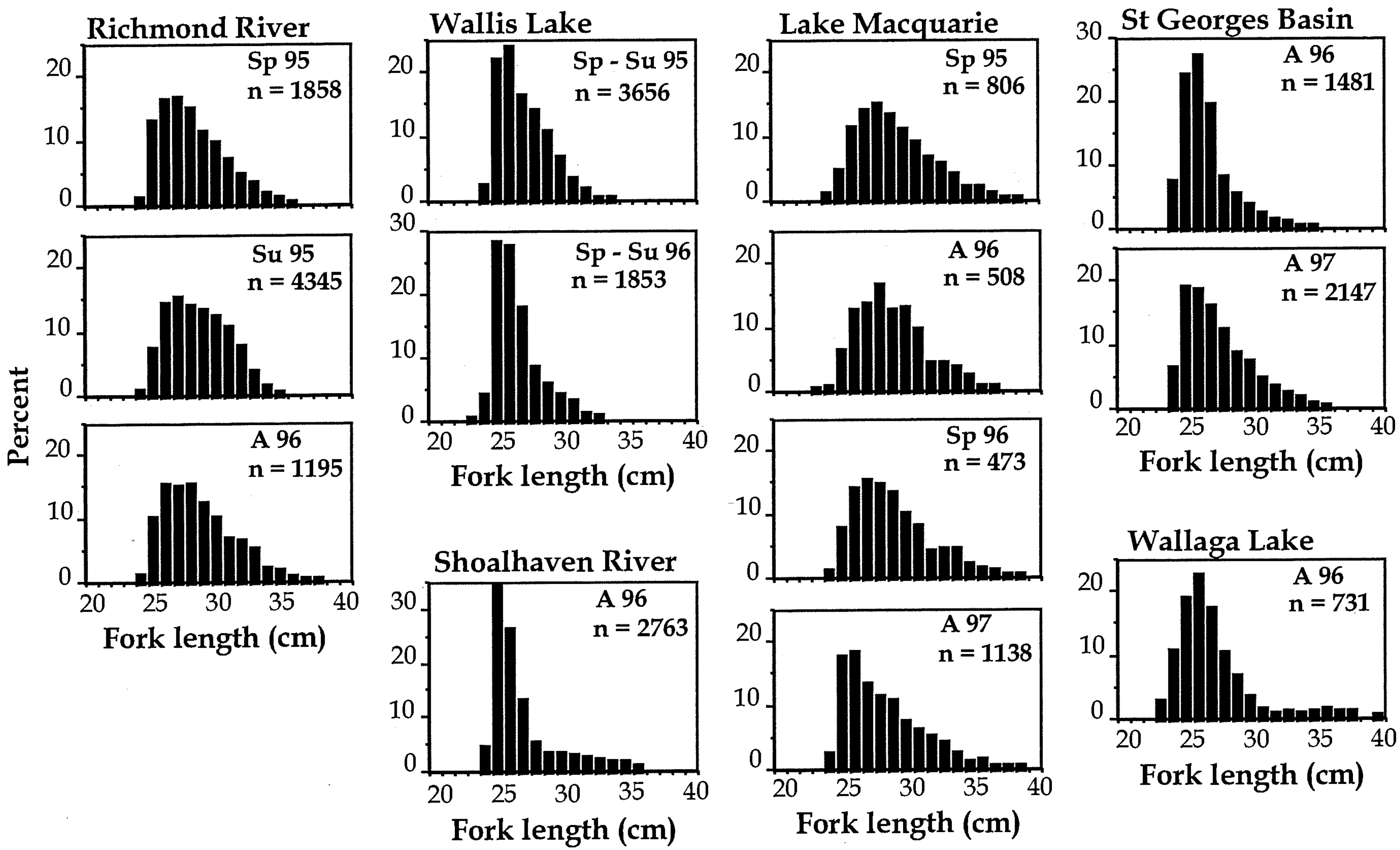


Figure 5.5. continued.

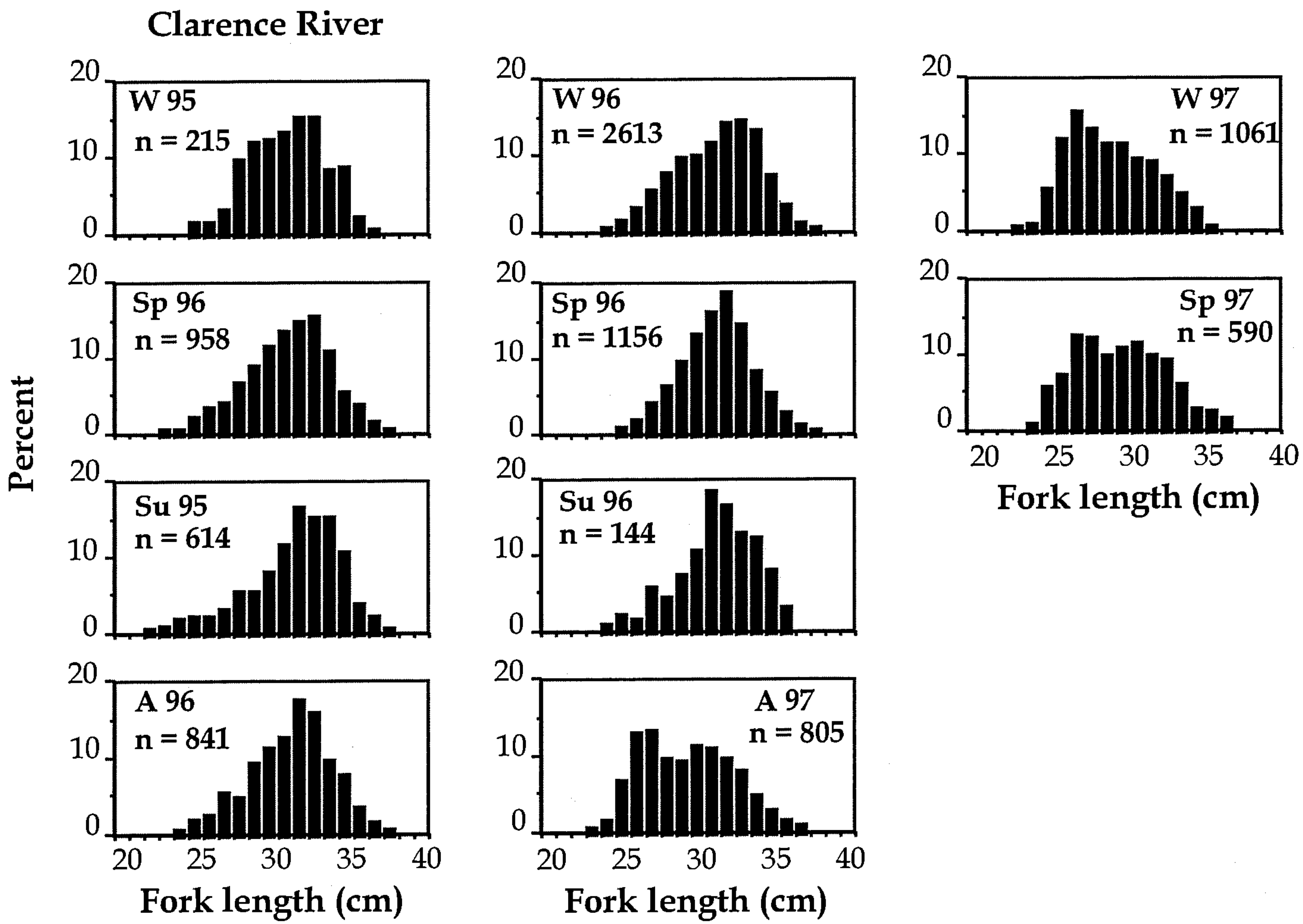
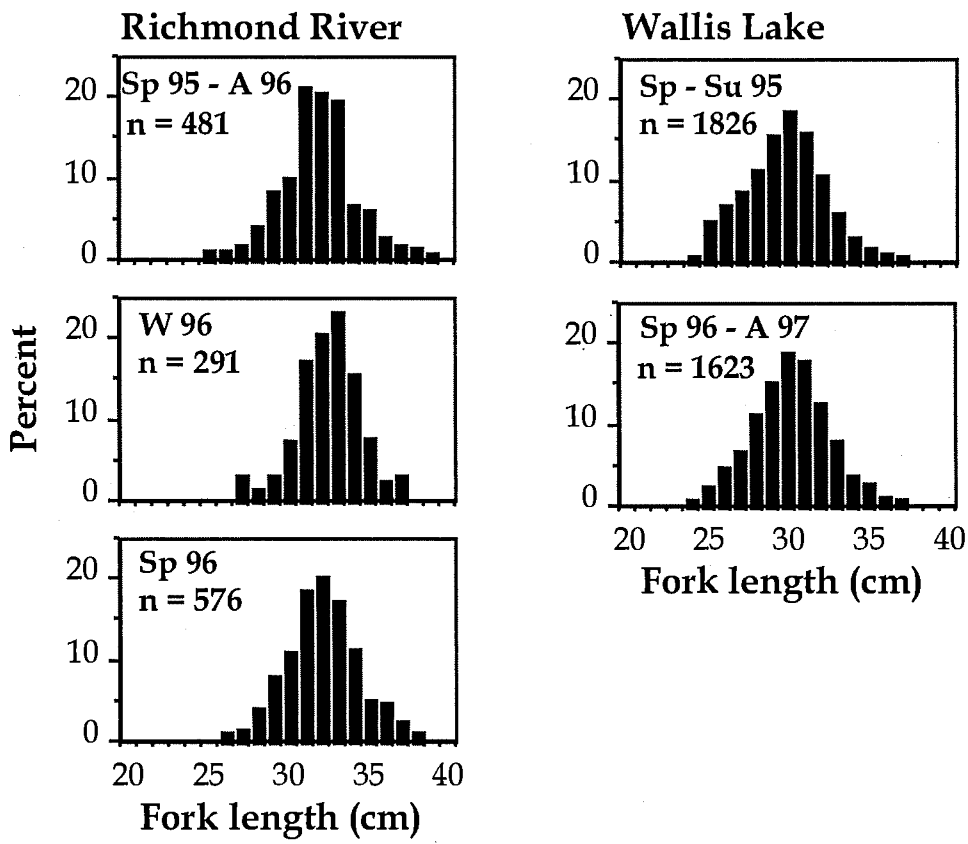


Figure 5.6. Size-frequencies of commercial estuarine mesh net landings of sand whiting.

Figure 5.6. continued.



minimum legal size of approximately 25 cm FL), whereas those retained in mesh nets were predominantly larger with the majority between 30-35 cm FL (Figures 5.5- 5.7).

Although the general patterns of size composition of haul and mesh net catches were relatively similar across estuaries and time periods, there were notable exceptions. For mesh nets, the main exception to this pattern was in the Clarence River from autumn to spring 1997 when a smaller size range of fish were retained (Figure 5.6). This was due to the size of fish landed by two fishers being considerably smaller than all other fishers, indicating that these fishers were using alternative gears or smaller mesh sizes. The average size of fish retained in mesh nets in Wallis Lake was smaller than in the Clarence and Richmond Rivers, probably due to the inclusion of sand whiting retained from the flathead set nets, which have a smaller (70 mm) mesh size than general mesh net. Similarly, the size range of sand whiting retained in haul nets in Wallis Lake was generally smaller than in haul net catches in the other estuaries (Figure 5.5).

The sex compositions of commercial catches differed greatly between haul and mesh net catches. Females dominated mesh net catches, whereas more even sex ratios were observed in haul net catches (Figures 5.7). The size of males and females retained in commercial catches generally differed, with females on average being larger than males (Figure 5.9). It should be noted that some haul catches were dominated by one sex (up to 98%), suggesting that schools of sand whiting may segregate by sex (see also Morton 1982).

Figure 5.7. Total size-frequencies of commercial estuarine haul and mesh net landings of sand whiting.

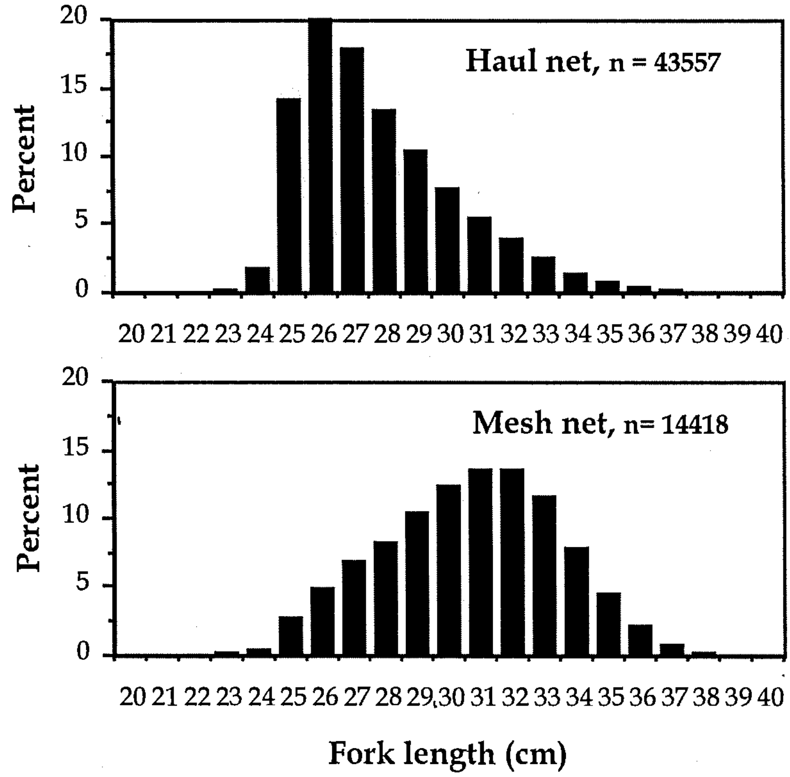


Figure 5.8. Sex ratios of commercial landings of sand whiting.

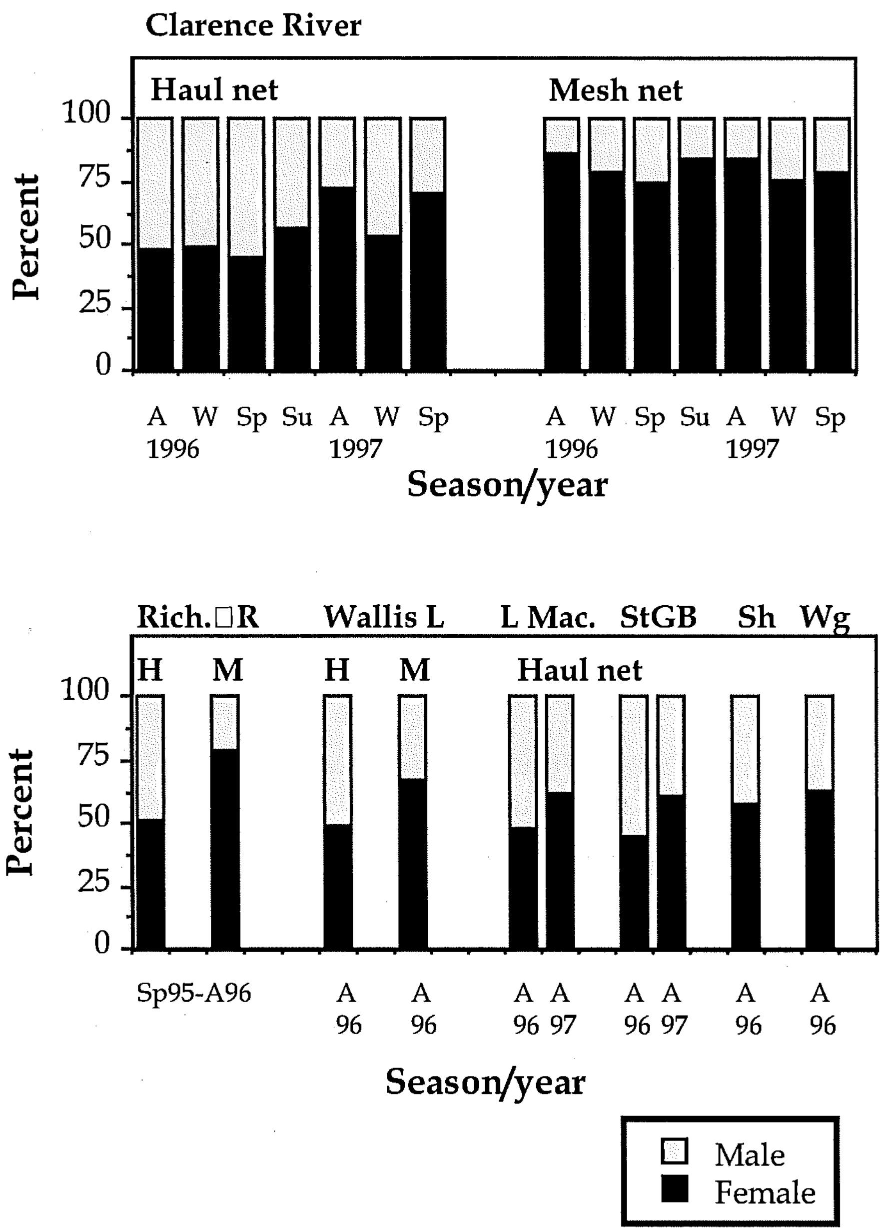
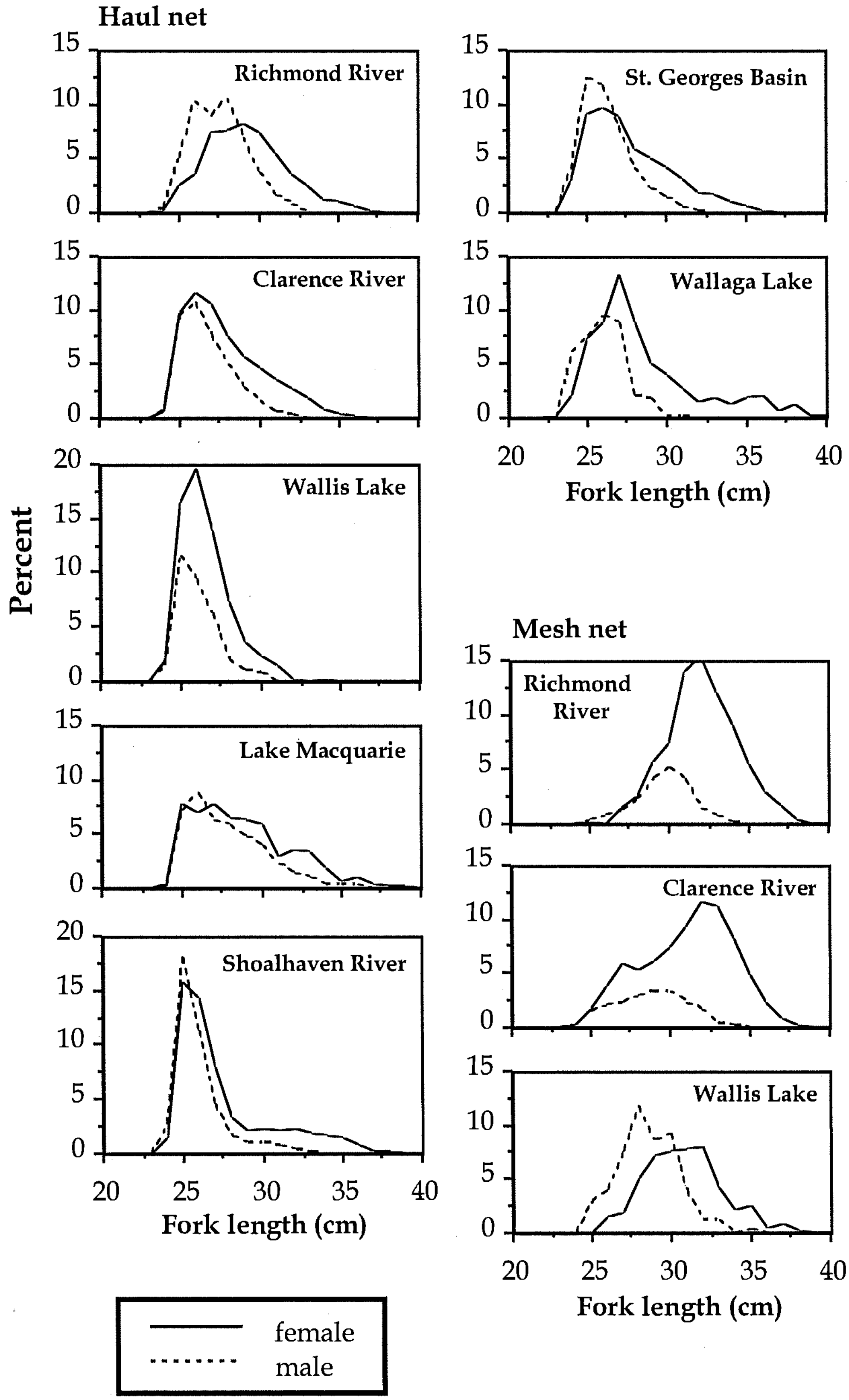


Figure 5.9. Total size-frequencies of male and female commercial estuarine haul and mesh net landings of sand whiting.



5.5.2 Age determination

Whole and sectioned sagittal otoliths displayed thin opaque and wide translucent zones (rings) that could be interpreted as annuli (Figure 5.10), although preliminary examination of whole otoliths from larger (and older) fish proved harder to interpret than thin sections because of the stacking of layers at the otolith margin. Sectioned otoliths were therefore used in this study to estimate the age of sand whiting.

Agreement between two independent readers in interpreting growth zones and assigning ages varied between 84-96% (Table 5.1). There was greater agreement between readers for samples from Wallaga Lake and St. Georges Basin (southern NSW) than those from the Clarence River (northern NSW). Discrepancies in assigning an age to otoliths were virtually all of 1 year, and were primarily due to differences in the interpretation of the inner most ring. The distance of first ring from the core of the otolith varied considerably between individual fish and there was no clear trend in this distance between estuaries.

Table 5.1. Replication of age interpretation of sand whiting otoliths by two independent readers. Note that there was no apparent bias over any particular age group.

Location	No. otoliths examined	% agree	% differ > 1yr
Clarence River 1995	451	84.9	0
Clarence River 1996	497	85.5	0
Clarence River 1997	534	86.3	0
Wallis Lake 1995	352	89.2	0
Wallis Lake 1996	236	88.1	0
Wallis Lake 1997	467	90.8	0.2
Lake Macquarie 1996	435	93.8	0
Lake Macquarie 1997	339	90.3	0.6
St. Georges Basin 1996	431	92.3	0
St. Georges Basin 1997	400	94.0	0
Richmond River 1996	402	94.0	0
Wallaga Lake 1996	379	95.8	0

There was large variation in the size (fork length) of male and female whiting at any given age, and the relationships between age and fork length for male and female sand whiting were relatively weak, suggesting that length is a poor indicator of age of sand whiting (Figure 5.11). Logarithmic equations best described the relationships between fork length and age, whereas linear equations best described the relationships between otolith weight and fork length, and otolith weight and age, although there was a large degree of variation in the weight of an otolith at any given size or age (Figure 5.11). Otolith weight tended to increase with increasing size and age of male and female sand whiting, indicating that they continued to grow throughout the life of a fish and that they potentially are a suitable structure to estimate age.

Figure 5.10. Image of a sectioned sand whiting otolith showing the alternate narrow opaque and wide translucent zones across the section.

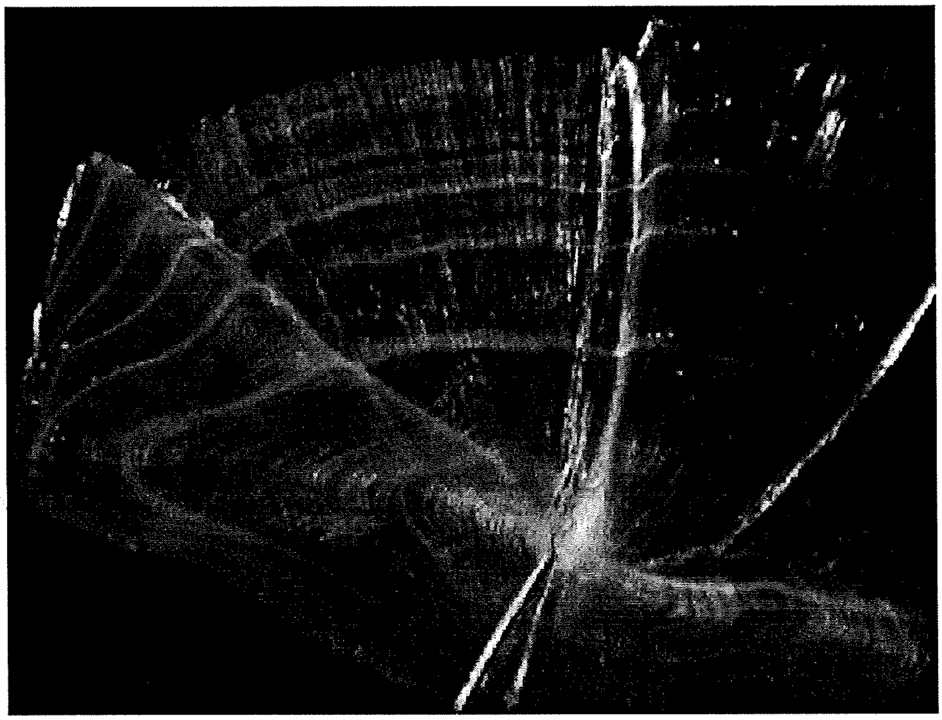
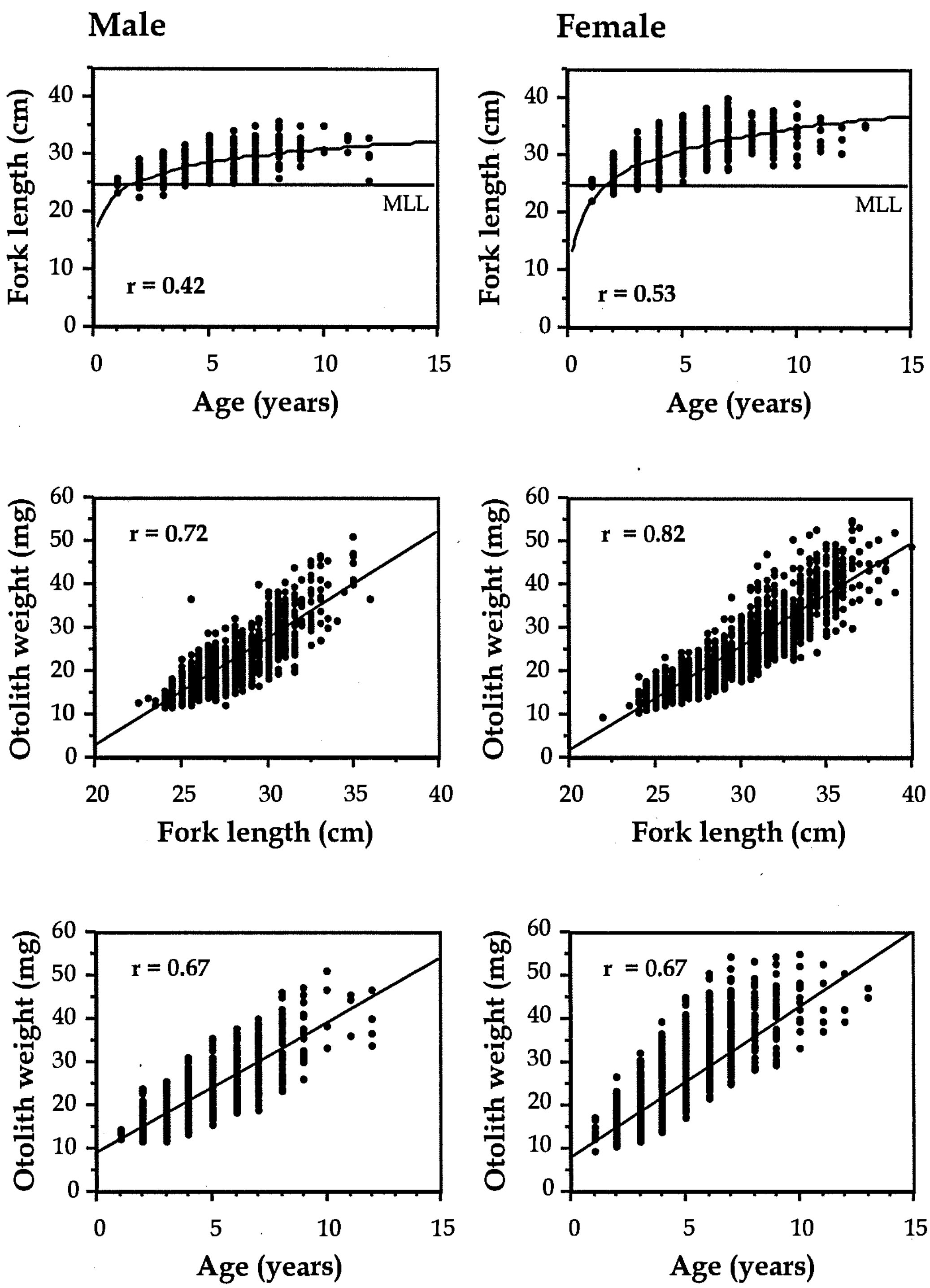


Figure 5.11. Relationships between estimated age, fork length and otolith weight for male and female sand whiting above the minimum legal limit (MML).



5.5.3 Variation in age structure of commercial catches

Although females were generally larger than males, the age structure of the male and female component of haul and mesh net catches was fairly similar (Figure 5.12), and therefore further presentations of the results are based on data pooled across sexes.

Commercial catches of sand whiting comprised fish aged from 1 to 16^+ years. However the age structures of commercial catches differed between haul and mesh nets, and to a lesser extent between estuaries and years (Figures 5.13 and 5.14). Fish aged $2\text{-}5^+$ generally dominated haul net catches, whereas fish aged $3\text{-}10^+$ were abundant in mesh net catches (Figures 5.13 and 5.14). The main exception to this pattern was the haul net catch in the Richmond River in 1996 which resembled most mesh net catches from elsewhere.

Although several year classes were represented in haul and mesh net catches, the progression of particular year classes could generally not be followed through time. The notable exception was the progression of the dominant 4^+ year class in mesh net catches in the Clarence River in 1995 which appears as 5^+ year olds in 1996 (Figure 5.14).

5.5.4 Variation in size at age and growth

Although there was substantial variation in the size of male and female sand whiting at any given age (Figure 5.11), females appeared to grow faster and they attained a greater maximum length than males (Figure 5.15). The largest male and female sand whiting sampled throughout this study was 36 and 42 cm FL respectively. The male was captured in Lake Macquarie and the female in Wallaga Lake. The oldest male and female sand whiting aged in this study were 12^+ (several fish 29-33 cm FL) and 16^+ (36 cm FL) respectively.

Realistic growth descriptions of male and female sand whiting could not be generated because of the lack of small (undersized) fish in the data. Nevertheless, the average length (pooled across all estuaries and years) of male and female sand whiting at ages 2 and 10 was 25.5 and 31.3 cm FL and 26.0 and 33.5 cm FL, respectively. There was no obvious latitudinal variation in mean length at age of sand whiting.

5.6 Discussion

5.6.1 Age determination

Sand whiting marked with oxytetracycline, released into estuaries in southern NSW and subsequently recaptured showed that one growth zone was deposited annually on the otoliths (Appendix I), and therefore the method of ageing sand whiting used here has been partially validated. The age of fish at the time the

Figure 5.12. Estimated age composition of male and female commercial landings of sand whiting.

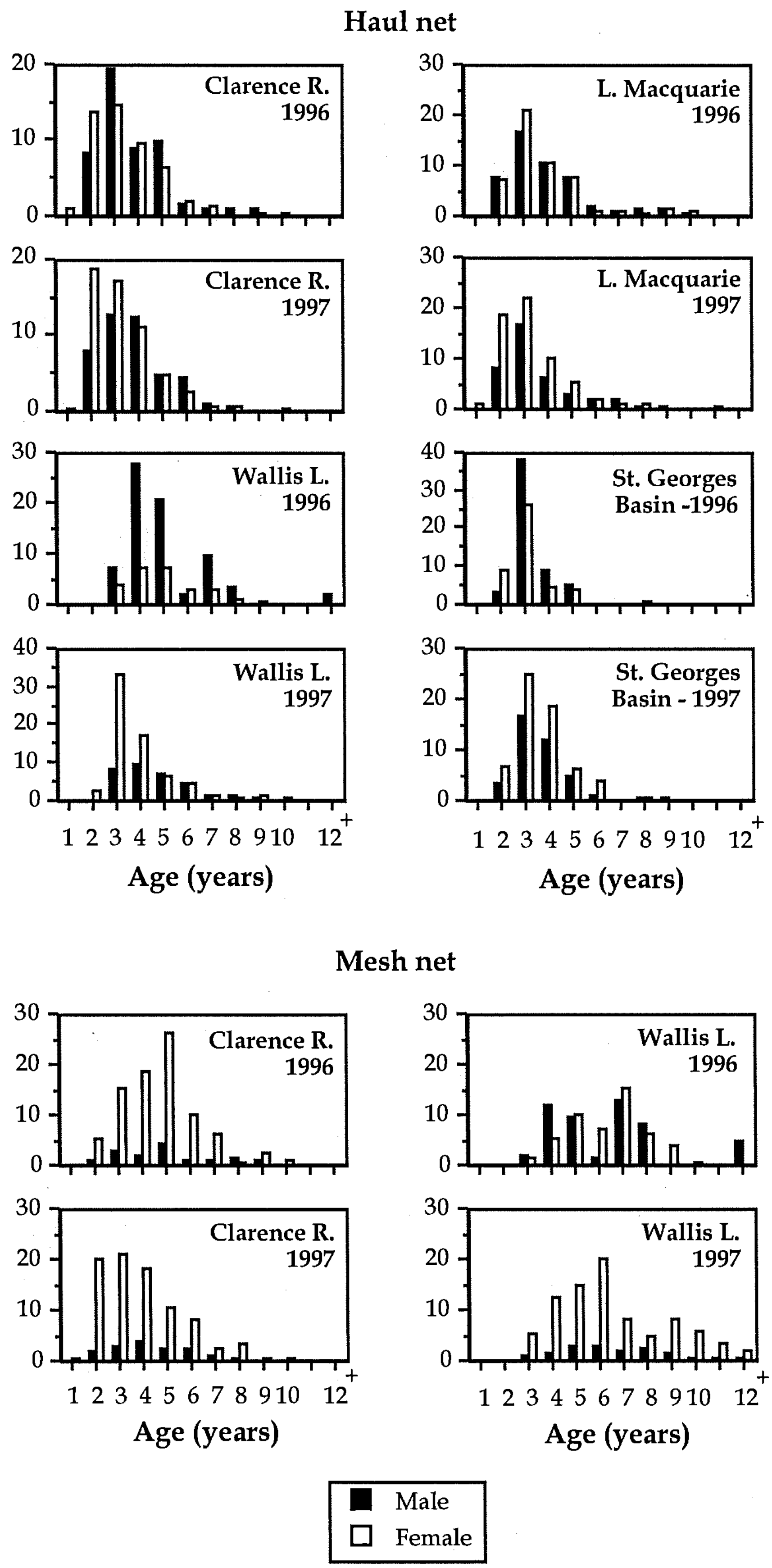


Figure 5.13. Estimated age composition of commercial haul net landings of sand whiting. n = number of otoliths examined; a = average age in years.

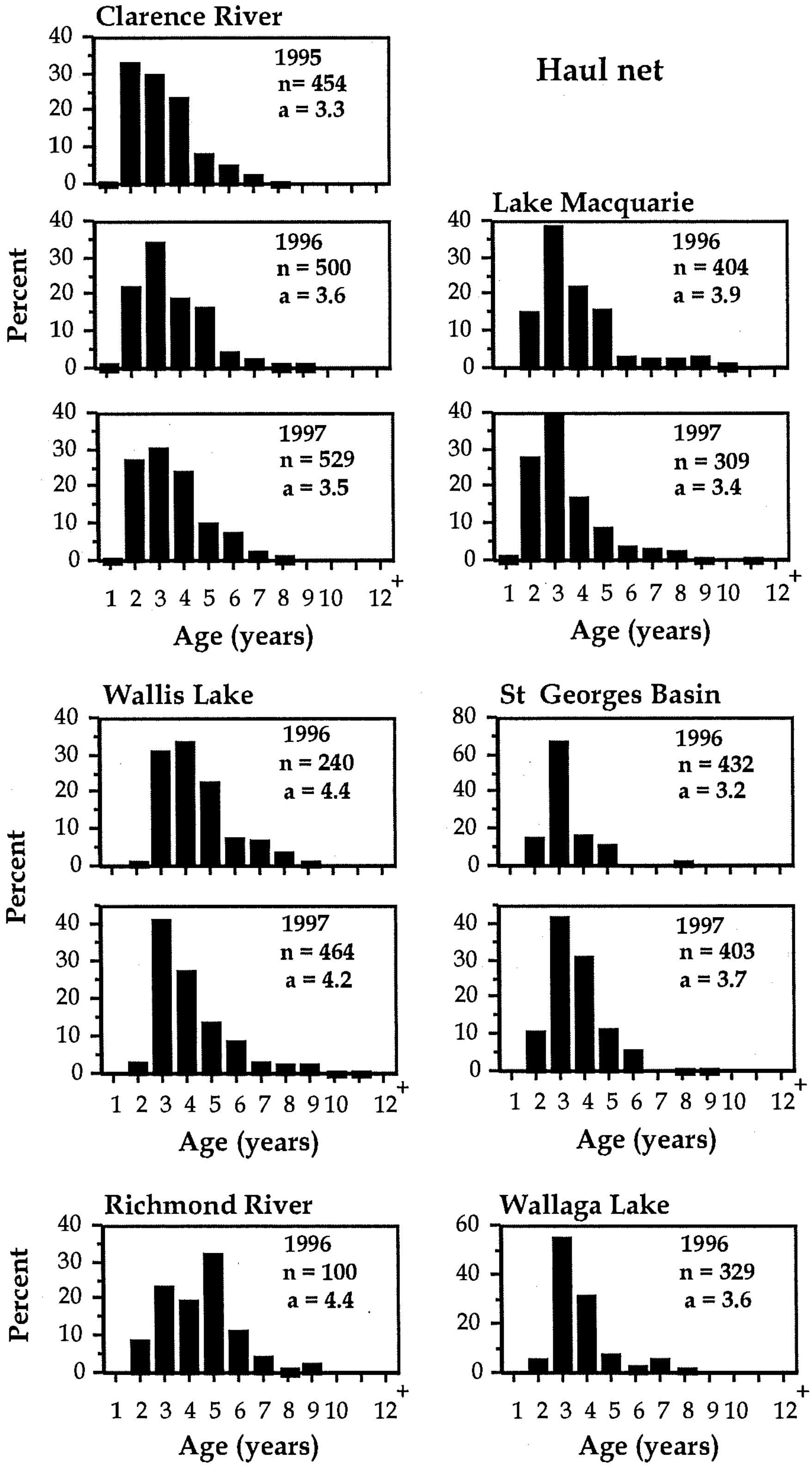
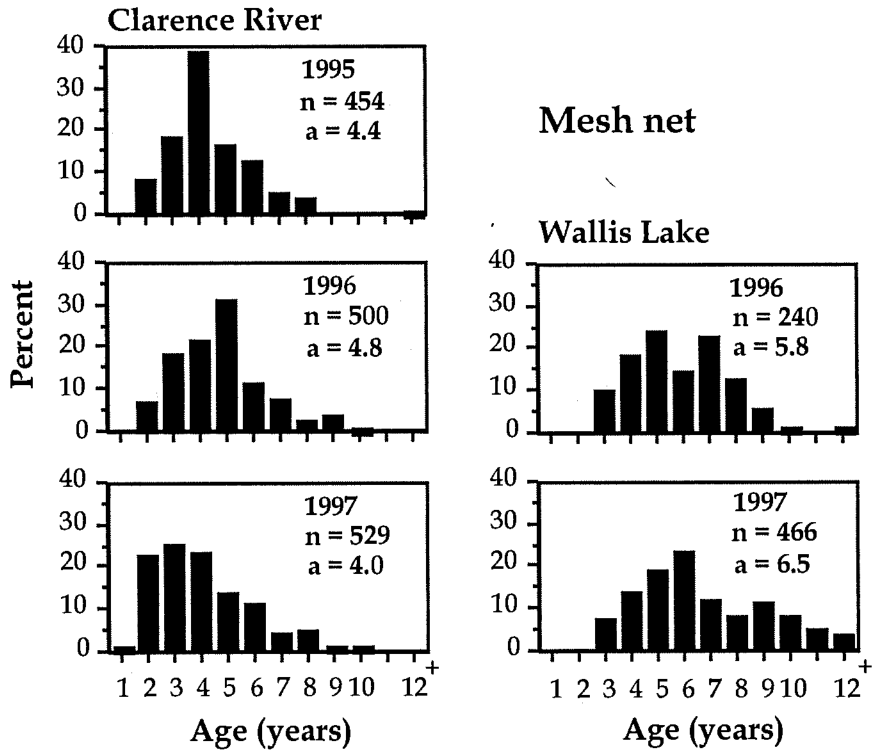


Figure 5.14. Estimated age composition of commercial mesh net landings of sand whiting. n = number of otoliths examined; a = average age in years.



first growth zone is deposited has not been determined, and there was large variation in the distance (position) of the first zone from the core of the otolith. This may be related to differences in the spawning and subsequent recruitment of fish to estuaries along the coast (see Chapter 2).

Variation in the position of the first ring may have contributed to the observed lack of 2^+ aged fish in Wallis Lake. This difficulty in determining absolute ages for sand whiting otoliths needs to be resolved. Small sand whiting are currently being collected from the discards of commercial estuarine hauling operations to determine the age when the first ring is deposited.

Length of sand whiting is not a good indicator of fish age, and therefore any monitoring of the sand whiting stock based on length alone may provide little information on the demographic status of the stock. There may be some potential to use otolith weight to estimate the age of sand whiting, although this requires further investigation. The use of whole otoliths to age sand whiting proved less reliable than thin sections because of the stacking of layers near the otolith margin in larger and older fish, as observed in other relatively long lived sillaginid species (Hyndes et al. 1996, Hyndes and Potter 1996).

5.6.2 Variation in size at age and growth

Realistic growth curves for sand whiting could not be generated because of the lack of small fish, and the estimates of mean length at age for fish aged 2-4$^+$ are probably over estimates. Despite this, females appeared to grow faster and attained a larger length than males in all estuaries. The maximum ages of 12 and 16$^+$ years for male and female sand whiting found in this study concurs with that generally reported elsewhere. However, Cleland (1947) reported sand whiting to 22 years of age and 51 cm TL.

Despite the strongly skewed sex ratios in the larger fish, there was no evidence that sand whiting changed sex from male to female. No hermaphroditic fish were observed throughout this study, and it is most likely that female fish grow bigger than males, as found for other sillaginid species (Hyndes et al. 1996, Hyndes and Potter 1996).

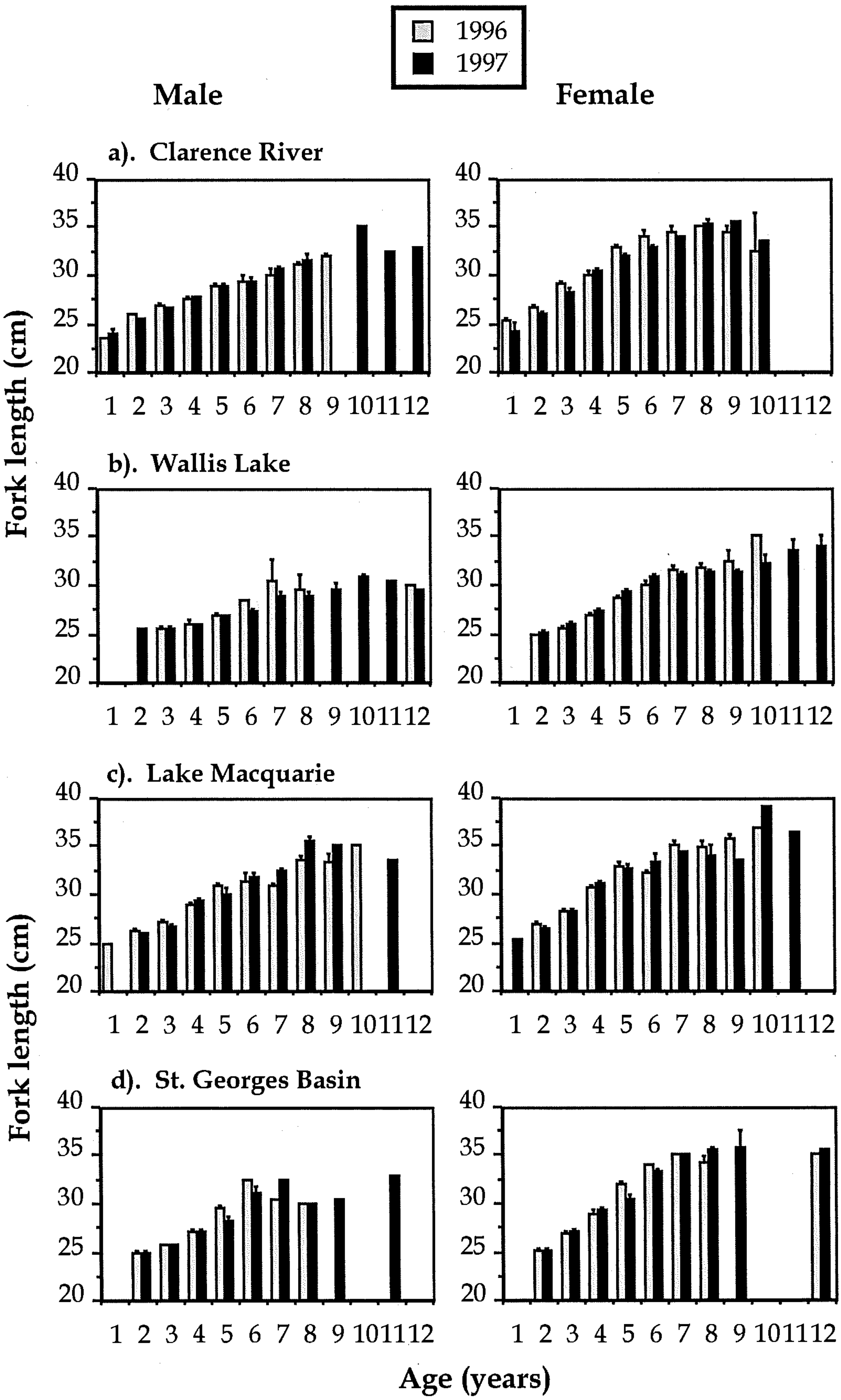
5.6.3 Variation in size, sex and age composition of commercial catches

The strongest variations in the size, sex and age composition of catches were those related to gear (haul versus mesh net), and it is likely that such patterns will also be evident in other estuaries throughout NSW. It is therefore imperative that future assessments of the commercial fishery for sand whiting incorporate some stratification for gear type. The majority of fish landed in haul nets were < 25 cm FL and were therefore very close to the minimum legal size. This pattern in size composition of haul nets is similar to that observed from haul net catches in the Clarence River in 1991 (Figure 5.16), indicating that the size structure of haul net catches has not changed dramatically over the past 7 years. Because mesh nets are highly size selective, it is also most likely that the observed patterns in the size composition of sand whiting catches from mesh nets has also remained relatively consistent throughout time. It is unknown, however, whether the corresponding age structures of commercial catches have varied substantially.

Female sand whiting dominated mesh net catches whereas more even sex ratios were observed in haul net catches. From the reported sizes at maturity, it appears that most sand whiting have attained sexual maturity prior to being harvested. Although the average size of the male and female components of catches generally differed, the corresponding age structures were similar. Future assessments of the fishery therefore do not need to be stratified according to sex.

The fishery for sand whiting in NSW is primarily based on fish 2-8$^+$ years, although the age structure of catches differed between gear types, with older fish dominating mesh net catches. Within each gear type, the dominance of any particular year class varied among estuaries and years, indicating that recruitment of

Figure 5.15. Mean (+ 1 SE) size at age of male and female sand whiting.



young fish to the fishery varies spatially and temporally. Although the magnitude of variation in age structure of catches was not as great as that observed for bream, it needs to be considered in any future sampling strategy of assessing the sand whiting stock in NSW.

Many small sand whiting are retained in haul net catches and subsequently discarded (Gray et al. 2000), and the fate of these fish is presently unknown. Sand whiting are not very resilient to stress (Broadhurst et al. 1997) and depending on the mortality levels of the discarded catch, this component needs to be incorporated into future modeling of the impacts of fishing on the stock. This is currently being investigated, and will also aid in obtaining better growth information of juvenile fish.

Sand whiting move between estuaries, although the extent of these movements has not been quantified. For assessment purposes it is probably best to treat the sand whiting stock as a single unit, although gear-related and between estuary variations in size, sex and age composition of catches needs to be incorporated into the designs of future assessments of the fishery for sand whiting.

5.6.4 Consequences for future studies

An overview of the commercial fishery for sand whiting has been presented here, which has documented the gear-related and spatial and temporal variations in the demographic characteristics of commercial estuarine catches. There is little comparable data on the recreational fishery for sand whiting in NSW. The few studies that have considered the recreational fishery indicate that it may be of a similar magnitude to the commercial fishery. It is therefore important that any future stock assessment of sand whiting incorporate the recreational component. A lucrative export market has been developed for sand whiting, and consequently more commercial fishers may target the species. It is therefore warranted that future monitoring of the stock be considered.

6. Variations in size, sex and age compositions of commercial catches of luderick (*Girella tricuspidata*) in NSW

6.1 Summary of relevant literature

Luderick (*Girella tricuspidata*) are primarily a herbivorous fish (Anderson 1987), inhabiting estuaries and nearshore coastal waters along the eastern and southern seaboard of Australia, including Tasmania, between Hervey Bay in Queensland to Kangaroo Island in South Australia (Kailola et al. 1993). They also occur around the north island of New Zealand. There is no information on the stock structure of luderick in Australian waters, although tagging studies in NSW show that some individuals travel among estuaries and in a north and south direction along the coast (> 150 km) (Thomson 1959, West 1993, NSW Fisheries unpublished data). This information suggests that a single stock of luderick occurs between southern Queensland and NSW.

Although there have been no reported studies on the reproductive biology of luderick in Australia, it is believed that spawning occurs between July to September in southern Queensland and northern NSW, August to December in central NSW, and October to March in central Victoria (Kailola et al. 1993, West 1993). Larval luderick have been captured in coastal and estuarine waters of central NSW between September and January (Miskiewicz 1987, Gray 1995). In NSW, luderick reach sexual maturity at 22-28 cm FL (male) and 26-32 cm FL (female) (SPCC 1981, West 1993). Luderick appear to undertake pre-spawning migrations along the coast of NSW between May and July (generally after the bream), travelling along open surf beaches, but the extent of these migrations is largely unquantified. It is generally assumed that luderick spawn in the coastal zone, along surf beaches and near the mouths of estuaries. Immediate post-settlement luderick frequent shallow seagrass beds for 2-3 months, after which they move to mangrove creeks and rock walls (Middleton et al. 1984, see Chapter 2).

Reported rates of growth of luderick throughout southeastern Australia have been relatively similar, with fish reaching approximately 17 cm in 1 year and 22-26 cm FL in 3 years (see Kailola et al. 1993). The maximum recorded sizes of luderick are 71 cm FL and 4 kg (Kailola et al. 1993).

6.2 Overview of the NSW commercial fishery

The majority of the commercial catch of luderick in NSW is taken in estuaries, with estuarine production having remained relatively stable over the past 40 years, fluctuating around 400 tonnes, with distinct peaks in 1973/74 and 1987/88 (Figure 6.1), whereas production from ocean waters has fluctuated around 80 tonnes. The commercial estuarine catch in 1996/97 was 396 tonnes, whereas the ocean catch was 84 tonnes (Figure 6.1), with a total value of approximately $600,000 to commercial fishers. The fishery for luderick is characterised by high volume, but low value, and consequently luderick are often used as bait in the lobster

Figure 6.1 Annual commercial estuarine and ocean landings of luderick from 1954/55 to 1996/97.

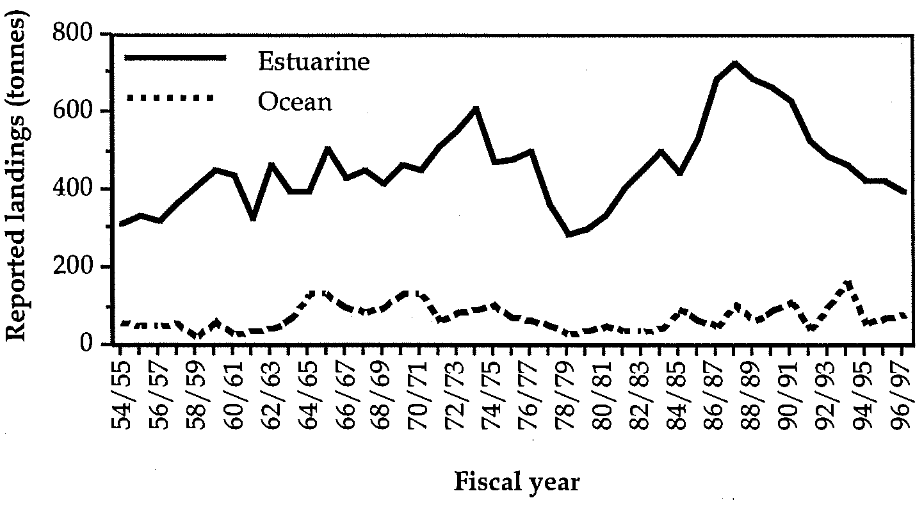


Figure 6.2 Average (+ 1 se) commercial estuarine landings of luderick in the top 20 estuaries in NSW for the period 1992/93 to 1996/97.

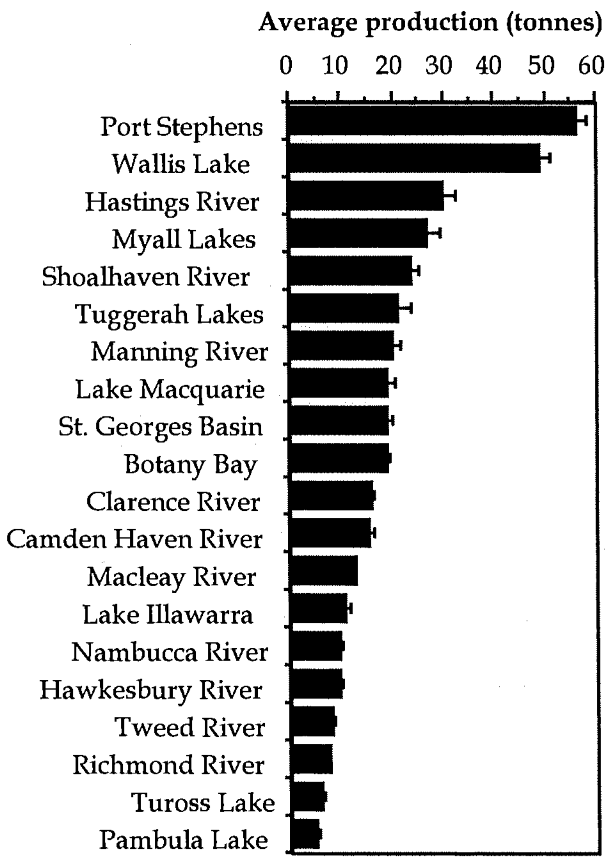


Figure 6.3 Average (+ 1se) commercial ocean landings of luderick in each ocean zone in NSW for the period 1992/93 and 1996/97.

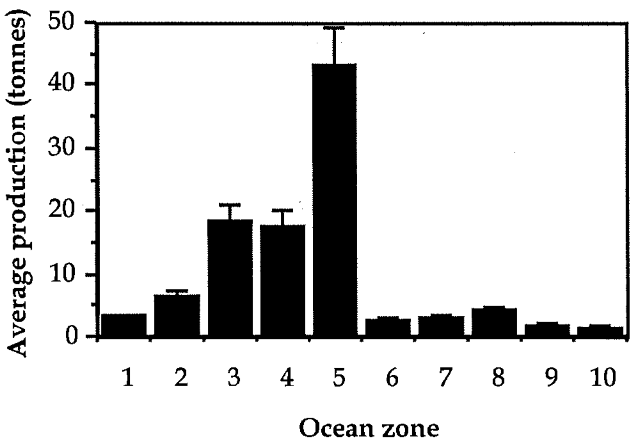
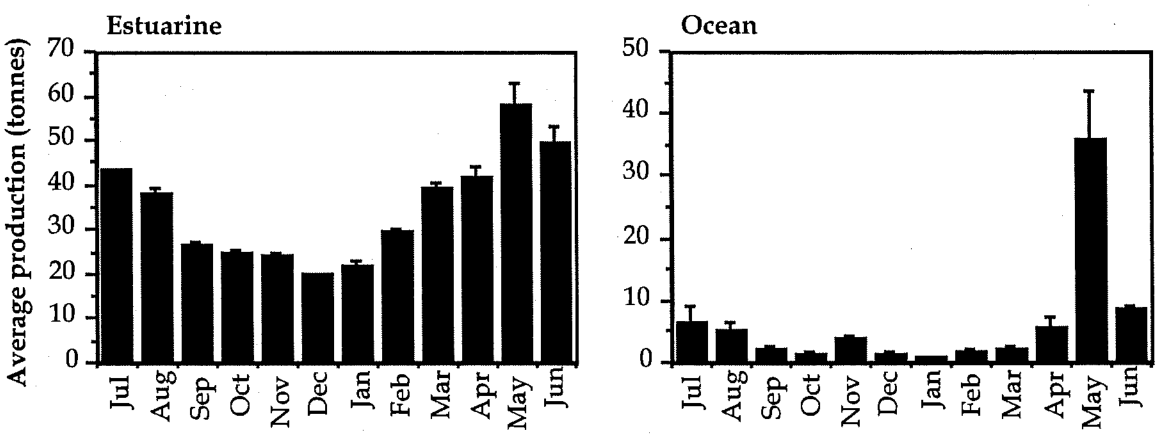


Figure 6.4 Average (+ 1se) monthly commercial estuarine and ocean landings of luderick in NSW for the period 1992/93 and 1996/97.



and crab fisheries throughout the state. Luderick are predominantly caught in estuaries by mesh and haul nets, with the principal estuaries over the past 5 years being Port Stephens, Wallis Lake, Hastings River, Myall Lakes and Shoalhaven River (Figure 6.3). The top 10 estuaries generally account for over 60% of the total annual estuarine production of luderick. Luderick are primarily caught in haul nets in ocean waters, with most fish taken from zones 3 to 5 (Coffs Harbour to Newcastle) (Figure 6.4). Commercial fishing for luderick occurs year round, although greatest catches generally occur between March and August (autumn/winter) in estuaries and in May in ocean waters (Figure 6.4), when luderick are generally travelling.

There have been no reported studies on the sex, size and age composition of commercial catches of luderick in NSW. In Moreton Bay (Queensland), however, commercial catches of luderick consist of fish primarily of 4-6^+ years of age (Pollock 1981). Luderick are highly sought after by a specialised group of recreational fishers in NSW, with the recreational catch reported to be significant. In Lake Macquarie and Tuggerah Lakes the recreational catch was only slightly less than the commercial catch in 1978-79 (Henry and Virgona 1981). In contrast, West and Gordon (1995) reported that the commercial catch was more than double the recreational catch in the Richmond and Clarence Rivers.

As well as the general regulations affecting the commercial estuarine finfish fishery in NSW, there is a minimum legal size on luderick of 25 cm TL (approximately 22 cm FL) applying to commercial and recreational fishers. Recreational anglers have a daily bag limit of 20 fish.

6.3 Aims of this chapter

This chapter describes spatial, temporal and gear-related variations in the size, sex and age composition of estuarine and ocean commercial landings of luderick in NSW between 1995 and 1997. Relationships between age and length of luderick and preliminary estimates of growth are presented and recommendations for future assessments of the fishery for luderick in NSW are discussed.

6.4 Materials and methods

Commercial catches of luderick in the Richmond River, Clarence River, Wallis Lake, Port Stephens, Lake Macquarie, St. Georges Basin, Tuross River and Wallaga Lake were assessed for their size compositions. Otolith samples were obtained from catches in the Clarence River, Port Stephens, Lake Macquarie and St. Georges Basin. Because of time constraints, only the otolith samples from the Clarence River and Port Stephens have been processed and therefore reported here.

The protocol for field sampling, laboratory processing of samples and analyses of data generally followed that described in Chapter 3.

6.5 Results

6.5.1 Variation in size and sex composition of commercial catches

The size composition of estuarine commercial catches of luderick varied among seasons within an estuary, as well as between estuaries (albeit sample sizes were relatively low for some seasons/estuaries). Commercial catches of luderick sampled in this study included fish 22-56 cm FL, although the majority were 25-35 cm FL (Figures 6.5 and 6.6). There were no consistent inter-estuary or gear-related (mesh net versus haul net) differences in the size compositions of catches.

The ocean and pound net catches of luderick comprised fish 22-41 cm FL (Figure 6.7). The average length of luderick sampled in pound nets in the Port Stephens area varied between 1996 and 1997, indicating that the size structure of 'travelling' fish may vary annually.

Commercial landings of luderick in the Clarence River, Lake Macquarie, St. Georges Basin and Port Stephens were generally biased towards females (Figure 6.8). In the Clarence River, the size of female fish landed was on average greater than that of males, but this was not evident in the commercial haul net catches from Lake Macquarie and St. Georges Basin, and pound net catches from Port Stephens (data pooled across all time periods) (Figure 6.9).

6.5.2 Age determination

The otoliths of luderick displayed wide translucent and thin opaque growth zones (Figure 6.10), that could be interpreted as annuli. Preliminary investigations of whole otoliths proved considerably harder to interpret than thin sections because of the stacking of growth layers at the otolith margin. Sectioned otoliths were therefore used to estimate the ages of luderick in this study. Relationships between the age and fork length of male and female luderick from the Clarence River were best described by logarithmic equations, but were relatively weak because of the considerable variation in the length of fish at any given age (Figure 6.11). Otolith weight generally increased with size and age of fish (Figure 6.11), and relationships were best described by linear models.

6.5.3 Variation in age structure of commercial catches

There was little difference in the age composition of the male and female components of the commercial catch in the Clarence River between 1995 and 1997 and likewise in the Port Stephens pound net catch in 1997 (Figure 6.12). Therefore further analyses concerning the age structure of catches were performed on data with sexes combined.

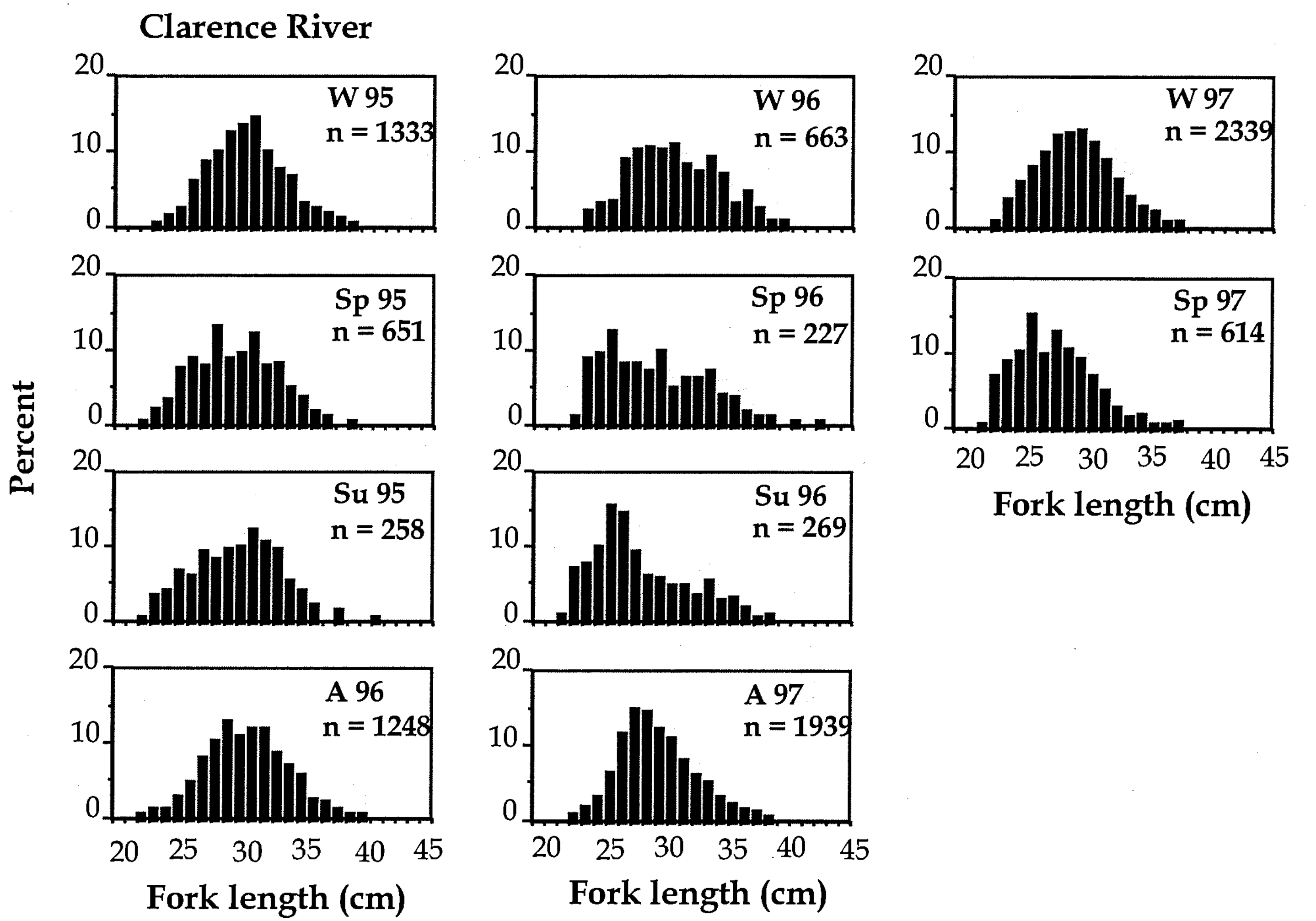


Figure 6.5. Size-frequencies of commercial estuarine mesh net landings of luderick.

Figure 6.5. continued.

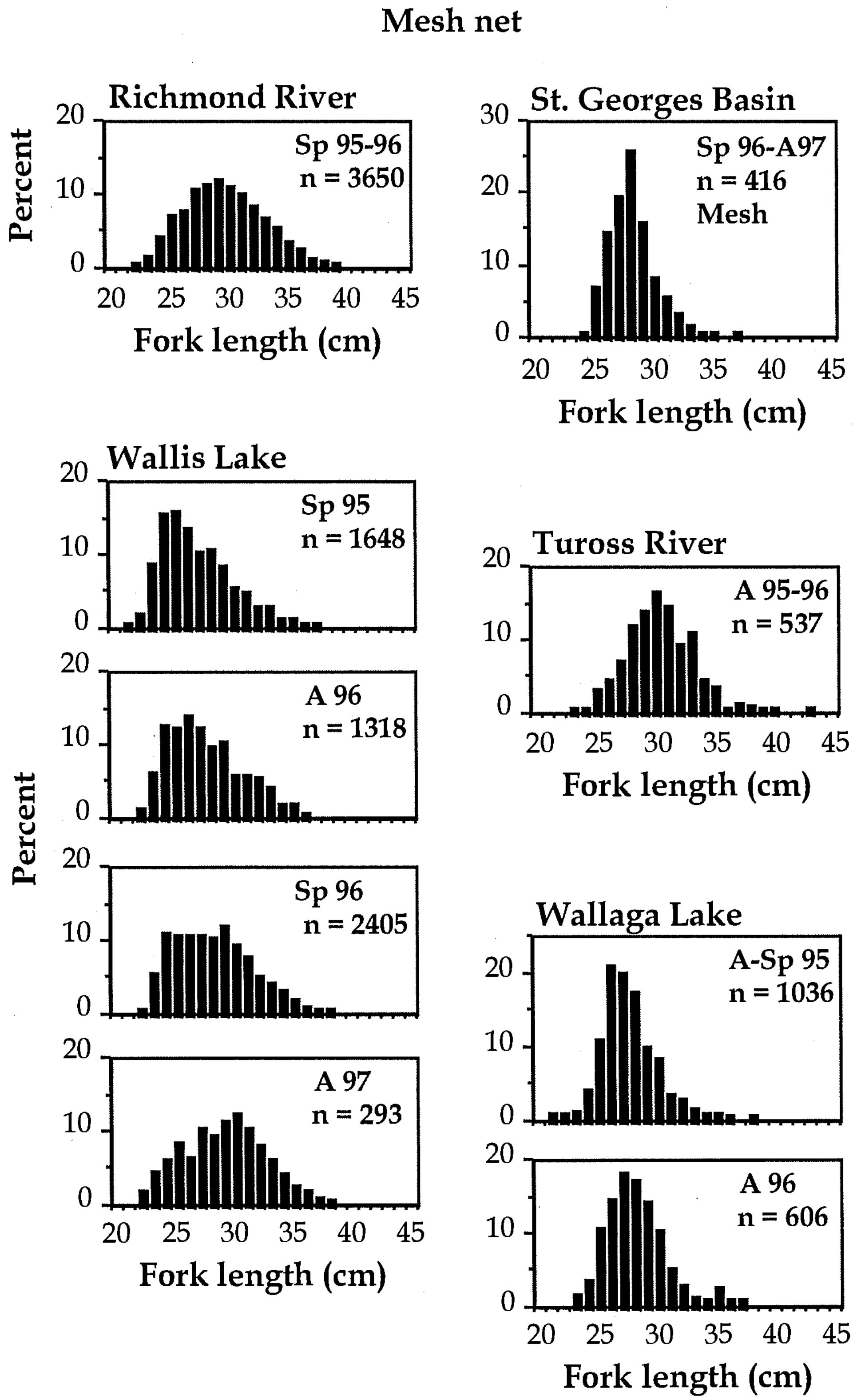


Figure 6.6. Size-frequencies of commercial estuarine haul net landings of luderick.

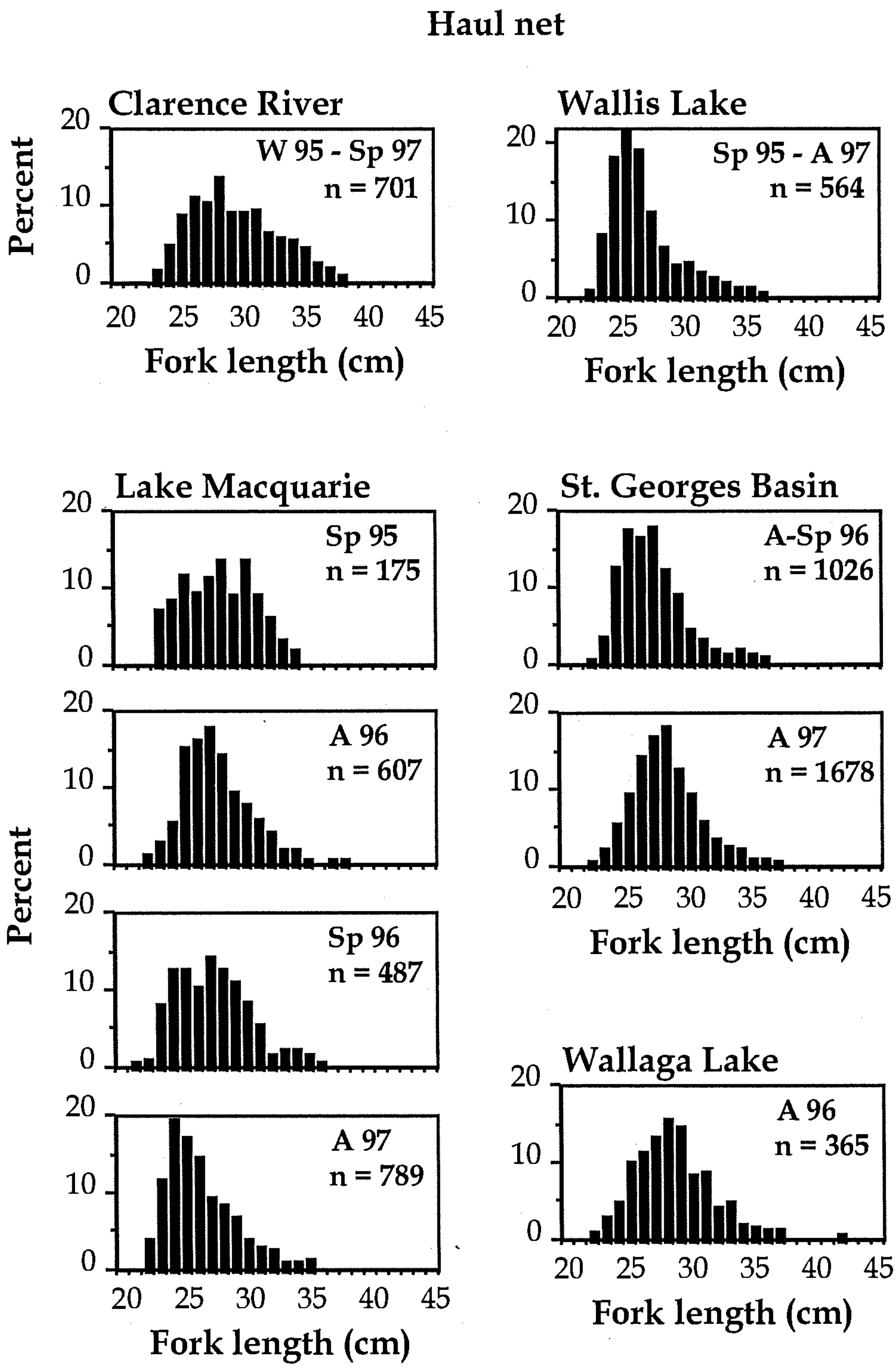


Figure 6.7. Size-frequencies of commercial landings of luderick from pound nets in Port Stephens and from ocean haul nets in Wreck Bay.

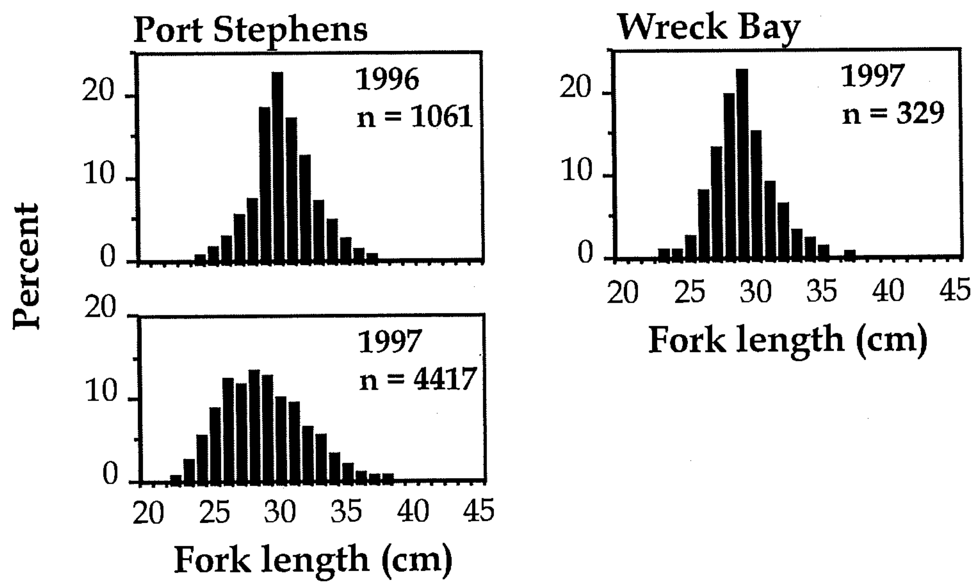
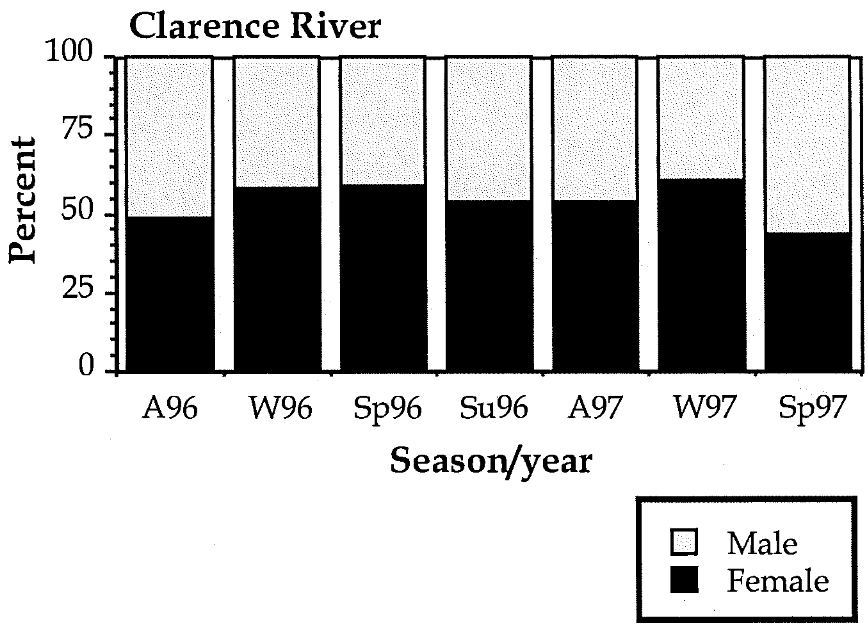


Figure 6.8. Sex ratios of commercial landings of luderick.



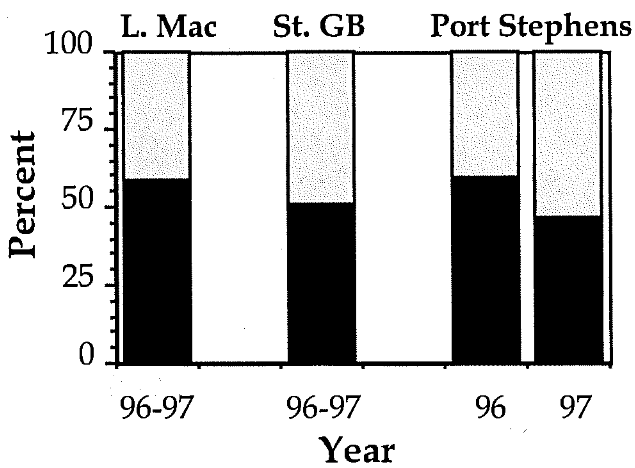


Figure 6.9. Total size-frequencies of male and female commercial landings of luderick.

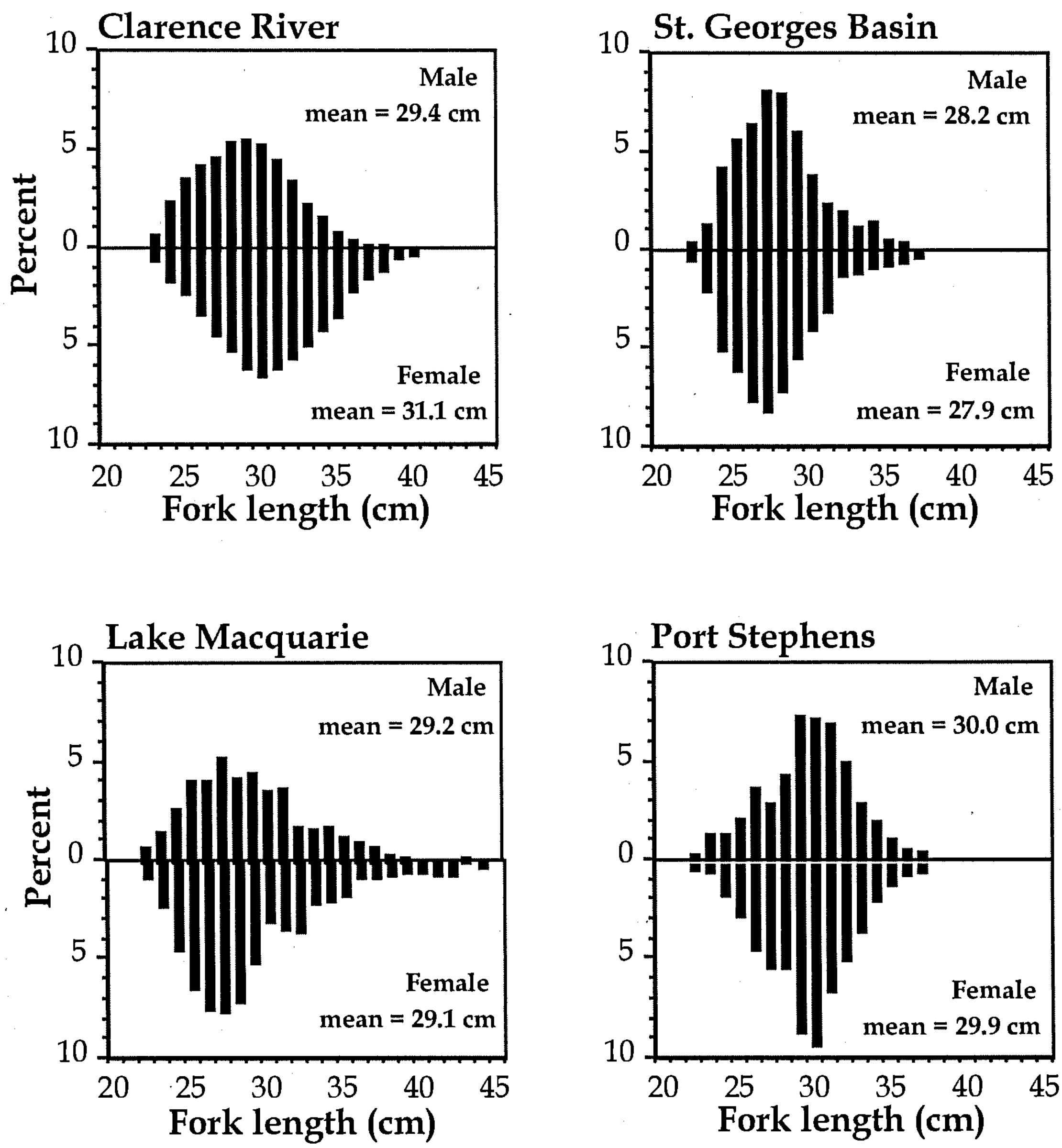


Figure 6.10. Images of sectioned otoliths of luderick showing the alternate narrow opaque and wide translucent zones across each otolith.

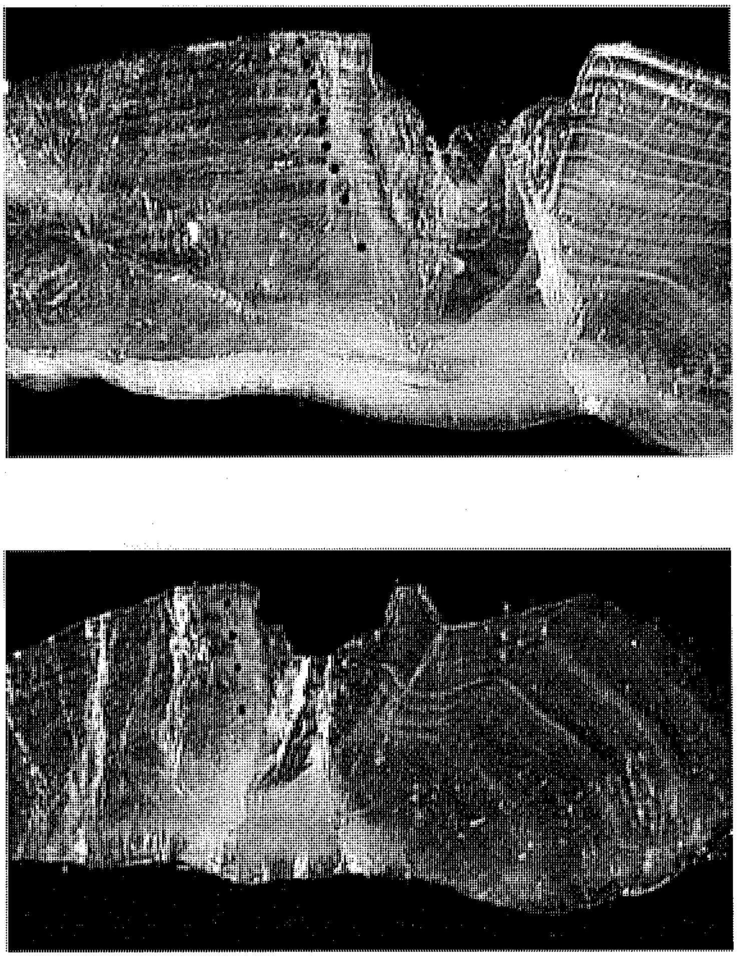


Figure 6.11. Relationships between estimated age, fork length and otolith weight of male and female luderick greater than the minimum legal length (MLL).

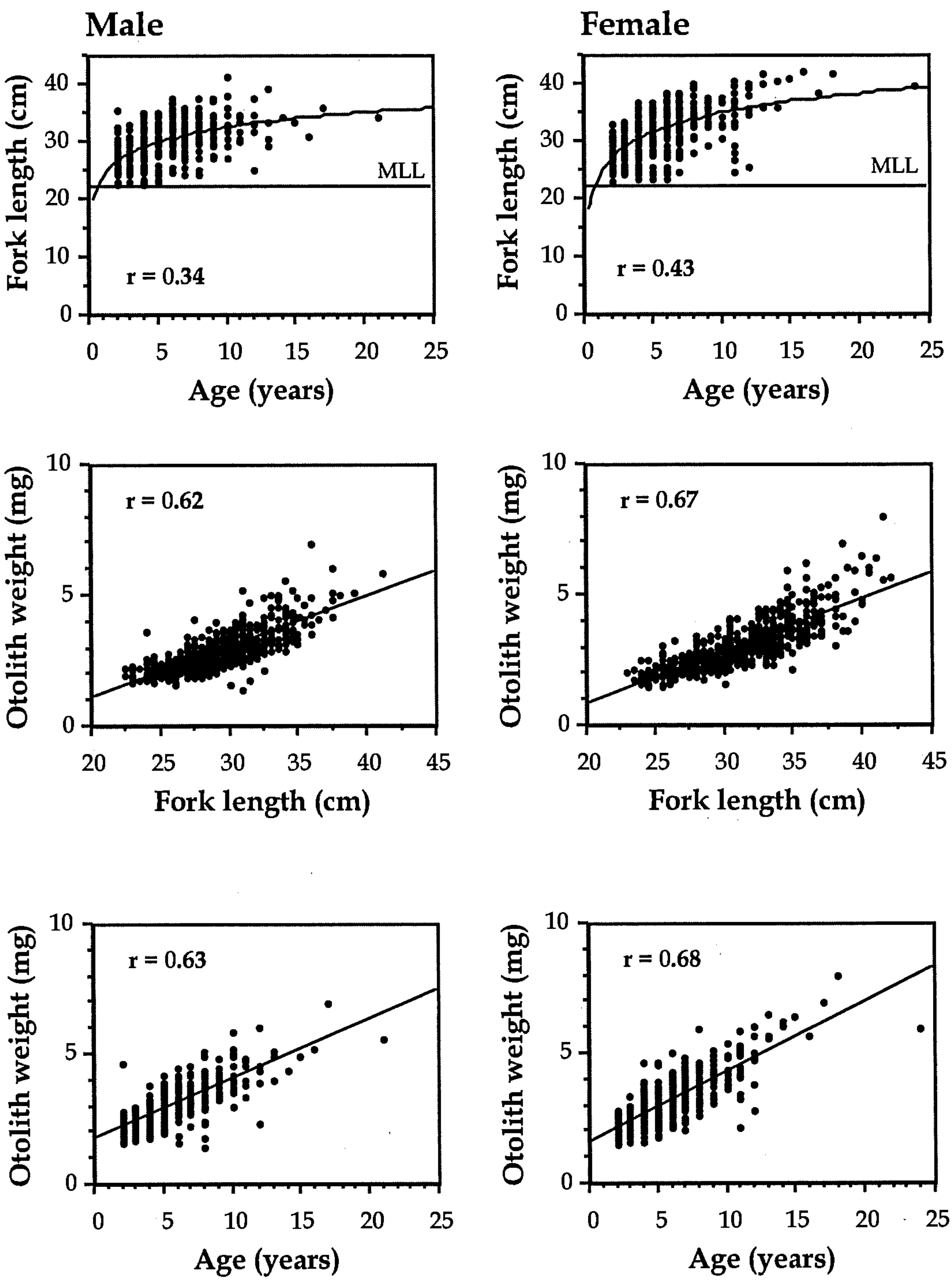
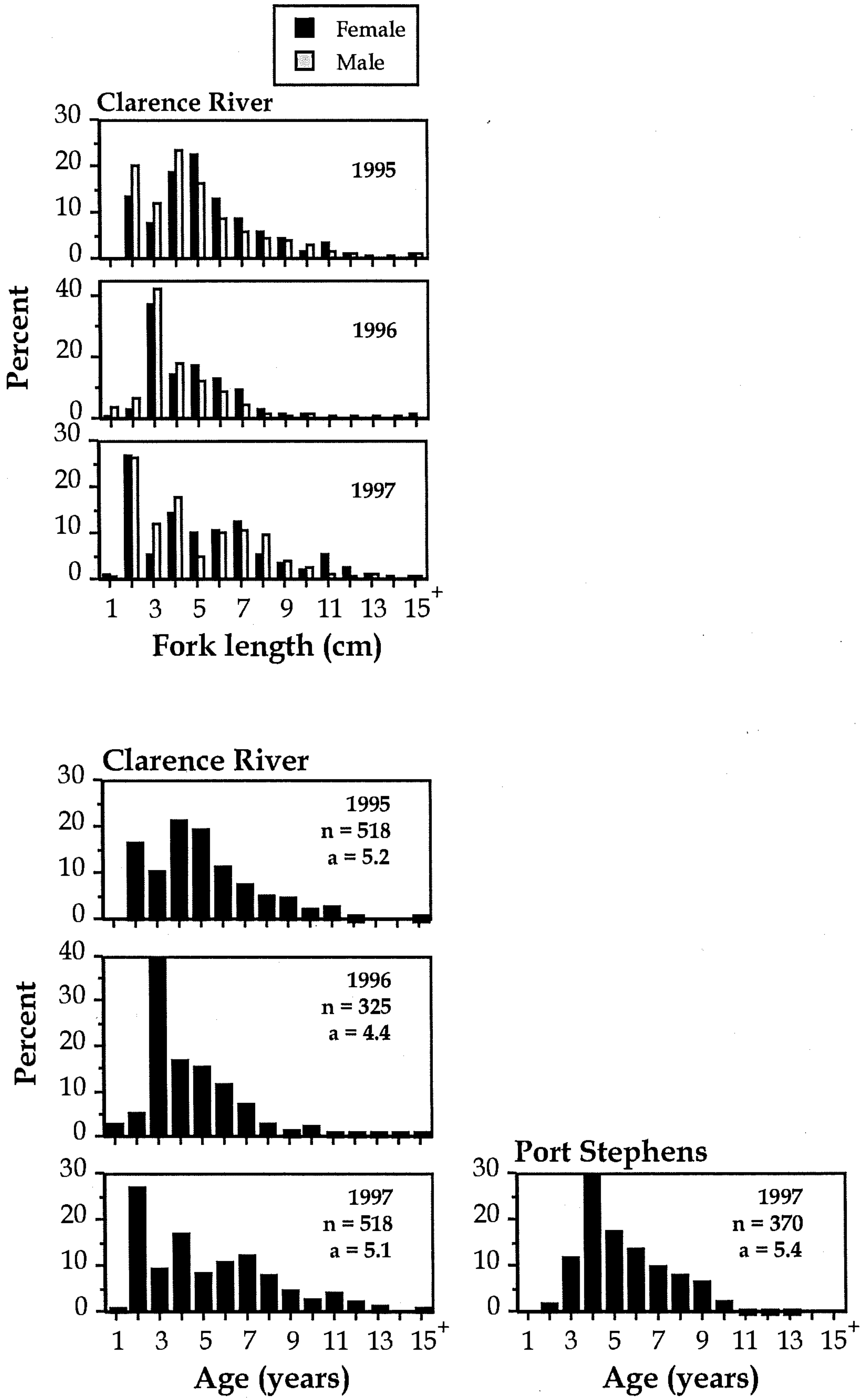


Figure 6.12. Age structures of commercial landings of luderick from mesh nets in the Clarence River and pound nets in Port Stephens. Bottom figures show combined sexes. n = number of otoliths examined; a = average age in years.



Commercially caught luderick from the Clarence River ranged between 1-24$^+$ years, but the majority of fish were aged between 2-9$^+$ years (Figure 6.12). The age composition of catches varied between years, and in particular the estimated age structure in 1996 was different to that of 1995 and 1997. The progression of certain year classes in the fishery could be observed between 1995 and 1997, in particular the relatively strong 2, 4 and 5 and weak 3$^+$ age classes in 1995 could be seen as the corresponding strong 4,6 and 7 and weak 5$^+$ age classes in 1997 (Figure 6.12). The estimated age structure of the pound net/ocean catch at Port Stephens in 1997 was generally similar to that of catches from the Clarence River.

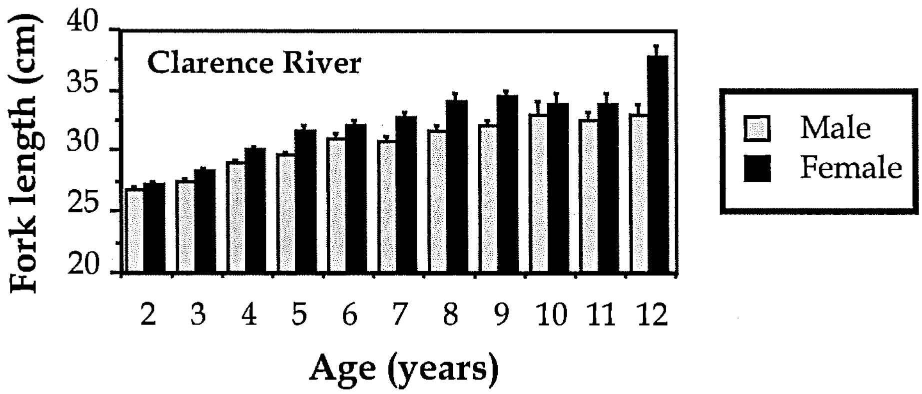
6.5.4 Variation in size at age and growth

The mean size at age of female luderick tended to be greater than that of males for all age groups in the Clarence River, indicating a faster rate of growth for females (Figure 6.13). The estimated mean size at age for 2 and 3 year old fish is probably an over-estimate due to the lack of fish < 22 cm FL in the data.

The oldest male and female luderick aged from the Clarence River during this study were 21 and 24$^+$ years, and from the pound net in Port Stephens 12 and 13$^+$ years, respectively. The largest luderick sampled in this study were 56 cm FL (female) and 48 cm (male), both of which were captured in the Clarence River.

Initial estimates of growth of male and female luderick in the Clarence River were performed on data pooled across years. The von Bertalanffy growth equation estimated the parameters L_∞, K and t_0 to be 34.4, 0.174 and -6.5 for males, and 39.1, 0.14 and -6.9 for females. The 3 parameter Schnute model (case 2 in Schnute) best estimated mean size of males at ages 2 and 10 to be 26.6 and 32.5 cm FL, and females to be 27.3 and 35.1 cm FL, respectively.

Figure 6.13. Mean fork length (+ 1 se) at age of male and female luderick.



6.6 Discussion

6.6.1 Age determination

The field based oxytetracycline mark and recapture study of luderick showed that the opaque and translucent zones observed on sectioned luderick otoliths and used to age fish here are annuli (Appendix I). Although it can therefore be assumed that the method of aging luderick used in this study has been validated, the age of the luderick at the first observed opaque zone needs to be investigated. Notably, the distance from the otolith core to the first opaque ring varied greatly among individuals and may be related to variations in the initial timing of recruitment and settlement of fish within and among estuaries along the coast (see Chapter 2).

Length-based aging methods have been used to assess the status of some fisheries. Because of the wide range in the length of luderick at any given age, using length alone to monitor the stock may not prove adequate for development of population models. Otolith weight showed a reasonable correlation with length and age and therefore may potentially be a cheaper method to estimate the age of luderick. The feasibility of this requires further investigation.

6.6.2 Variations in size at age and growth

There was considerable variation in the size of luderick at any given age, and realistic growth curves for luderick could not be generated here because of the lack of fish below 22 cm FL in the data. The estimated lengths of 26-27 and 32-35 cm FL for luderick at 3 and 10 years of age respectively, are slightly greater than those found elsewhere of 22-26 and 31 cm FL for fish of the same age (see Kailola et al. 1993, West 1993), which suggests that the growth of luderick may not vary greatly throughout southeastern Australia. Female luderick in the Clarence River appeared to grow faster, and they attained a greater length, than males, which contrasts with the findings by West (1993) for the same river, and by Pollock (1981) for Moreton Bay. The maximum age of luderick found in this study of 21 and 24^+ years for males and females respectively, is greater than that previously reported of 9 and 11^+ years (Pollock 1981).

6.6.3 Variation in sex, size and age composition of commercial catches

The data show that the estuarine commercial fishery for luderick in the Clarence River and the 'spawning run' ocean beach and pound net fishery is based on several age classes, primarily those between 2-9^+ years. The age structure of Clarence River fishery varied between years, but the strong and weak year classes could be followed annually.

Luderick and bream display similar life histories in that adults undertake relatively large pre-spawning migrations along the coast and the subsequent recruitment of juveniles to shallow regions of estuaries varies considerably in space and throughout time (see Chapter 2). Hence, the recruitment of young fish to the fishery could also vary substantially between estuaries and thus impact on population age structures. The age structures of luderick catches from other estuaries needs to be determined to assess this hypothesis and to assess if age structures vary with latitude as suggested for bream. Variations between estuaries in the demographic characteristics of commercial catches of luderick needs to be evaluated before an assessment of the status of the fishery in NSW can be undertaken.

The size structure of commercial catches varied between time periods within an estuary and also between estuaries, but there were no obvious gear-related differences in catch compositions. The sex ratios of commercial estuarine and ocean/pound net catches were slightly biased towards females, similar to that found for bream. Many of the luderick harvested were less than the reported sizes at first maturity (28-32 cm FL).

Because of the reported relatively large movements of luderick along the coast the stock needs to be considered as a single unit for assessment purposes. However, future monitoring of the stock should take into consideration possible variations in age structure between estuaries. Luderick otoliths which remain unprocessed need to be aged.

6.6.4 Conclusions and consequences for future assessments of the fishery

Although the age composition data presented here are for only one estuary and ocean area, they indicate that the luderick stock is probably not subject to high total mortality, which supports the previous yield-per-recruit modeling done by West (1993) . The low market value for the species deters many fishers from targeting this fish, reducing effective fishing mortality. If the market prices for luderick increase dramatically and/or catches increase, then the age composition of the commercial catch will need to be reassessed. Future monitoring and assessment of the fishery for luderick should be given a lower priority than the other species examined in this study at this time. The otoliths collected for the other ports (Lake Macquarie and St. Georges Basin) should be aged to provide a more detailed assessment of the state of the resource than that presented here.

The recreational fishery for luderick has not been assessed, and it is important that any future stock assessments of the species incorporate the recreational component. Future studies need also to examine the size at first maturity in luderick throughout NSW, and also the degree of mixing and movement of the spawning run fishery to assist in the stock assessment of luderick in NSW.

7. Variations in size, sex and age compositions of commercial catches of dusky flathead (*Platycephalus fuscus*) in NSW

7.1 Summary of relevant ecological literature

Dusky flathead are endemic to Australia, inhabiting estuaries and nearshore coastal waters along the east coast between Cairns in Queensland and the Gippsland Lakes in Victoria. There is little information on the stock structure of dusky flathead, although tagging studies in NSW and Queensland show that some individuals move between estuaries, and that other individuals undertake relatively large movements (> 200 km) (Kailola et al. 1993, West 1993 and NSW Fisheries unpublished data). It is therefore likely that the dusky flathead population consists of a single stock (at least between southern Queensland and Victoria).

Dusky flathead have been reported to spawn between September and March in northern Queensland, November and February in southern Queensland, and between January and March in NSW and Victoria (Dredge 1976, SPCC 1981, Russell 1988). Larvae of dusky flathead have been captured in coastal and estuarine NSW waters between September and May (Miskiewicz 1987, Gray 1995). It is not known whether dusky flathead spawn more than once in each spawning period. Although not quantified, it is believed that spawning takes place in the lower reaches of estuaries and in nearshore coastal waters (SPCC 1981, Kailola et al. 1993), where small congregations of one (relatively large) female and several (smaller) male fish have been observed. Although there have been no reported studies on the reproductive biology of dusky flathead, there is conflicting information on whether dusky flathead are protandrous sex reversers (i.e. change sex from male to female) (Dredge 1976, SPCC 1981), and it has been suggested that if this is the case, then it probably takes place at 4 to 5 years of age (Dredge 1976). Size at maturity probably varies with latitude, with reported total length (TL) at first maturity being 46 cm (male) and 56 cm (female) in Queensland, 32 cm (male) and 38 cm (female) in central NSW, and about 26 cm (male and female) in southern NSW and Victoria (see Kailola et al. 1993). Growth of dusky flathead appears to be relatively fast, with fish reported to reach a size of about 18 cm TL in 1 year, and 40 cm TL in 3 years in southern Queensland and northern NSW (Dredge 1976, West 1993). Dredge (1976) reported no differences in the growth rates of male and female fish. Dusky flathead can attain a maximum size of 1.2 m TL (approximately 15 kg) (Kailola et al. 1993).

7.2 Overview of the NSW commercial fishery

The annual commercial production of dusky flathead in NSW has been relatively stable over the past 40 years, fluctuating between 150 - 200 tonnes, with virtually all of the commercial catch being taken in estuaries (Figure 7.1). The major estuaries contributing to total production of dusky flathead have predominantly been in the central region, notably Wallis Lake, Tuggerah Lakes, Lake Illawarra and Lake Macquarie, and the Clarence and Camden Haven Rivers (Figure 7.2). Greatest ocean catches were taken

Figure 7.1 Annual commercial estuarine and ocean landings of dusky flathead from 1954/55 to 1996/97.

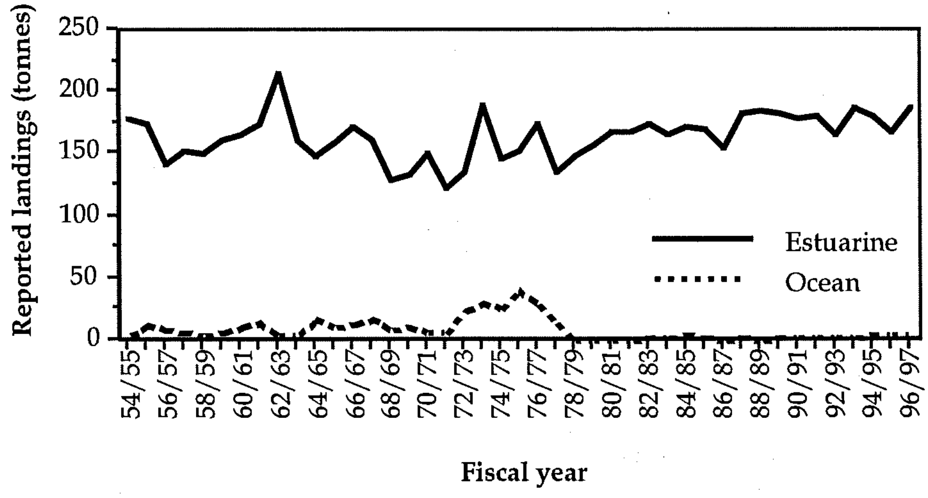


Figure 7.2 Average (+ 1se) commercial estuarine landings of dusky flathead in the top 20 estuaries in NSW for the period 1992/93 and 1996/97.

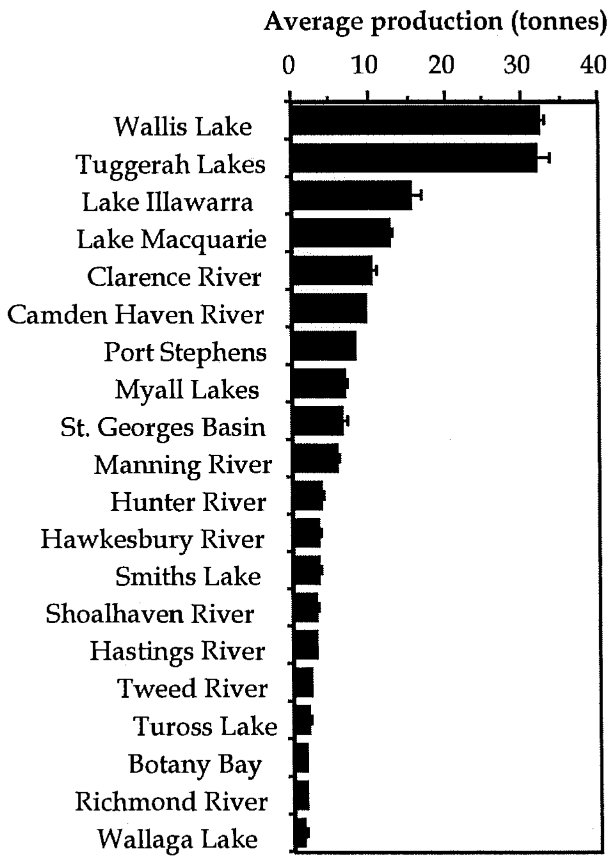


Figure 7.3 Average (+ 1 se) annual commercial ocean landings of dusky flathead in each ocean zone in NSW for the period 1992/93 and 1996/97.

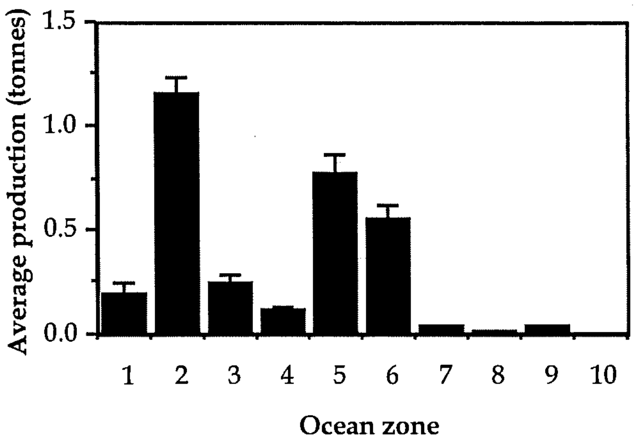
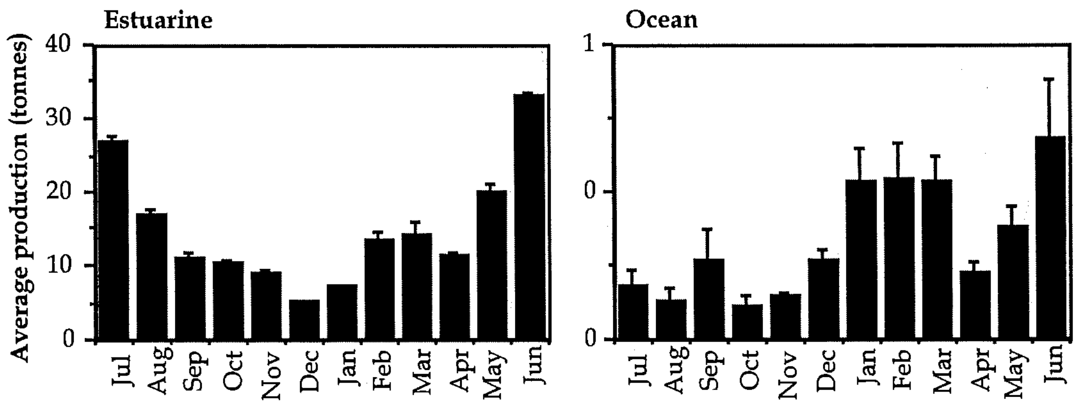


Figure 7.4 Average (+ 1 se) monthly commercial estuarine and ocean landings of dusky flathead in NSW for the period 1992/93 to 1996/97.



in zones 2, 5 and 6 (Figure 7.3). Dusky flathead are predominantly caught by mesh nets, although significant quantities are also caught in haul nets. Commercial fishers are permitted to use a 'flathead set net' (type of mesh net) in 5 estuaries in NSW (Wallis Lake, Smiths Lake, Tuggerah Lakes, Lake Illawarra and St. Georges Basin), although the times governing the use of this set net vary between estuaries. Although the fishery for dusky flathead occurs year round, greatest catches are generally taken in June and July (winter) (Figure 7.3), when overnight setting of mesh nets in estuaries is permitted.

In 1996/97 the commercial estuarine dusky flathead catch in NSW was 187 tonnes, valued at approximately $650,000 to commercial fishers. Recently a export market has been developed for dusky flathead, which promises to increase the value of this species to commercial fishers. This export market is presently based on fish between 40 and 50 cm TL.

The fishery for dusky flathead in NSW is managed through gear restrictions, temporal and areal closures and a minimum legal size of 33 cm TL. This minimum legal size also applies to recreational fishers in NSW, in conjunction with a bag limit of 10 fish per angler per day.

Although dusky flathead are harvested by commercial and recreational fishers throughout NSW, little research has been done on the biology and fishery of this species in NSW. West (1993) provided some initial data on the size compositions of commercial and recreational catches of dusky flathead in the Clarence and Richmond Rivers in northern NSW, including some preliminary growth estimates based on tag recaptures and some preliminary yield per recruit modelling of the dusky flathead fishery.

7.3 Aims of this chapter

This chapter describes spatial, temporal and gear-related variations in the sex, size and age composition of commercial estuarine catches of dusky flathead in NSW. Relationships between the age and length of flathead and preliminary growth models are presented. Recommendations for future research and management strategies concerning the fishery for dusky flathead are discussed in view of the findings.

7.4 Methods

The sex, size and age compositions of commercial landings of dusky flathead were assessed from the Clarence River, Wallis Lake, Lake Macquarie and St. Georges Basin between 1995 and 1997. Catches of dusky flathead from the Tuross River and Wallaga Lake were sampled in 1995 and 1996, but because few fish were captured during the sampling period, data for these two estuaries were pooled and no sampling in these locations occurred after April 1996.

Because catches of dusky flathead in coastal waters are very sporadic and contribute relatively little to total landings, no samples were collected from ocean waters to assess variations in size and age structure of catches between ocean and estuarine waters.

Field and laboratory methods and analyses of data generally followed that outlined in Chapter 3. However, the age structures of commercial catches of dusky flathead were determined using age length keys which considered fish > 50 cm TL to be from the one size category. This was done because it was not possible to collect otoliths from every 1 cm length class for fish above 50 cm TL.

7.5 Results

7.5.1 Variation in size and sex composition of commercial catches

The size structure of commercial landings of dusky flathead varied by method, especially for mesh nets of different mesh sizes (Figure 7.5), with the average size of fish retained being least in the 70 mm flathead set nets. Dusky flathead between 30-96 cm TL were sampled during this study, although catches predominantly comprised fish between 35-50 cm TL (Figures 7.6 and 7.7). In general, the size range of dusky flathead retained in catches from Wallis Lake and St. Georges Basin was smaller than in the other two estuaries.

Commercial landings of dusky flathead in all estuaries were dominated by females (Figure 7.8). This was particularly evident in the Clarence River where landings were virtually comprised solely of females. The length frequency data showed that females contributed a greater size range to the fishery, particularly in the Clarence River and Wallis Lake, where few males over 45 cm were captured (Figure 7.9). Some larger males (> 45 cm TL) were caught in Lake Macquarie and St. Georges Basin.

7.5.2 Age determination

Whole and sectioned sagittal otoliths displayed opaque and translucent zones that could be interpreted as annual age counts (Figure 7.10). Preliminary examination of whole otoliths proved considerably harder to estimate ages than thin sections, and thus sectioned otoliths were used to estimate the age of dusky flathead in this study.

There was good agreement between the two independent readers in the interpretation of ages from thin sectioned sagittal otoliths of dusky flathead, ranging from 87-97 % (Table 7.1). The majority of discrepancies in ageing flathead were of 1 year. There was no latitudinal trend in the agreement between readers.

Relationships between age and size (total length) of dusky flathead were relatively weak, particularly for males (Figure 7.11). Otolith weight generally increased with size and age of fish (Figure 7.11), indicating that otoliths continued to grow throughout the life of a fish, and that they were potentially a suitable structure to estimate age of dusky flathead. However, the relationship between otolith weight and age was relatively weak. Relationships between length, age and otolith weight were best described by linear and exponential equations.

Figure 7.5. Gear-related differences in the size-frequency of commercial mesh net landings mesh net of dusky flathead. n = number of fish measured; m = mean length.

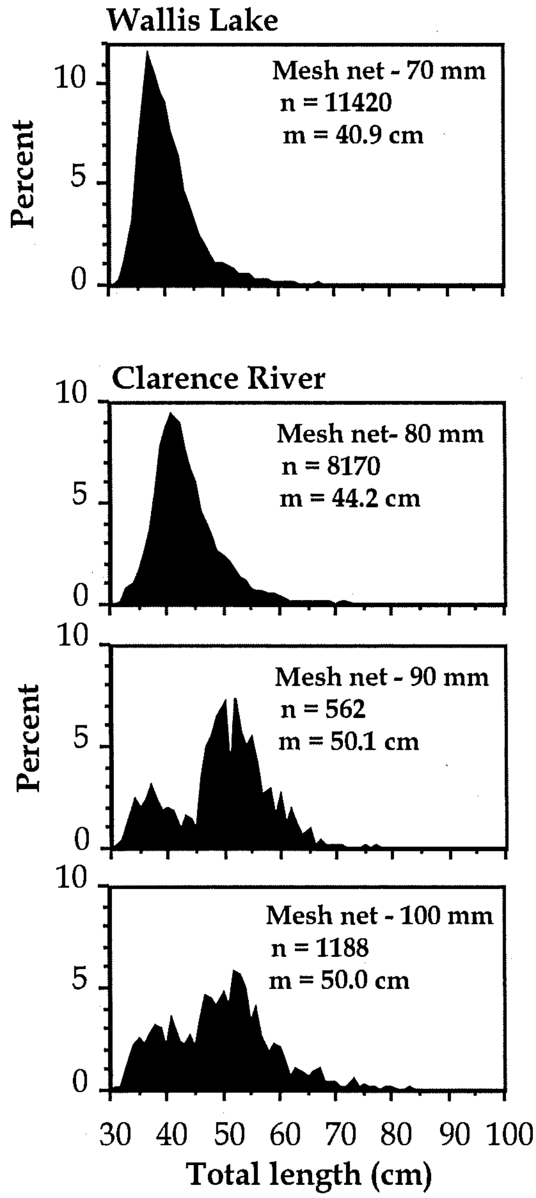


Figure 7.6. Size-frequencies of commercial estuarine mesh net landings of dusky flathead.

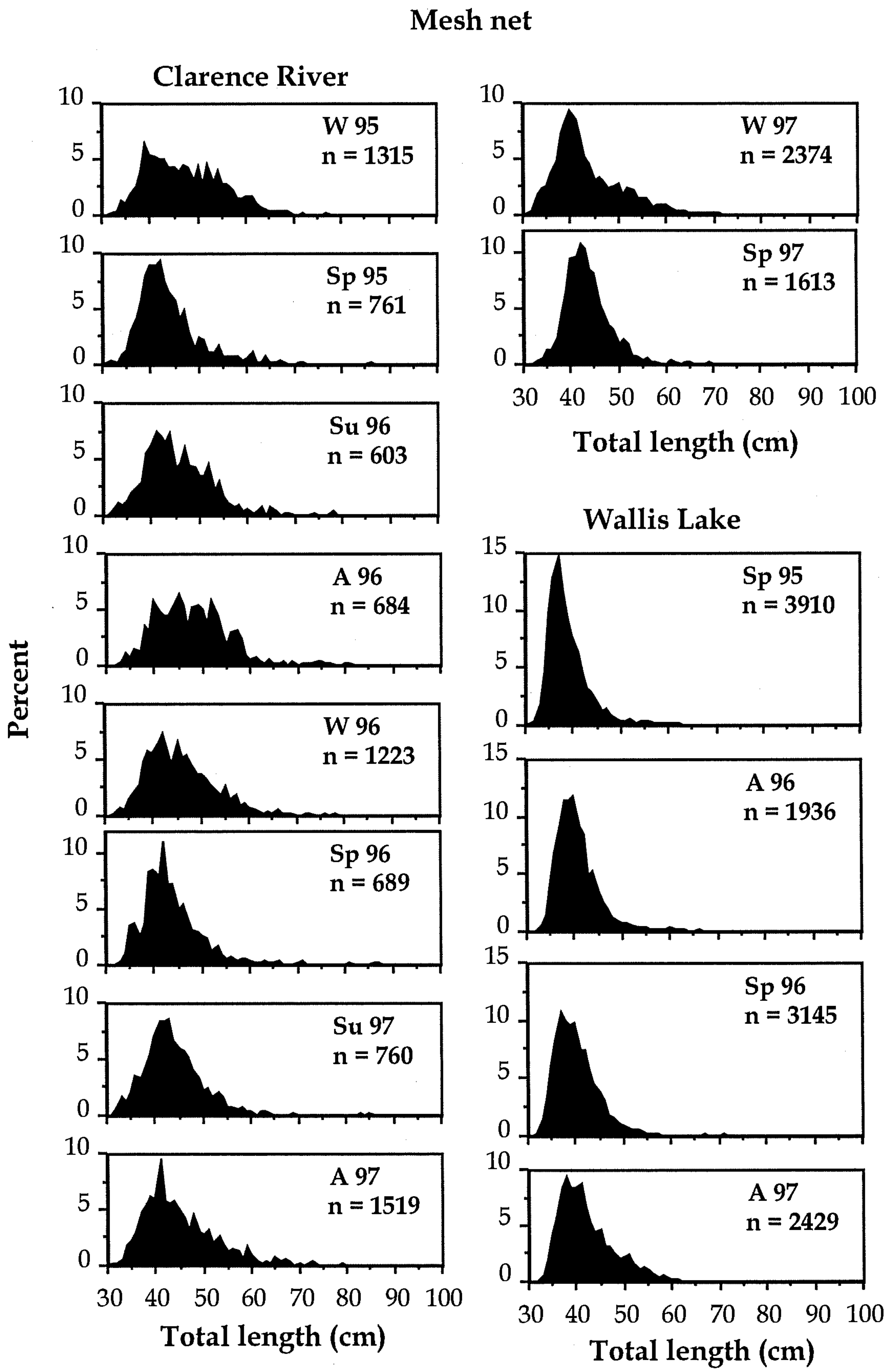


Figure 7.7. Size-frequencies of commercial estuarine haul net landings of dusky flathead.

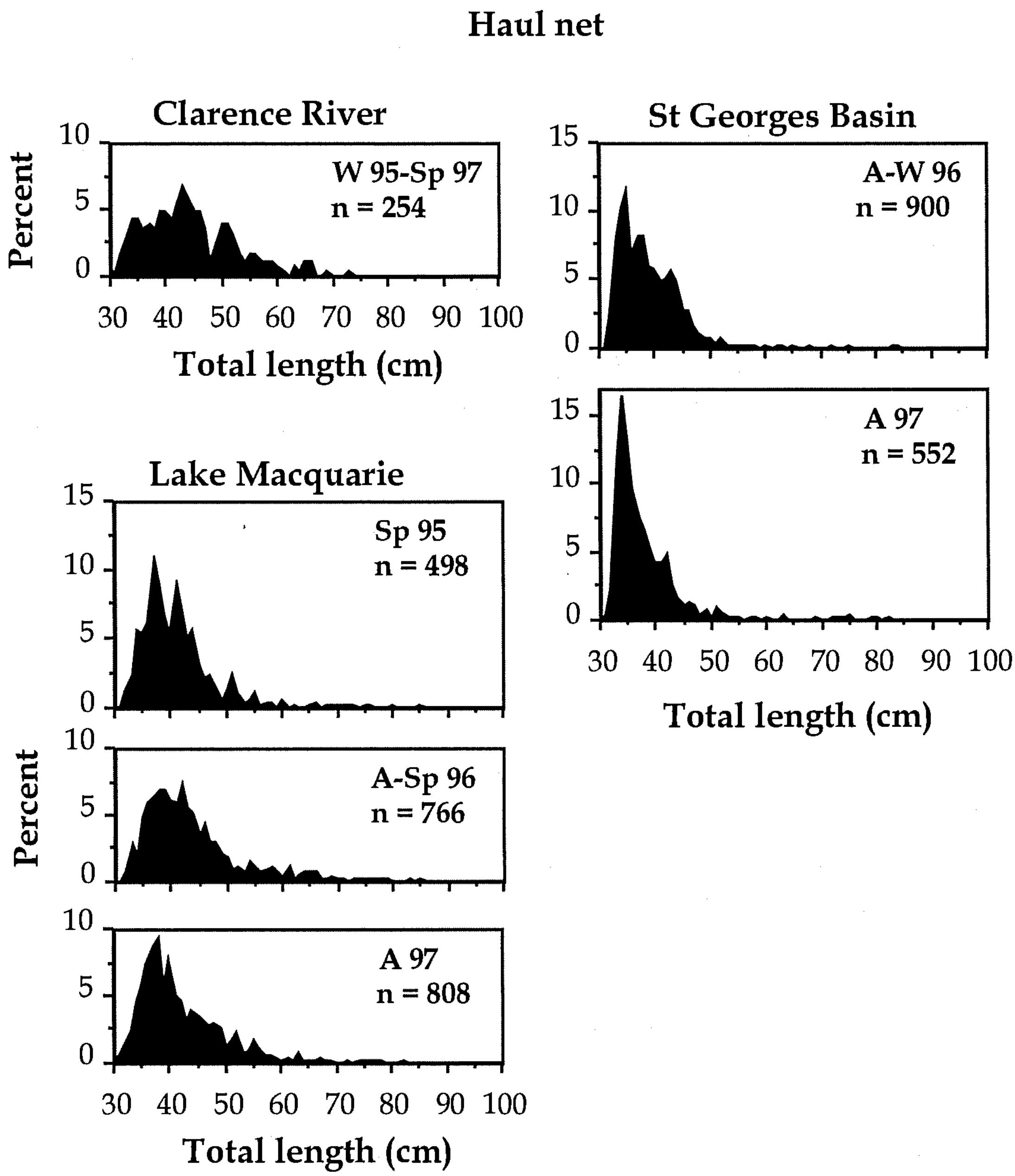


Figure 7.8. Sex ratios of commercial estuarine haul net landings of dusky flathead.

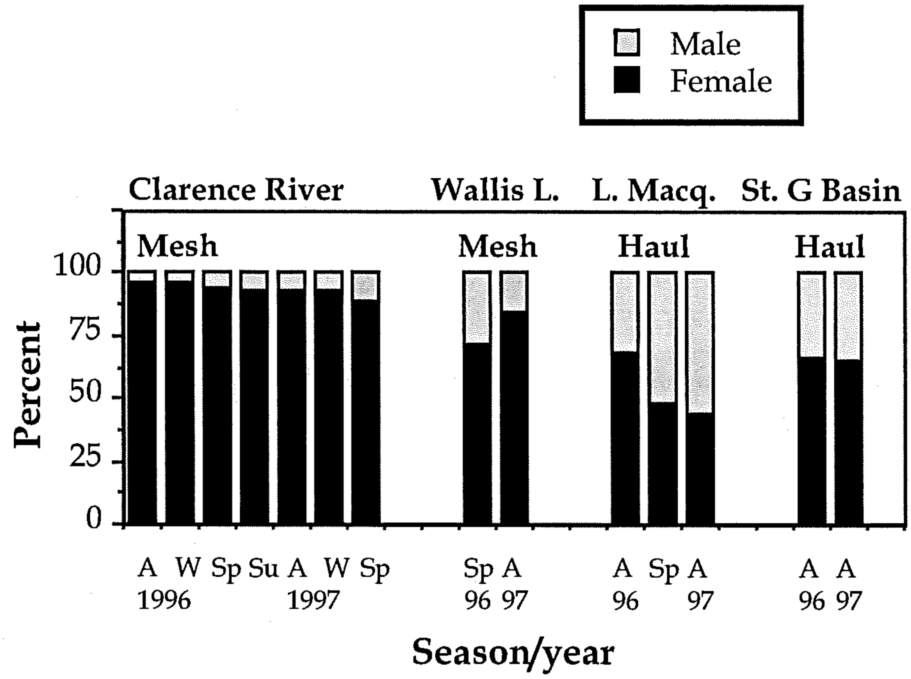


Figure 7.9. Total size-frequencies of male and female commercial estuarine landings of dusky flathead. n = number of fish measured; m = mean length of males; f = mean length of females.

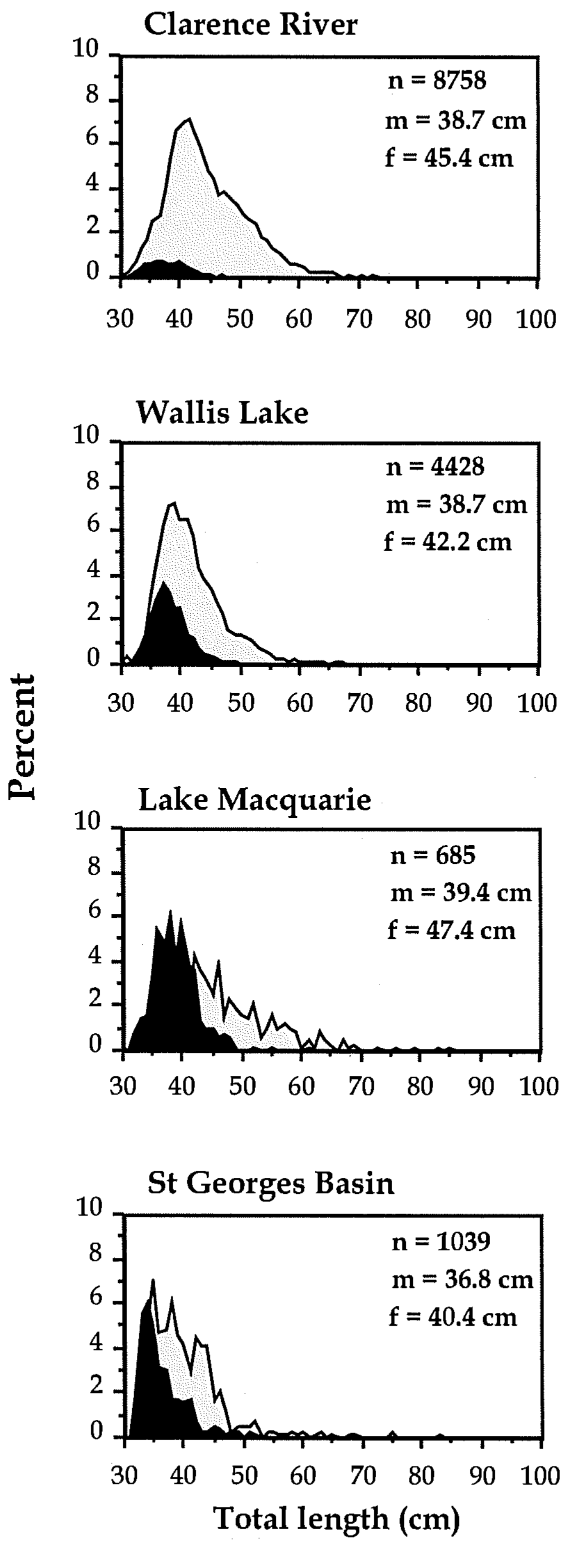


Figure 7.10. Images of sectioned dusky flathead otoliths showing the alternate narrow opaque and wide translucent zones across the section.

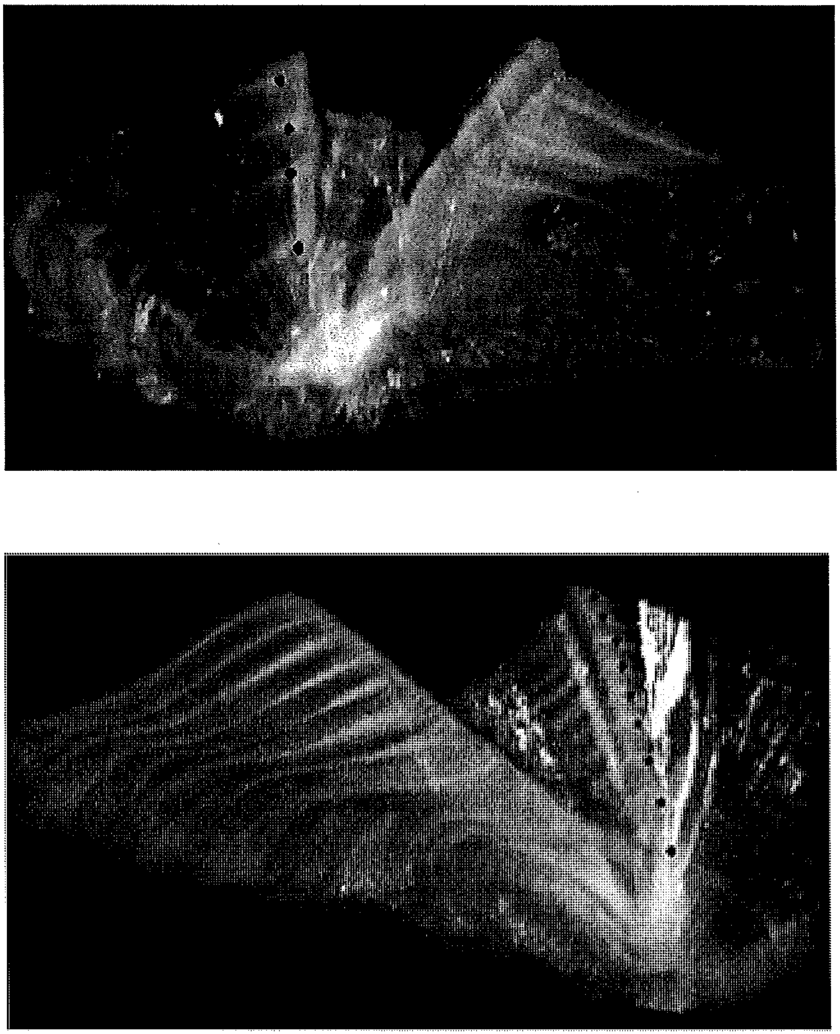


Figure 7.11. Relationships between estimated age, fork length and otolith weight of male and female dusky flathead greater than the minimum legal limit (MLL).

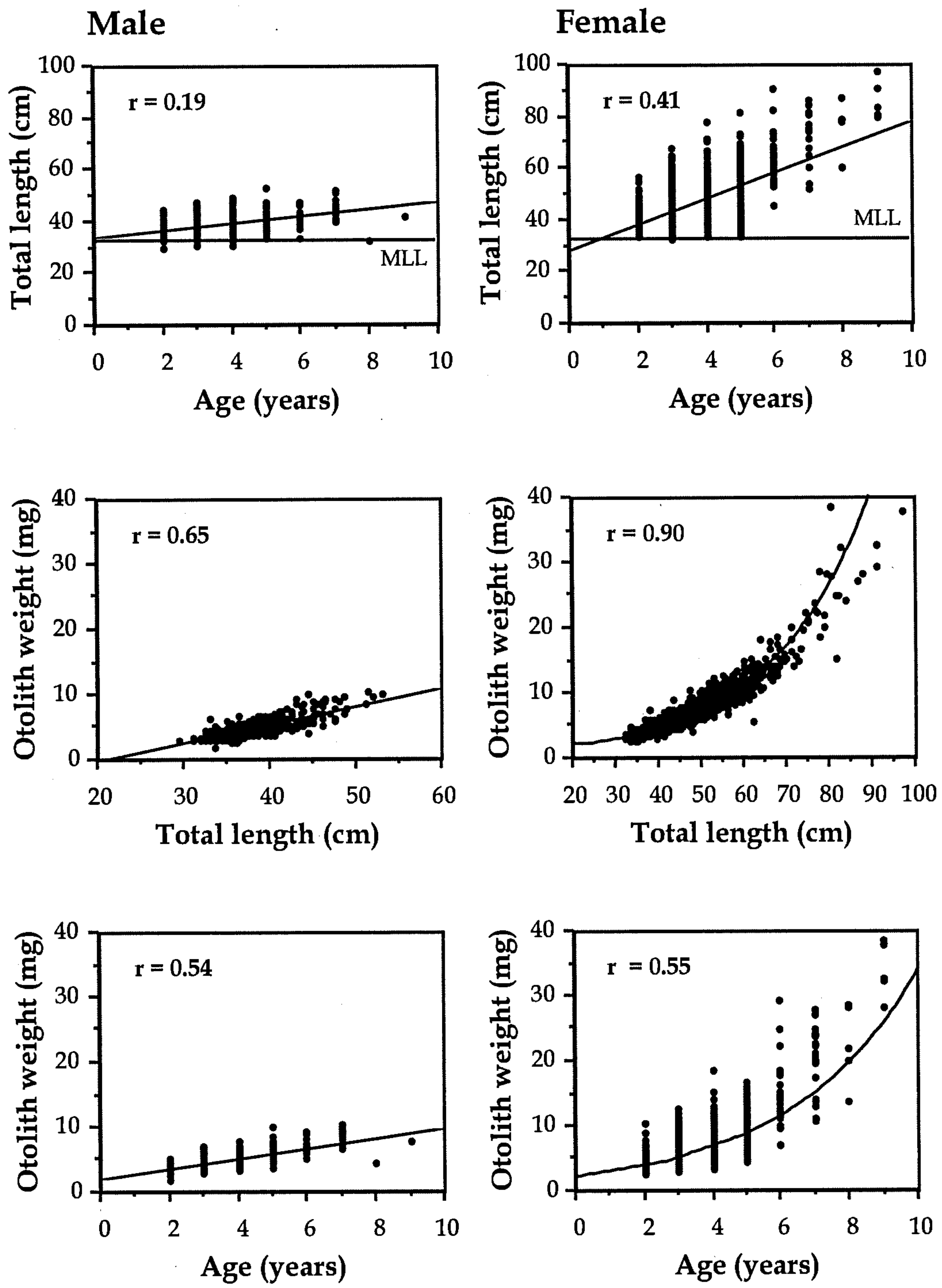


Table 7.1. Replication of age interpretation of dusky flathead otoliths by two independent readers. Note that there was no apparent bias over any particular age group.

Location	No. otoliths examined	% agree	% differ > 1yr
Clarence River 1995	360	88.9	0
Clarence River 1996	371	89.5	0.5
Clarence River 1997	461	94.4	0.2
Wallis Lake 1995	380	89.2	0
Wallis Lake 1996	470	92.8	0
Wallis Lake 1997	467	95.5	0.2
Lake Macquarie 1996	427	90.9	0
Lake Macquarie 1997	342	87.4	0.9
St. Georges Basin 1996	372	94.1	0
St. Georges Basin 1997	171	97.7	0
Tuross R./Wallaga L. 1995	61	96.7	0
Tuross R./Wallaga L. 1996	32	87.5	0

7.5.3 Variation in age structure of commercial catches

Although the size composition of catches of dusky flathead varied considerably between sexes, the age structure of the male and female component of the catch was generally similar within each estuary (except Lake Macquarie 1996) (Figure 7.12), and therefore further analyses were done on data pooled across sexes.

Ages of dusky flathead in commercial catches ranged from 2-9$^+$ years, although the age structure of catches varied considerably between estuaries and years (Figures 7.13). Fish aged 2-4$^+$ years dominated catches in the Clarence River and Wallis Lake, whereas 3-4$^+$ fish dominated catches in St. Georges Basin, and 3-6$^+$ fish predominated in Lake Macquarie. Consequently, the average age of fish retained in commercial catches was greatest in Lake Macquarie. Since the fishery in each estuary was primarily based on young fish, the progression of strong or weak year classes could generally not be followed, the exception being Lake Macquarie, where the relatively weaker 4$^+$ age class in 1996 could be observed as the relatively weak 5$^+$ age class in 1996.

7.5.4 Variation in size at age relationships and growth

The mean length at age of female dusky flathead was generally greater than that of males in all estuaries and years, indicating that they grew faster (Figure 7.14). Female dusky flathead also attained a greater maximum length than males. Mean size of males at ages 2 and 6 were 36.6 and 40.7 cm TL, respectively, whereas females at the same age were 38.7 and 57.0 cm TL respectively. The largest male and female dusky flathead observed in this study was 56 and 96 cm TL, respectively. The oldest male and female dusky flathead aged during this study were both 9$^+$ years, but no males greater than 6$^+$ years were recorded from the Clarence River and Wallis Lake (Figure 7.14).

Figure 7.12. Age compositions of male and female commercial estuarine landings of dusky flathead. CR = Clarence River; LM = Lake Macquarie; WL = Wallis Lake; StGB = St. Georges Basin.

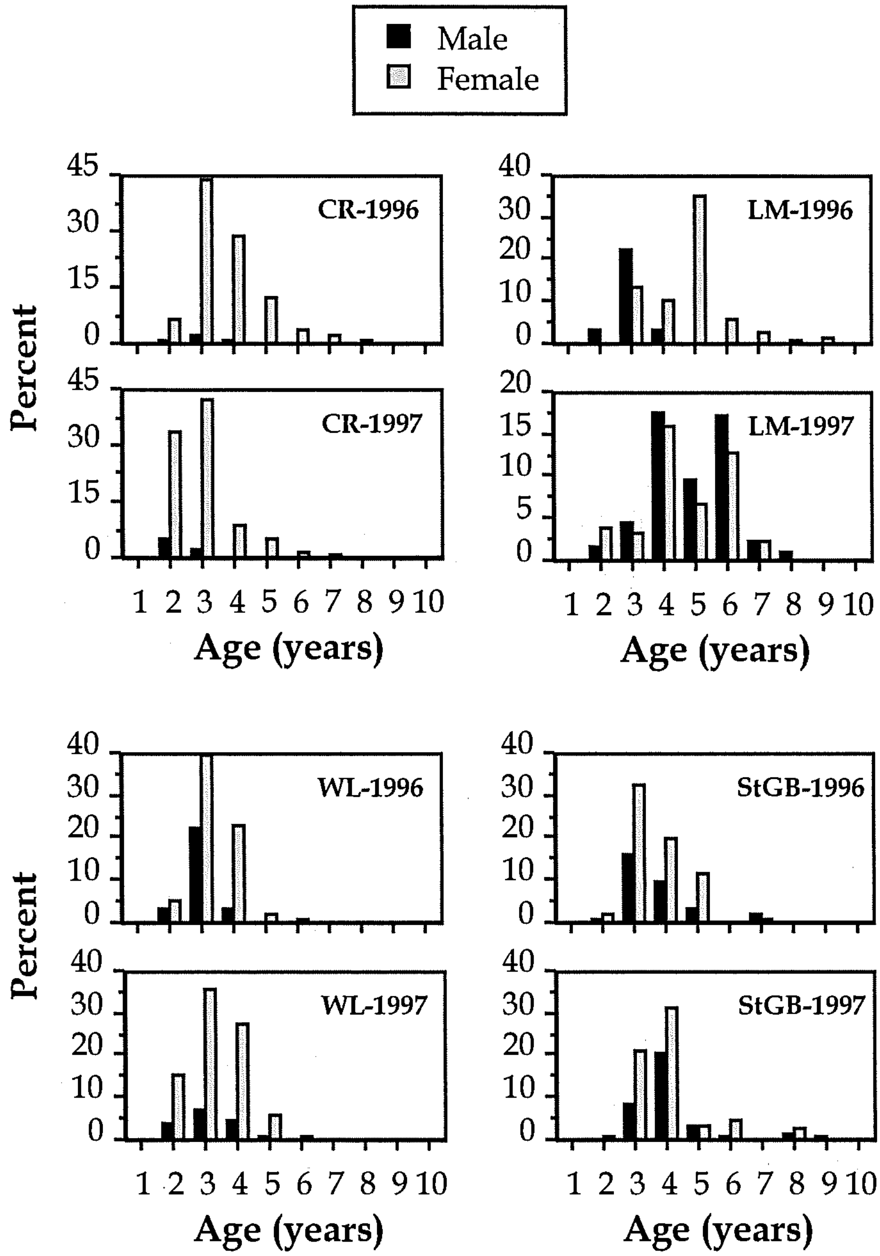


Figure 7.13. Age compositions of commercial estuarine landings of dusky flathead.
n = number of otoliths; a = average age in years.

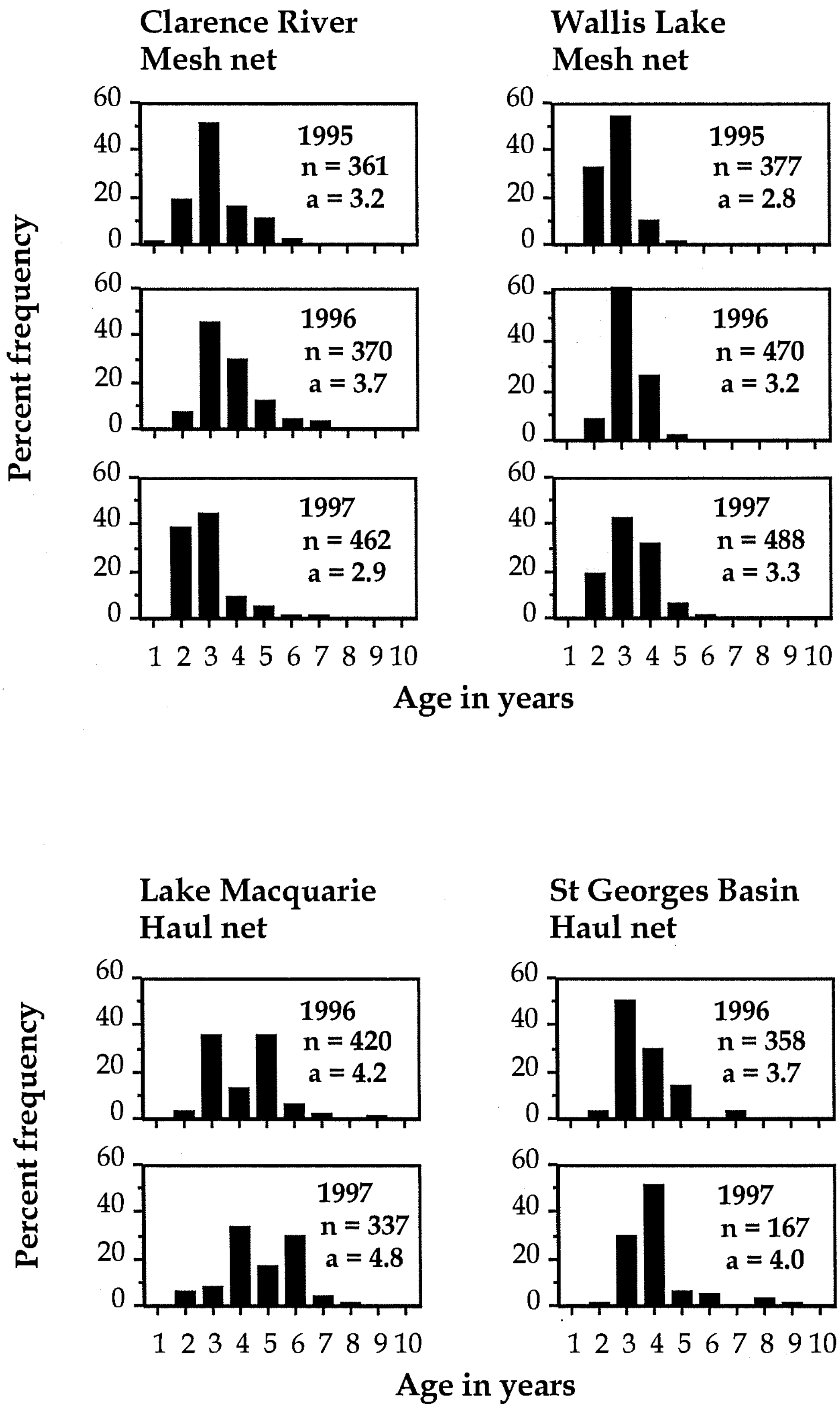
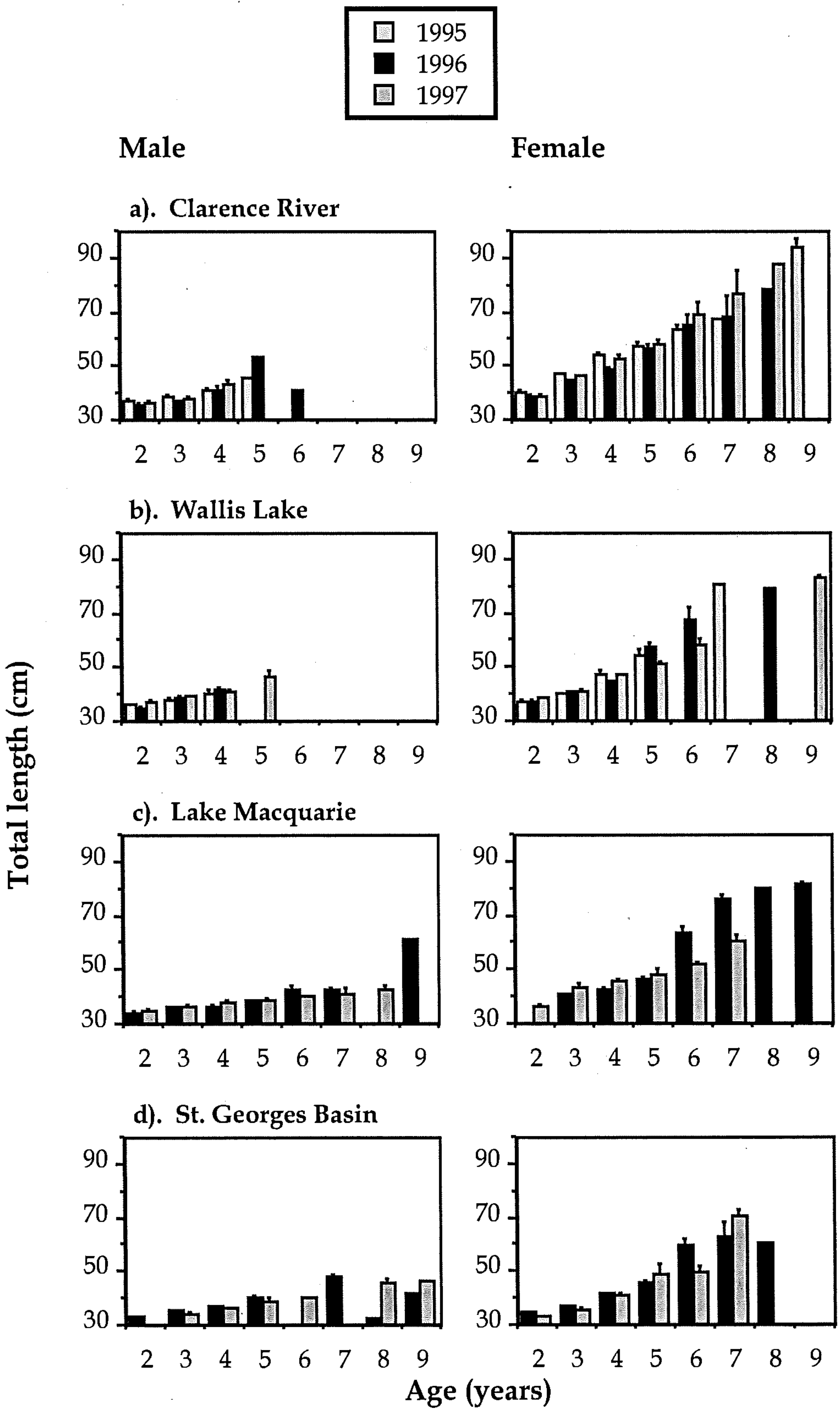


Figure 7.14. Mean length at age (+ 1se) of male and female dusky flathead.



7.6 Discussion

7.6.1 Age determination

Fish length and otolith weight have been used to age successfully some species of fish, but for dusky flathead these cheaper options do not appear viable as relationships between age and length, and age and otolith weight were weak. Sectioned otoliths were more easily interpreted than whole otoliths as found for other platycephalids (Hyndes et al. 1992), and the use of whole otoliths to age dusky flathead may result in a underestimation of ages as demonstrated for *Platycephalus speculator* (Hyndes et al. 1992).

Although sectioned dusky flathead otoliths proved relatively easy to read and there was reasonable agreement between readers (> 87%) in assigning ages to fish, the ages of dusky flathead reported here can only be described as preliminary. Unfortunately, very few flathead were recaptured from the tag/recapture experiment (see Appendix I) to validate the aging process used here (i.e. it was assumed zones on otoliths were annuli and the first zone represented 1 years growth). Despite this, the observed progression of age classes in the Lake Macquarie fishery suggest that the zones observed on otoliths were produced annually. However, the age of fish at the time the first growth increment (opaque zone) is formed needs to be determined. Dredge (1976) estimated this to be 6 months for dusky flathead in Moreton Bay. Dusky flathead otoliths were collected on a monthly basis over 1 year from the Clarence River for a marginal increment study to validate the method of aging flathead used here. These otoliths should be given a priority for processing for this purpose.

7.6.2 Variations in size at age and growth

In all estuaries females appeared to grow faster and they attained a greater maximum length than males, which contrasts with the findings of Dredge (1976) who reported no sex-related differences in growth rates. The largest male captured in the current study was 56 cm TL whereas the largest female was 96 cm TL. Despite these differences in size, the maximum age of 9^{+} was the same for both sexes. Large disparities between sexes in the sizes, but not ages, of other platycephalids have also been recorded (Hyndes et al. 1992). Dusky flathead have been aged to 12 years in Moreton Bay (see Kerby and Brown 1994).

Because of the observed skewed sex ratios in dusky flathead populations it has been argued that dusky flathead may be protandrous sex reversers, in that most fish function as males for several years before undergoing a sex reversal (Dredge 1976). However, no hermaphroditic fish were observed in this study (see also West 1993), and in the absence of any reproductive study, the data presented here indicate that it is most likely that dusky flathead do not change sex, but rather male fish do not grow as large as females.

7.6.3 Variations in sex, size and age compositions of commercial catches

The data show that the commercial estuarine fishery for dusky flathead in NSW is primarily based on young (1-3^+ years) recruiting female fish. Although no reproductive studies have been done on dusky flathead in NSW, it appears that a significant proportion of female fish in the commercial catch were below the size at first maturity of approximately 38-45 cm TL (see also West 1993). The predominance of a few young year classes supporting the dusky flathead fishery indicates the possibility of high rates of total mortality and suggest that the fishery for dusky flathead may be prone to over-exploitation (although the long-term stability of the commercial catch suggests otherwise). However, larger (and presumably older) fish may not be as selected by the fishing gear and this needs to be examined.

There was a slight trend for more older and male fish to be more predominant in the fishery in Lake Macquarie and St. Georges Basin, indicating that there may be some latitudinal or gear effect. Further research is required to test if these trends occur in other estuaries or if these trends are related to fishing effort and production.

The size structure of commercial catches varied between estuaries, and for mesh net catches was greatly dependent on mesh size. Mesh nets are highly size-selective, and it was not unexpected that the 70 mm flathead nets used in Wallis Lake generally harvested a smaller sized fish than the general purpose 80-100 mm mesh nets in the Clarence River. Despite the differences in the size compositions of these mesh net catches, the corresponding age structures were similarly based on 2 and 3^+ fish, and therefore small changes in minimum mesh sizes of nets may have little effect on the ages of flathead harvested.

7.6.4 Consequences for future research on the fishery for dusky flathead

An overview of the commercial fishery for dusky flathead in several estuaries in NSW has been presented. The data show that the commercial fishery for dusky flathead is primarily sustained by female fish aged 2-6^+ years, and consequently the stock may be subject to high total mortalities and the fishery may be prone to over-exploitation. Continued monitoring and assessment of the commercial fishery is therefore warranted.

Very little information exists on the recreational fishery for dusky flathead in NSW. The few studies that have been conducted indicate that the recreational harvest of dusky flathead may be at least as great as the commercial harvest (West and Gordon 1995), and that the size (and maybe age) composition of the recreational harvest may differ to that harvested by commercial fishers (West 1993). It is therefore important that the quantity, size and age composition of the recreational fishery of dusky flathead in NSW is quantified, and incorporated into a stock assessment program for the species.

Further fisheries-related investigations on dusky flathead are required to assist with the stock assessment process, in particular examinations of: (a) size at first maturity throughout NSW, (b) most appropriate mesh size for harvesting the species, (c) estimation of exploitation rates.

8. Development of a voluntary daily catch and effort logbook for commercial estuarine fisheries

8.1 Introduction

Due to the complexity of the estuarine fisheries, it is difficult to collect catch and effort data that is suitable for stock assessment of estuarine species using production or biomass dynamic models. Catch and effort information for all commercial fisheries in New South Wales has historically been collected by means of a mandatory monthly catch return system (Pease and Grinberg 1995). When this study commenced in 1995, all mandatory catch and effort information for one fisher's monthly commercial fishing activities in an estuary was recorded on a single form with the catch summed across all methods. Therefore, the mandatory system could not provide an accurate measure of catch per unit of effort by fishing method when multiple methods were used by one fisher during the month.

In July 1997 the mandatory monthly catch return system was modified to record the catch by species separately for each fishing method used in each estuary during the month. Gear characteristics, such as length, drop and mesh size, vary greatly for mesh and haul nets, which are the main fishing methods used in the Estuary General Fishery. These gear characteristics are not recorded on either the old or new systems and a fisher may use a wide range of gear types within a single method category during one month. There are a number of other characteristics of the monthly catch and effort recording system which affect the usefulness of the data for stock assessment. Daily catches need to be summed at the end of the month. Many fishers use accurate landing receipts and summaries from the Fishermen's Co-operatives to compile monthly returns, but these records are not separated by method type. Other fishers may compile relatively inaccurate monthly estimates without using any daily records. The mandatory nature of the system also results in a large amount of variability in the accuracy of information from different fishers. In recent years the catch return system has also been used as a management tool to allocate shares in new share managed fisheries. This may provide an incentive for fishers to inflate their catch estimates (Fisheries Statistical Working Group 1997a).

The objective of this component of the study was to develop and implement a voluntary research logbook system for efficiently recording, storing, analysing and disseminating daily catch and effort information for the Estuary General fishery. In order to efficiently capture the relatively high volume of daily data, an Optical Character Recognition (OCR) computer system was tested. A standardised quarterly reporting system to provide summaries of the logbook data to all participants was implemented to provide quality control feedback, as well as an incentive for fishers to actively participate in the project.

8.2 Materials and Methods

8.2.1 Optical Character Recognition system

A primary objective of this study was to implement and assess an OCR system, which consists of computer hardware and software that automates the process of data entry from paper forms to a computer database. In an OCR system, paper forms with input data are fed into a fax machine or scanner, which takes a digital picture of the form and sends it to a connected computer. Software on the computer analyses the digital image and converts the printed or hand-written characters in specified input fields into equivalent digital text or numerical data, which is then stored in a database. This process replaces manual data entry by a human operator.

The OCR software for this project was carefully selected because it is critical to the success of the entire logbook project. Criteria for selection were: a) integrated, powerful and easy to use form designer, b) accurate and flexible recognition software to maximise the automatic entry of hand written data while minimising queries and errors, c) powerful and robust internal database engine for verifying, tracking, storing, archiving and exporting the data received by common fax machines or scanners, d) support and connection to most popular database systems, particularly Microsoft Access and e) relatively inexpensive and must run on a personal computer, rather than an expensive, dedicated computer system.

After reviewing several software alternatives we selected the Teleform system by Cardiff Software (California, USA) which runs under Windows on an IBM compatible personal computer. The system was supplied and supported by Telesystems (Drummoyne, NSW). We started with Teleform version 2.33 running under Windows 3.11 and during the course of the project progressively upgraded to version 5.2 running under Windows 95. This is a rapidly evolving field of software development and each upgrade was found to be a substantial improvement. Some of these software upgrades also required substantial hardware upgrades. We started with a 66 MHz 486 processor with 8 megabytes of ram and a 400 megabyte hard disk. By the end of the project we had upgraded to a 120 MHz Pentium processor with 32 megabytes of ram and a 2 gigabyte hard disk.

Logbook forms were designed using the Teleform software. The type of catch and effort information to list on the form was carefully chosen after reviewing the existing monthly Form 19 catch return system as well as the daily logbook forms used by Commonwealth and other Australian state fisheries agencies. The project leader for this component of the study was also a member of the Fisheries Statistics Working Group, a subcommittee of the Standing Committee on Fisheries, which has collected extensive information about existing logbook programs around Australia (Fisheries Statistics Working Group 1997b). The main criteria for structuring information on the form was to provide the maximum amount of information in a format that simplified selection and recording using a minimum of codes. Tick boxes were used wherever possible.

Decisions about which methods, estuaries and species to list on the form were based on ordinated lists extracted from the LCATCH database of monthly catch return data. In order to ensure confidentiality, the identity of the participant is hidden in special coded fields that can only be read by the computer system. Initial drafts of the logbook form were reviewed internally by relevant scientific staff and fisheries managers. Form design was finalised after reviews by representative estuarine fishers selected by the Commercial Fisheries Advisory Committee from Regional Advisory Committee Regions 2, 4 and 6.

Data from the forms were faxed to the OCR computer through a telephone connection to an internal Intel modem. Extensive in-house tests of the OCR software and hardware were conducted. Ten forms were filled out by each of 10 staff at the Fisheries Research Institute and faxed into the computer system. The effects of varying style and quality of hand writing were evaluated on these 100 forms and it was determined that a confidence level of 98% provided the most efficient recognition rate. Systems were developed for range, look-up and context checking, tracking data through the computer system, maintaining system files and organising image archives. An Access database application was designed for the logbook data so that information could be rapidly checked, retrieved, and summarised. The OCR system was linked to the Access database so that the data was automatically imported into the database as it was successfully read.

8.2.2 Implementation of the logbook system

After drafting the logbook form, a clearly written and comprehensive set of instructions was drafted to ensure accurate and consistent responses from fishers. Complete reference lists for species and estuaries were extracted from the LCATCH database and the instructions for other logbook programs were reviewed. Draft instructions and reference codes for this logbook were critically reviewed by relevant scientific staff, fisheries managers and representative estuarine fishers.

This program focused on obtaining logbook information from finfish fishers in: a) the Clarence and Richmond Rivers to provide data from the northern region of NSW, b) Wallis Lake and Lake Macquarie to provide data from the central region of NSW and c) any of the small estuaries south of St. Georges Basin to provide information from the southern region of NSW. Several fishers in Lake Macquarie were contacted by telephone in September 1995 and arrangements were made to start collecting some pilot data. In October 1995 all fishers who reported landings of finfish from the above estuaries, which were listed on mandatory monthly catch returns submitted during the previous fiscal year (1994/95), were contacted by mail and asked to participate in the voluntary logbook program. Total reported finfish landings from these estuaries over the previous two fiscal years were also sorted by fisher. During the period October 1995 through February 1996, fishers with the largest catches of sea mullet, bream, luderick, dusky flathead, or sand whiting during the previous two year period were contacted by telephone and encouraged to participate in the logbook program.

After fishers initially agreed to participate in the program they were visited by project staff. Participating fishers were given a logbook binder containing the instructions, a packet of 50 logbook forms encoded with their name, five pre-addressed and postage paid envelopes, and a mechanical pencil. During this visit, the fisher supplied detailed information about the dimensions of each type of net and trap that they owned. Each gear type was given a simple code for identification on the log form and all gear information was stored in the main Access database. The fisher was then instructed about how to fill out a separate logbook form for each day, estuary and fishing method/gear. They were asked to complete log forms for all days that they targeted finfish and were also encouraged to complete forms for shellfish fishing activity. However, it was understood that data on shellfish fishing activity was optional and only completed as a second priority to the finfish fishing activity.

Each participant sent their completed log forms to the Fisheries Research Institute every two to six weeks in the postage paid envelopes. Project staff then faxed the forms into the OCR system. Fishers were sent more log forms and envelopes on request. Data on dates and quantities of forms and envelopes sent to fishers, was recorded in a sub-component of the Access database. If no forms were received from a fisher for 2-3 months, the fisher was contacted to determine why.

In order to get a better understanding of fishing effort characteristics associated with hauling and meshing, project staff observed the fishing activities of some of the logbook participants during typical hauling and meshing activity in a number of estuaries during the project period. During these field trips, details were recorded about the gear (length, drop and mesh size) and the manner in which this gear was set and retrieved. The species composition of each set or shot was recorded and the length of each commercially valuable species in the mesh nets was recorded. If catches of a species were to be processed, each individual of that species was weighed before and after processing.

The report system within the Access database was programmed to provide standard quarterly summaries of catch per unit of effort from the logbook data. Four types of report were generated by the program. The first report summarised average, minimum and maximum catch per unit of effort (cpue in kg/hr) for each estuary which had been fished by more than two logbook participants during the quarter, by meshing (each mesh size separately) and hauling gear types for each of the five primary finfish species (bream, dusky flathead, luderick, sea mullet and sand whiting). The second report summarised average, minimum and maximum cpue for each logbook participant who fished for finfish during the quarter, by each of their meshing (by mesh size) and hauling gear types for each of the five primary finfish species. The third report summarised average, minimum and maximum cpue for each logbook participant who fished primarily for shellfish (school, greasyback or king prawns and blue swimmer or mud crabs) or river eels during the quarter, by each netting (prawn trawl, hauling, set pocket, seine and running nets) and trapping (crab and eel) gear type for each of these species. At the end of the calendar year, a fourth report was used to summarise annual trends in cpue by estuary and gear type using colour graphs along with a tabular summary of the number of log sheets received during the year, by estuary and gear type.

The quarterly reports (customised by fisher, estuary, and gear type) were sent to each logbook participant as part of a quarterly newsletter along with information about the progress of the study and other relevant estuarine research and monitoring carried out by NSW Fisheries. This feedback was provided as an incentive to participate in the voluntary programme, to make the fishers aware that the information was being used and to provide a final correction mechanism for incorrect data. Even if a fisher did not fish during a quarter, he was given the standard summary of finfish cpue for the estuaries he historically fished.

8.3 Results

8.3.1 Implementation of the logbook system

The design of the logbook form is critical to the success of a voluntary daily programme. It must include all of the necessary information but most importantly it must be logically arranged and easy to fill out. Therefore, a great deal of effort was put into designing the forms used in this study.

After testing and reviewing a number of alternatives, the two forms in Appendix II were designed using the Teleforms software. Two separate forms were needed in order to list all of the commercially fished estuaries on the coast of NSW. The form in Appendix IIa is for fishers on the north and central coast and the one in Appendix IIb is for those on the south coast, where there are many small estuaries.

For ease of completion, the information about estuary fished, fishing method, specific fishing gear and type of catch weight is entered in tick bubbles. Large boxes are provided for each alphabetical or numeric character, where hand-written characters are required. Most of the fishing methods, commonly fished estuaries and commonly caught species were listed on the form, but fishers are given the option to write in others. The period between the "date" and "last date fished" fields provides information about when the fisher did not fish. Therefore, the fishers only needed to fill out forms on days that they fished, not every day of the year. A complete list of all processing codes, along with lists of other commonly fished estuaries and commonly caught species which were not listed on the form, were provided on the back of each log sheet.

Details of fishing effort included fishing time (hours fished and search time), number of replicates (sets/shots/hauls) and gear details related to each fishing method. Each piece of fishing gear (usually nets of different dimensions or mesh size) owned by the fisher was related to a fishing method and assigned a number from one to seven. This assigned gear number was always used to identify a specific net with dimensions and mesh size recorded in the main Access database by fisher and fishing method. If the fisher owned multiple nets with identical dimensions and mesh size, the gear number referred to the gear type rather than an individual net. The diversity of fishing gear used in this fishery is indicated by the fact that we had to increase the maximum gear number from five to seven after initial trials. We also had to add the total net length field because some fishers often connect individual mesh nets of one mesh size together.

The 29 species that contribute most of the annual landings in the Estuary General Fishery and are most commonly reported on the mandatory monthly catch returns, were listed on the form. Only codes for minor species, not listed on the forms, were entered by the fishers. No additional (minor) species were listed on 84% of the daily log sheets received during this study, indicating that the 29 listed species did indeed account for most of the catch provided on daily logs. The fishers were specifically asked to list the catch of each individual species, not species groups. The lists of species codes provided on the back of each log sheet and attached to the instructions contained very few species groups.

For each species listed on the form, space was provided for landed or estimated weight in kilograms and a processing code. If the catch of a species was not processed, the processing field for the species was left blank. If the listed weights were taken from a landing docket, the "Landed" bubble was ticked. If the listed weights were estimated by the fisher, the "Estimated" bubble was ticked. Ninety percent of the weights listed on the daily log sheets received during this study were landed weights.

There is little published information about processing of estuarine catches. The processing information on the forms submitted during this study indicate that mulloway and snapper are often gilled and gutted, dusky flathead is often gutted, the leatherjacket and catfish species are usually headed and gutted, sharks are often cut into "barrels" and blue swimmer crabs and prawns are often cooked. Some pre and post-processing weights of dusky flathead and fanbellied, yellowfinned and six-spinned leatherjackets were measured during field work conducted on this study. An estimated value of 1.1 was obtained for converting gutted weights of dusky flathead to whole weight and 1.8 was the estimated value for converting headed and gutted weights of the three leatherjacket species to whole weight. Conversion factors for gilled and gutted snapper are available, but the conversion factors for processing of mulloway, catfish (primarily forktailed), sharks (mainly black-tipped or bull sharks), blue swimmer crabs and prawns (eastern king, school and greasyback) must be determined from additional research.

The instructions for filling out the daily logbook are given in Appendix III. The optical character recognition system is explained and additional information is given for each field on the form. The information about each field was based on an example of a completed log sheet, because examples often provide the least complicated means of explaining this type of information. Complete reference tables were supplied for all estuaries and species caught in New South Wales. A guide for identifying the common leatherjacket, shark, catfish and eel species was also provided, because the fishers have difficulty identifying species belonging to these groups, which often have a plethora of common names applied to similar species within the groups.

Seven quarterly newsletters with cpue summaries were sent to the participating fishers during the period December 1995 through August 1997. An annual cpue summary was sent with the newsletter for the quarter ending in November 1996. Sample quarterly and annual cpue summaries for the quarter ending in November 1996 are shown in Appendix IV.

8.3.2 Participation

The number of participants in the logbook program each month during the project period is summarised in Figure 8.1. Meshers and haulers are shown separately because they were targeted for this project. The participation rate increased rapidly during the recruitment phase of the project, until January 1996. The number of haulers remained relatively stable until January 1997, then declined until the end of the project in December. The number of meshers submitting log sheets varied seasonally, with peaks in the autumn and spring, until the participation rate plunged after June 1997. The total number of fishers submitting log sheets peaked during the summers of 1995/96 and 1996/97, then declined throughout 1997.

Another, more direct indicator of fishing activity, is the number of log sheets submitted monthly. Figure 8.2 shows that the fishing activity of haulers remained relatively stable throughout the year, except for a small declined in winter, then plunged drastically when the participation rate dropped after July 1997 (Figure 8.1). Fishing activity of meshers peaked in the autumn and spring of 1996, then remained relatively low in 1997 before plunging after June 1998 with the decline in participation rate (Figure 8.1). The total number of log sheets for all methods peaked in summer and declined in winter, then declined rapidly after July 1997.

It appears that participation in the logbook program was quite consistent during 1996, then started declining in early 1997, particularly participation by meshers. Participation by all fishers then declined abruptly after June 1997. The decline in early 1997 was due to some waning interest after one year of participation. The abrupt decline after June 1997 was due to the introduction of a new mandatory catch return system. The new system requires increased numbers of monthly forms to be submitted and most fishers indicated that it became too much of a burden to complete forms for both the monthly and daily systems.

Table 8.1 provides some summary information about the proportional contribution of logbook fishers to the total catch and effort in the primary study estuaries. The data in Table 8.1 is for the 1996 calendar year, when participation was stable. In these estuaries, it can be seen that a low proportion of the fishers targeting these species, catches a relatively high proportion of the landings. Mean participation ratios of 21 to 24 percent in Lake Macquarie and the Richmond River resulted in mean catch ratios of 23 to 61 percent. Low participation ratios of 6 to 7 percent in the Clarence River and Wallis Lake resulted in relatively low catch ratios of 8 to 28 percent.

Figure 8.1. The number of estuarine mesh and haul fishers that participated in the log book study between September 1995 and December 1997.

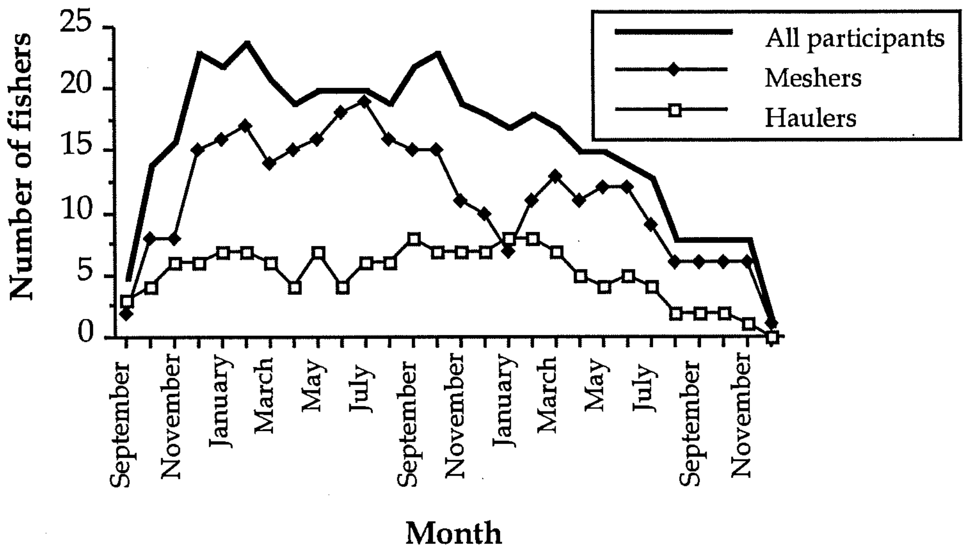


Figure 8.2. The number of completed log sheets from estuarine mesh and haul fishers between September 1995 and December 1997.

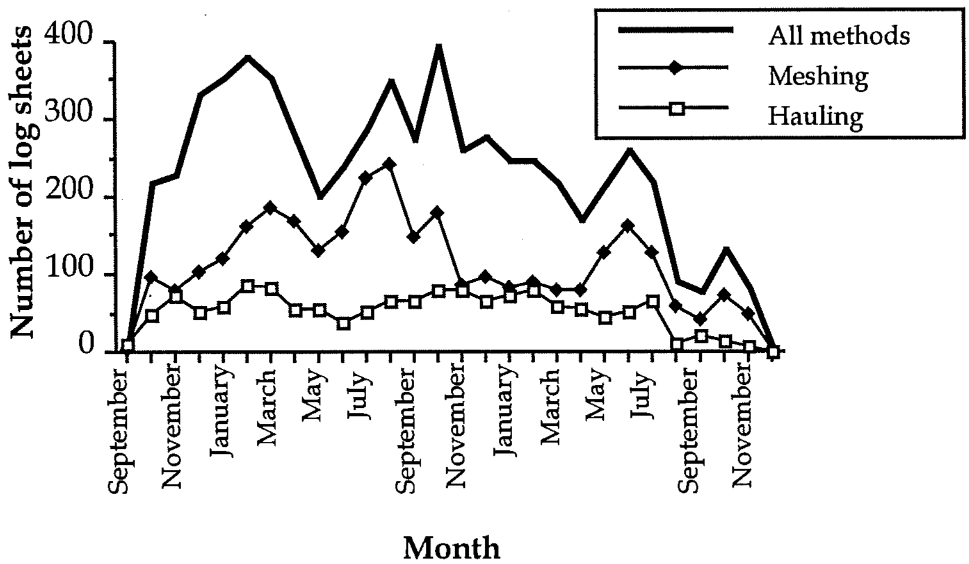


Table 8.1. The maximum, mean and minimum percent of total catch by species obtained by logbook participants and percent of total fishers participating in the logbook program at each of the primary estuaries during 1996.

	Richmond River			Clarence River		
	Maximum	Mean	Minimum	Maximum	Mean	Minimum
Bream	86	30	3	31	10	0
Dusky flathead	100	54	9	33	10	0
Luderick	100	61	19	34	10	0
Sand whiting	68	33	2	38	18	0
Sea mullet	69	25	2	35	14	0
Fishers*	36	24	11	7	6	4
	Wallis Lake			Lake Macquarie		
	Maximum	Mean	Minimum	Maximum	Mean	Minimum
Bream	74	28	1	52	36	21
Dusky flathead	21	8	0	80	46	22
Luderick	47	16	1	41	23	4
Sand whiting	59	18	1	84	51	13
Sea mullet	26	11	2	94	51	20
Fishers*	9	7	5	32	21	11

* Fishers were calculated as the percent of fishers who submitted mandatory monthly catch returns with one of the species listed.

8.3.3 Optical Character Recognition system

The Teleforms OCR system worked well for entering the data from daily log sheets into the Access database. The speed and accuracy of the Teleforms system improved with each of the three software and two hardware upgrades during the project period. One Fisheries Technician operated the computer system to enter all incoming daily log sheet data for approximately one half of a working day each fortnight. In this manner it took only one person-day to enter the 200 to 400 log sheets submitted during each month of consistent participation in 1996. The Access database called FISH95 holds 6463 records of daily fishing activity. It also holds the contact and gear details of 40 participating fishers. The digital image of each submitted log sheet is also accessible on the computer system.

8.4 Discussion

We found that it was possible to implement and maintain a pilot voluntary daily logbook system for the Estuary General Fishery of New South Wales. The teleforms OCR system worked well for designing logbook forms and allowed one half-time fisheries technician to maintain the database system for this project, along with other unrelated duties.

The declining participation rate during the second year of the project, indicates that a quarterly newsletter with summary catch and effort information is not a sufficient incentive to maintain an ongoing voluntary daily logbook system. This would probably require a stronger incentive, such as waiving the requirement to submit mandatory monthly returns for the Estuary General Fishery if daily logbooks are completed. It would not be a difficult task for the computer system to automate the process of consolidating the daily information to the mandatory monthly format and exporting it to the relevant database.

NSW Fisheries implemented a revised mandatory monthly catch return system in July 1997. The new system now separates monthly catches by fishing method, which was one of the principal reasons for implementing the voluntary daily logbook system. It is now necessary for NSW Fisheries to analyse and assess the data collected by this project, in order to decide whether it is worth the effort and expense of implementing a voluntary daily logbook system on a permanent basis. The Department must decide what level of participation would be required and whether the increased resolution of fishing effort is necessary. Preliminary regression analysis of the logbook data from this project indicates that net length, drop and mesh size are significantly related to catches of most of the main species. These gear factors are not recorded in the new mandatory monthly system. Intuitively, cpue estimates may be biased when dimensions of hauling nets range from over 3 km in length (including hauling ropes) to less than 1 km and the legal mesh sizes of mesh nets range from 65 mm to over 100 mm.

Based on the results of this project, it would be possible for one full-time technician to use the OCR system to run a voluntary daily logbook system with a participation rate of at least one quarter of the Estuary General fishers. This person could also check and maintain the data from the mandatory monthly return system, integrate daily logbook data, as well as producing and distributing newsletters and data summaries to the fishers of this fishery.

9. Recommendations and implications

9.1 Benefits

This project has provided data on: (a) patterns of recruitment and growth of juvenile estuarine fishes; (b) spatial and temporal variability in the sex, size and age composition of commercial catches of estuarine fishes from different sectors of the commercial industry; (c) detailed analysis of daily catch and effort data. These data will provide information for future long-term monitoring and assessments of estuarine fish stocks in NSW, and provide commercial and recreational fishers, fisheries managers and the community with initial information on the status of these important fish stocks.

9.2 Intellectual property

No commercial value came from this project, however the information is relevant to researchers and managers of commercial finfish fisheries in NSW, other Australian states and other countries. The work reported in this report will be published in scientific journals and industry magazines.

9.3 Further developments

Before the aging data can be fully used additional research is required to: (a). validate the first ring in all four species; (b). validate all age classes for dusky flathead (note that samples have been collected for marginal increment work for this species). Quantification of catches of the estuarine recreational fishery is required for full stock assessments on these species. Future research is required to determine: (1) the mesh selectivities of the various commercial methods used to capture these species; (2) the mortalities of fish discarded from commercial estuarine operations. Continued monitoring of the NSW estuarine fishery is highly recommended.

9.4 Staff

Staff directly employed on this project with FRDC funds were:

Research Scientist:

Dr Charles Gray (August 1994 - May 1998)

Fisheries Technicians:

Ms Samantha Stringfellow (March 1995 - September 1997)

Ms Deannea McElligott (March 1995 - December 1995)

Mr William Macbeth (March 1995 - May 1996)

Ms Leeanne Raines (January 1996 - September 1997)

Mr Brett Rankin (June 1996 - September 1997)

Ms Vanessa Gail (June 1996 - May 1997)

Mr Adam Schmaltz (June 1997 - September 1997)

Casual Field Assistants (part-time):

Mr Glen Cuthbert (Clarence River)

Mr John Staines (Richmond River)

Ms Fiona Staines (Richmond River)

Mr Martin Tucker (Wallis Lake)

Mr Gavin Edmonson (Wallaga Lake)

Staff who contributed to the project but were not directly funded by FRDC were:

Scientists:

Dr Philip Gibbs

Dr Bruce Pease

Fisheries Technician:

Ms Trudy Walford

Statistician:

Mr Geoff Gordon

10. Literature cited

Anderson, T.A. (1987) Utilization of algal cell fractions by the marine herbivore, the luderick, *Girella tricuspidata*, (Quoy and Gaimand). *Journal of Fish Biology* 31: 221-228.

Beamish, R.J., McFarlane, G.A. (1983) The forgotton requirement of age validation in fisheries biology. *Transactions of the American Fisheries Society* 112: 735-743.

Bell, J.D., Steffe, A.S., Westoby, M. (1988) Location of seagrass beds in estuaries: effects on associated fish and decapods. *Journal of Experimental Marine Biology and Ecology* 122: 127-146.

Bell, J.D., Westoby, M. (1986a) Importance of local changes in leaf height and density to fish and decapods associated with seagrasses. *Journal of Experimental Marine Biology and Ecology* 104: 249-274.

Bell, J.D., Westoby, M. (1986b) Variation in seagrass height and density over a wide spatial scale: effects on common fish and decapods. *Journal of Experimental Marine Biology and Ecology* 104: 275-295.

Broadhurst, M.K., Kennelly, S.J., Barker, D.T. (1997) Simulated escape of juvenile sand whiting (*Sillago ciliata*, Cuvier) through square meshes: effects on scale-loss and survival. *Fisheries Research* 32: 51-60.

Burchmore, J.J., Pollard, D.A., Middleton, M.J., Bell, J.D., Pease, B.C. (1988) Biology of four species of whiting (Pisces:Sillaginidae) in Botany Bay, New South Wales. *Australian Journal of Marine and Freshwater Research* 39:709-727.

Buxton, C.D. (1993) Life-history changes in exploited reef fishes on the east coast of South Africa. *Environmental Biology of Fishes* 36: 47-63.

Buxton, C.D., Garratt, P.A. (1990) Alternative reproductive styles in seabreams (Pisces:Sparidae). *Environmental Biology of Fishes* 28: 113-124.

Campana, S.E., Frank, K.T., Hurley, P.C.F., Koeller, P.A., Page, F.H., Smith, P.C. (1989) Survival and abundance of young Atlantic cod (*Gadus morhua*) and haddock (*Melanogrammus aeglefinus*) as indicators of year-class strength. *Canadian Journal of Fisheries and Aquatic Sciences* 46 (Supplement 1): 171-182.

Caputi, N., Fletcher, W.J., Pearce, A., Chubb, C.F. (1996) effect of the Leeuwin current on the recruitment of fish and invertebrates along the Western Australian coast. *Marine and Freshwater Research* 47: 147-155.

Cleland, K.W. (1947) Studies on the economic biology of the sand whiting (*Sillago ciliata* C.&V.). *Proceedings of the Linnean Society of New South Wales* 72: 215-228.

Connolly, R.M. (1994) A comparison of fish assemblages from seagrass and unvegetated areas of a southern Australian estuary. *Australian Journal of Marine and Freshwater Research* 45: 1033-44.

Dixon, P.I., Crozier, R.H., Black, M., Church, R. (1987) Stock identification and discrimination of commercially important whiting in Australian waters using genetic criteria. (FIRTA 83/16) Final report. Centre for Marine Science University of New South Wales. 69 pp.

Doherty, P.J., Fowler, A.J. (1994) An emperical test of recruitment limitation in a coral reef fish. *Science* 263: 935-939.

Dredge, M.C.L. (1976) Aspects of the ecology of three estuarine dwelling fish in south-east Queensland. M.Sc. Thesis, University of Queensland. 122 pp.

Fairbridge, W.S. (1946) The age and size of fish. *Fisheries Newsletter* 5: 33-47.

Ferrell, D.J., Bell, J.D. (1991) Differences among assemblages of fish associated with *Zostera capricorni* and bare sand over a large spatial scale. *Marine Ecology Progress Series* 72: 15-24.

Ferrell, D.J., McNeill, S.E., Worthington, D.G., Bell, J.D. (1993) Temporal and spatial variation in the abundance of fish associated with the seagrass *Posidonia australis* in south-eastern Australia. *Australian Journal of Marine and Freshwater Research* 44: 881-899.

Fisheries Statistical Working Group (1997a) Best Practice for Collection of Fisheries Statistics. Technical Report by Fisheries Statistical Working Group of the Standing Committee on Fisheries and Aquaculture. Bureau of Resource Science, Canberra. 10 pp.

Fisheries Statistical Working Group (1997b) Collection of Commercial Fisheries Statistics in Australia. Technical Report by Fisheries Statistical Working Group of the Standing on Fisheries and Aquaculture. Bureau of Resource Science, Canberra. 125 pp.

Fletcher, W.J. (1991) A test of the relationship between otolith weight and age for the pilchard *Sardinops neopilchardus*. *Canadian Journal of Fisheries and Aquatic Sciences* 48: 35-38.

Fletcher, W.J., Blight, S. (1996) Validity of using translucent zones of otoliths to age the pilchard *Sardinops sagax neopilchardus* from Albany, Western Australia. *Marine and Freshwater Research* 47: 617-624.

Fletcher, W.J., Jones, B., Pearce, A.F., Hosja, W. (1997) Environmental and biological aspects of the mass mortality of pilchards (Autumn 1995) in Western Australia. Fisheries department of Western Australia, Fisheries Research Report No. 106.

Fogarty, M.J., Sissenwine, M.P., Cohen, E.B. (1991) Recruitment variability and the dynamics of exploited marine populations. *Trends in Ecology and Evolution* 6: 241-246.

Fowler, A.J., Doherty, P.J., Williams, D.McB. (1992) Multi-scale analysis of recruitment of a coral reef fish on the Great Barrier Reef. *Marine Ecology Progress Series* 82: 131-141.

Fowler, A.J., Short, D.A. (1996) Temporal variation in the early life-history characteristics of the King George Whiting (*Sillaginodes punctata*) from analysis of otolith microstructure. *Marine and Freshwater Research* 47: 809-818.

Fowler, A.J., Short, D.A. (1998) Validation of age determination from otoliths of the King George whiting *Sillaginodes punctata* (Perciformes). *Marine Biology* 130: 577-587.

Gibbs, P.J. (1997) A review of information on NSW south coast estuarine fisheries. NSW Fisheries Research Institute.74 pp.

Goodall, J.A., Capra, M.F., Blackshaw, A.W. (1987) Quantitative histology of the seasonal changes in the gonads of summer whiting, *Sillago ciliata*. *Journal of Fish Biology* 30: 589-595.

Gray, C.A. (1991) Temporal variability in the demography of the palaemonid prawn *Macrobrachium intermedium* in two seagrasses. *Marine Ecology Progress Series* 75: 227-237.

Gray, C.A. (1995) The influences of sewage plumes and oceanography on assemblages of larval fishes. P.HD. Thesis University of Sydney. pp 439.

Gray, C.A., Chick, R.C., McElligott, D.M. (1998) Diel changes in assemblages of fishes associated with shallow seagrass and bare sand. *Estuarine, Coastal and Shelf Science* 46: 849-859.

Gray, C.A., Larsen, R.B., Kennelly, S.J. (2000) Use of transparent netting may improve size selectivity and reduce bycatch in fish seine nets. *Fisheries Research* xx

Gray, C.A., McElligott, D.M., Chick, R.W. (1995) Fish communities in northern NSW estuaries. NSW Natural Resource Audit Council project S12 final report.

Gray, C.A., McElligott, D.M., Chick, R.W. (1996) Intra- and inter-estuary differences in assemblages of fishes associated with shallow seagrass and bare sand. *Marine and Freshwater Research* 47: 723-735.

Hannan, J.C., Williams, R.J. (1998) Recruitment of juvenile marine fishes to seagrass habitat in a temperate Australian estuary. *Estuaries* 21: 29-51.

Henry, G.W. (1983) Biology and fisheries of yellowfin bream, *Acanthopagrus australis* (Teleostei: Sparidae) in Tuggerah Lakes, NSW. M.Sc. Thesis, University of New South Wales. 139pp.

Horn, P.L. (1986) Distribution and growth of snapper *Chrysophrys auratus* in the North Taranaki Bight, and management implications of these data. *New Zealand Journal of Marine and Freshwater Research* 20: 419-430.

Houde, E.D. (1987) Fish early life dynamics and recruitment variability. *American Fisheries Society Symposium* 2: 17-29.

Hyndes, G.A., Loneragan, N.R., Potter, I.C. (1992) Influence of sectioning otoliths on marginal increment trends and age and growth estimates for the flathead *Platycephalus speculator*. U.S. Fishery Bulletin 90: 276-284.

Hyndes, G.A., Potter, I.C. (1996) Comparisons between the age structures, growth and reproductive biology of two co-occurring sillaginids, *Sillago robusta* and *S. bassensis*, in temperate coastal waters of Australia. *Journal of Fish Biology* 49: 14-32.

Hyndes, G.A., Potter, I.C., Hesp, S.A. (1996) Relationships between the movements, growth, age structures, and reproductive biology of the teleosts *Sillago burrus* and *S. vittata* in temperate marine waters. *Marine Biology* 126: 549-558.

Jenkins, G.P., Black, K.P., Wheatley, M.J., Hatton, D.N. (1997a) Temporal and spatial variability in recruitment of a temperate, seagrass-associated fish is largely determined by physical processes in the pre- and post-settlement phases. *Marine Ecology Progress Series* 148: 23-35.

Jenkins, G.P., May, H.M., Wheatley, A.M.J., Holloway, M.G. (1997b) Comparison of fish assemblages associated with seagrass and adjacent unvegetated habitats of Port Phillip Bay and Corner Inlet, Victoria, Auatralia, with emphasis on commercial species. *Estuarine, Coastal and Shelf Science* 44: 569-588.

Jenkins, G.P., May, H.M.A. (1994) Variation in settlement and larval duration of King George whiting, *Sillaginoides punctata* (Sillaginidae), in Swan Bay, Victoria, Australia. *Bulletin of Marine Science* 54: 281-296.

Jenkins, G.P., Wheatley, M.J., Poore, A.G.B. (1996) Spatial variation in recruitment, growth, and feeding of postsettlement King George whiting, *Sillaginoides punctata*, associated with seagrass beds of port phillip Bay, Australia. *Canadian Journal of Fisheries and Aquatic Sciences* 53: 350-359.

Kailola, P.J., Williams, M.J., Stewart, P.C., Reichelt, R.E., McNee, A., Grieve, C. (1993) Australian Fisheries Resources. Bureau of Resource Sciences, Department of Primary Industries and Energy, and fisheries Research and Development Corporation. Canberra, Australia. 422 pp.

Kerby, B.M., Brown, I.W. (1994) Bream, whiting and flathead in south-east Queensland: a review of the literature. Queensland Department of Primary Industries, QI94028.

Kesteven, G.L., Serventy, D.L. (1941) On the biology of the black bream (*Roughleyia australis*). *Australian Journal of Science*.3: 171.

Liggins, G.W. (1996) The interaction between fish trawling (in NSW) and other commercial and recreational fisheries. NSW Fisheries Research Institue.

Masuda, H., Amaoka, K., Araga, C., Uyeno, T., Yoshino, T. (editors) (1984) *The fishes of the Japanese archipelago*. Tokai University press, Japan.

McKay, R.J. (1985) A revision of the fishes of the family Sillaginidae. *Memoirs of the Queensland Museum* 22:1-73.

McNeill, S.E., Worthington, D.G., Ferrell, D.J., Bell, J.D. (1992) Consistently outstanding recruitment of five species of fish to a seagrass bed in Botany Bay, NSW. *Australian Journal of Ecology* 17: 359-365.

Megrey, B.A. (1989) Review and comparison of the age-structured stock assessment models from the theoretical and applied points of view. *American Fisheries Society Symposium* 6: 8-48.

Middleton, M.J., Bell, J.D., Burchmore, J.J., Pollard, D.A., Pease, B.C. (1984) Structural differences in the fish communities of *Zostera capricorni* and *Posidonia australis* seagrass meadows in Botany Bay, New South Wales. *Aquatic Botany* 18: 89-109.

Miskiewicz, A.G. (1986) The season and length at entry into a temperate Australian estuary of the larvae of *Acanthopagrus australis*, *Rhabdosargus sarba* and *Chrysophrys auratus* (Teleostei: Sparidae) In: Uyeno, T, Arai, R, Taniuchi, T and Matsura, K. (Ed's) *Proceedings of the second international conference on Indo-Pacific fishes*. pp 740-747.

Miskiewicz, A.G. (1987) *Taxonomy and ecology of fish larvae in Lake Macquarie and New South Wales coastal waters*. PhD thesis, University of New South Wales.

Morton, R.M. (1985a) The reproductive biology of summer whiting, *Sillago ciliata* (C.&V.), in nortrhern Moreton Bay, Qld. *Australian Zoologist* 21: 491-502.

Morton, R.M. (1985b) The tagging of summer whiting, *Sillago ciliata*, in nortrhern Moreton Bay, Queensland. *Proceedings of the Royal Society of Queensland* 6: 19-23.

Munro, I.S.R. (1945) Australian bream. *Fisheries Newsletter* 4.

Munro, I.S.R. (1949) Revision of Australian silver breams, *Mylio* and *Rhabdosargus*. *Memiors of the Queensland Museum* 12:182-223. 4:2.

Pease, B.C., Grinberg, A. (1995) New South Wales Commercial Fisheries Statistics 1940 to 1992. NSW Fisheries, Cronulla, 351 pp.

Pollard, D.A. (1991) Spatial and temporal variability in the recruitment of a common estuarine fish, the yellowfin bream (*Acanthopagrus australis*, Sparidae), in south-eastern Australia. pp 85-88. In: Hancock, D.A. (ed) Recruitment processes. Australian Society for Fish Biology Workshop Proceedings No. 16. Australian Governement Publishing service..

Pollock, B.R. (1981) Age determination and growth of luderick, Girella tricuspidata (Quoy and Gaimard), taken from Moreton Bay, Australia. *Journal of Fish Biology* 19: 475-485.

Pollock, B.R. (1982a) Movements and migrations of yellowfin bream, *Acanthopagrus australis*, in Moreton Bay, Queensland as determined by tag recoveries. *Journal of Fish Biology* 20: 245-252.

Pollock, B.R. (1982b) Spawning period and growth of yellowfin bream, *Acanthopagrus australis*, in Moreton Bay, Australia. *Journal of Fish Biology* 21: 349-355.

Pollock, B.R. (1984) Relations between migration, reproduction and nutrition in yellowfin bream, *Acanthopagrus australis*. *Marine Ecology Progress Series* 19: 17-23.

Pollock, B.R. (1985) The reproductive cycle of yellowfin bream, *Acanthopagrus australis* (Gunther), with particular reference to protandrous sex inversion. *Journal of Fish Biology* 26: 301-311.

Pollock, B.R., Weng, H., Morton, R.M. (1983) The seasonal occurrence of postlarval stages of yellowfin bream, *Acanthopagrus australis* (Gunther) and some factors affecting their movement into an estuary. *Journal of Fish Biology* 22: 409-415.

Rowland, S.J. (1984) Hybridisation between estuarine fishes yellowfin bream, *Acanthopagrus australis* (Gunther) and black bream, *A. butcheri* (Munro) (Pisces:Sparidae). *Australian Journal of Marine and Freshwater Research* 35:427-440.

Russell, D.J. (1988) An assessment of the east Queensland inshore gill net fishery. *Queensland Department of Primary Industries, Information Series* Q188024. 57 pp.

Schnute, J. (1981) A versatile growth model with statistically stable parameters. *Canadian Journal of Fisheries and Aquatic Sciences* 38: 1128-1140.

Smale, M.J., Punt, A.E. (1991) Age and growth of the red steenbras *Petrus rupestris* (Pisces:Sparidae) on the south-east coast of South Africa. *South African Journal of Marine Science* 10: 131-139.

State Pollution Control Commission (1981) The ecology of fish in Botany Bay - Biology of commercially and recreationally valuable species. Environmental Control Study of Botany Bay, Sydney, Australia. 287 pp.

Suparta, M.H. (1988) Some aspects of the reproductive physiology of yellowfin bream, *Acanthopagrus australis* (Gunther, 1969). PhD thesis, University of Queensland.

Thomson, J.M. (1959) Some aspects of the ecology of Lake Macquarie, NSW, with regard to an alleged depletion of fish. X. The movements of fish. *Australian Journal of Marine and Freshwater Research* 10: 375-387.

Weng, H.T. (1983) Identification, habitats and seasonal occurrence of juvenile whiting (Sillaganidae) in Moreton Bay. *Journal of Fish Biology* 23: 195-200

Weng, H.T. (1986) Spatial and temporal distribution of whiting (Sillaginidae) in Moreton Bay, Queensland. *Journal of Fish Biology* 29: 755-764.

West, R.J. (1993) The fisheries resources of two southeastern Australian rivers. PHD Thesis, University of New South Wales. xxx pp.

West, R.J., Gordon, G. (1994) The commercial and recreational harvest of fish from two Australian coastal rivers. *Australian Journal of Marine and Freshwater Research* 45: 1259-1279

Worthington, D.G., Doherty, P.J., Fowler, A.J. (1995) Determination of the most efficient method of age determination for estimating the age structure of a fish population. *Canadian Journal of Fisheries and Aquatic Sciences* 152: 2320-2326.

Worthington, D.G., Doherty, P.J., Fowler, A.J. (1995) Variation in the relationship between otolith weight and age: implications for the estimation of age of two tropical damselfish (*Pomacentrus moluccensis* and *P. wardi*). *Canadian Journal of Fisheries and Aquatic Sciences* 148: 35-38.

Worthington, D.G., Ferrell, D.J., McNeill, S.E., Bell, J.D. (1992b) Growth of four species of juvenile fish associated with the seagrass *Zostera capricorni* in Botany Bay, New South Wales. *Australian Journal of Marine and Freshwater Research* 43: 1189-1198.

Worthington, D.G., Ferrell, D.J., McNeill, S.E., Bell, J.D. (1992a) Effects of root density of seagrass on fish and decapods: are correltaions evident over large spatial scales? *Marine Biology* 112; 139-146.

Appendix I. Validation of annual aging and sources of aging error in 4 coastal marine finfish from NSW

D.J. Ferrell

Abstract

A two year program to externally tag and mark estuarine fish with tetracycline was completed on the south coast of NSW. To date, a total of 413 tetracycline-marked individuals *Acanthopagrus australis* (Sparidae), *Sillago ciliata* (Sillaginidae), *Girella tricuspidata* (Girellidae) and *Platycephalus fuscus* (Platycephalidae) have been recaptured and examined for aging validation. The internal macrostructure of otoliths conforms to an annual periodicity, but the accuracy of the age estimates varies among species. Two important sources of aging error are described in this study. There is within-species variation in when the opaque zones are formed, and the magnitude of this variation differs amongst the four species. This appears to cause errors in age estimation because it influences the readers ability to correctly interpret the edge of the otolith, with respect to month of capture of the fish.. There are differences among species in months in which the edge of the otolith should be taken into account to get the most accurate age estimate. The second influence on aging accuracy arises from the degree of individual variation in the rate of growth of the otolith. Fish with either fast or slow growing otoliths are more likely to be incorrectly aged, also because they can present the reader with the same difficulty interpreting the edge of the otolith relative to the month of capture.

A1. Introduction

Beamish and McFarlane (1983) pointed out the importance of validating age estimates before the application of the estimates in any stock assessment or growth estimation process. Since then, there has been widespread acceptance of the importance of aging validation and numerous studies demonstrating the veracity of fish aging. However, many authors have viewed the validation process as one that demonstrated age estimation was accurate rather than describing *how* accurate the technique was.

Francis et al. (1992) used a tetracycline mark-recapture study to quantify the accuracy of ages from otoliths of the sparid fish *Pagrus auratus*. These authors identified and quantified errors of different types in the aging process. This work largely follows the example of Francis et al. (1992) and uses a tetracycline mark-recapture study to quantify age estimation errors in four species; yellowfin bream (*Acanthopagrus australis* Sparidae), sand whiting (*Sillago ciliata* Sillaginidae), luderick (*Girella tricuspidata* Girellidae) and sand flathead (*Platycephalus fuscus* Platycephalidae). Errors due to mis-counts and mis-identification of the state of the otolith edge are quantified separately and different means of considering the state of otolith edges are also compared.

A2. Materials and Methods

Tagging of fish was done in several estuaries along the southern coast of NSW between the Shoalhaven River in the north (Lat 34 50' S) and Lake Conjola in the south (Lat 35 17' S). Tagging took place year-round but was in association with commercial haul-net fishers so species tagged and locations used varied with the activity of the commercial fishers NSW Fisheries regulations prohibit haul nets with meshes in the body of the net finer than 50 mm. The nets used by commercial fishers were generally of that dimension. Fishers would set their hauling net in the normal way but the captured fish were moved into holding pens (~2 m diameter by 1 m deep) before being tagged and released.

All species were given an intraperitoneal injection of tetracycline hydrochloride at the rate of 50 mg kg^{-1}. Fish weights were estimated from length-weight relationships. Fish were tagged with external dart tags and the tagging program was advertised locally in the media and more widely in publications for professional fishers. Rewards were paid for returned fish.

Sections of otoliths from returned fish were prepared by mounting clean, dry otoliths in clear epoxy resin. A transverse section through the focus of the otolith was made using a low speed saw with two diamond blades spaced to leave a gap of about 0.25 mm. The resulting section was lightly polished on a sheet of fine abrasive and mounted on a standard microscope slide. Thin sections were viewed with either reflected or UV light at a magnification of 20 X on a compound microscope. Measurements were taken from video images using image processing software.

All otoliths were read by DJF with cross checking by a second reader (Peter Gibson) - neither reader took part in the routine aging for the remainder of the project. All measurements were made without any knowledge of the history of the specimen or any previous measurements, and measurements from UV and reflected light were made independently. Measurements from transverse sections were taken between the focus and the edge of the otolith, just ventral to the sulcus. The relative position of each opaque mark and the tetracycline mark was measured along that axis.

Tagging fish at different times of the year provided a means of documenting when opaque marks were formed in otoliths. To facilitate the description of this, distances measured between opaque and tetracycline marks were expressed as a proportion of the distance between the opaque marks that surrounded the tetracycline mark. Where insufficient time had elapsed for an opaque mark to form subsequent to the tetracycline mark, the distance from the terminal opaque mark to the tetracycline mark was expressed as a proportion of the distance between the two outermost opaque marks.

Two types of errors in counts of opaque zones were estimated using the tetracycline mark-recapture information. Edge detection errors arise when mistakes are made when assessing the terminal opaque zone in the otolith. The question being asked is whether the terminal opaque zone was formed in the most recent season or formed the year before. Two factors influence this determination; the date of capture and the distance from the terminal opaque zone to the edge of the otolith. Here the assumption is that opaque zones form in the cooler months of the year (see below) which will be referred to as "winter". Prior to reading with UV light, capture date and the state of the otolith margin were used to estimate which in winter the terminal opaque zone formed.

A fish captured late in summer should show a terminal ring formed the previous winter and no consideration of the edge is necessary. That same fish captured in autumn or winter of the same year should still show the same terminal opaque zone in the otolith. There will be a period during the year, however, when some otoliths display a terminal ring from the most recent winter while in others, the terminal ring is from the previous winter. These two conditions are separated by judging the distance between the terminal ring and the otolith edge. If that distance is long, the terminal opaque mark is from the winter before last but if the distance is short, the terminal mark is assumed to have been formed in the most recent winter. Two variables affect this determination; the period of the year when the judgement needs to be made and the distance between the terminal ring and the otolith edge that is considered to be either near or far.

The use of a formal algorithm to state how to judge otolith margins is rare (but see Francis et al. 1992). However, the edge identification process must be formally stated before errors in that process can be identified. The distance between the terminal ring and the otolith edge

Here, the time period when the otolith margin is assessed is varied to examine the effect on edge detection errors. In one case, all fish recaptured between August and February (inclusive) had otolith margins judged. For the other case, otolith margins were only considered in fish captured between October and February. In all cases, if the terminal opaque zone was distant from the otolith edge by greater than 60% of the distance to the terminal minus one opaque zone, then the terminal opaque mark was deemed not to have formed in the most recent winter. The winters in which the terminal and all preceding opaque marks formed were assigned on that basis.

Edge determination errors were those where the tetracycline mark could be used to demonstrate that the terminal opaque mark had been assigned to the wrong winter. The date of tagging was used to assign the opaque marks surrounding the tetracycline mark to their respective winters. The second error type occurred when rings were mis-identified, but not in association with determining the otolith edge. These errors could result from counting false rings or from not counting some opaque marks.

A3. Results

Numbers of fish returned with otoliths intact were 15 flathead, 63 luderick, 90 whiting and 227 bream. Most fish were at large for relatively brief periods and 35 % of recaptures were within 4 months and only 15% were at large more than one year (Figure A1). The luderick averaged the shortest periods at large and more than 75% of recaptures came within 6 months of tagging. Bream were the most common species recaptured long periods after tagging and more than 20% of bream were returned at least one year after tagging.

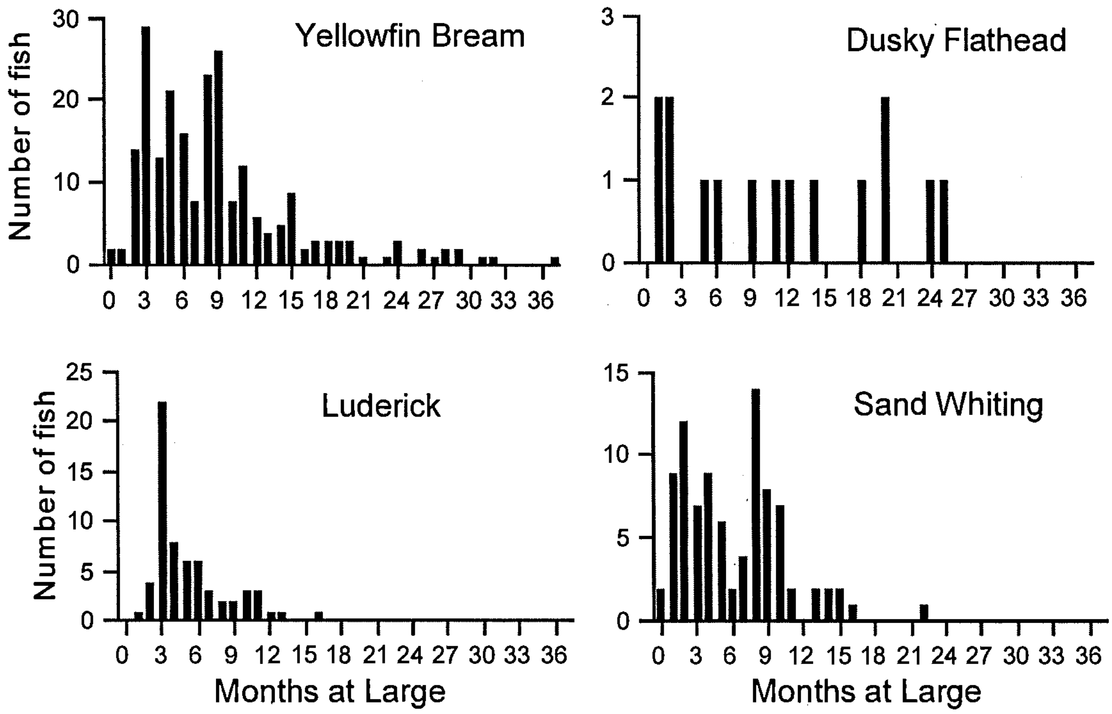


Figure A1. Distribution of the time fish were at large after tagging and treatment with tetracycline.

Tagging and marking fish with tetracycline at different times of year demonstrated that opaque bands were formed over a large part of the year from autumn to spring (Figure A2). Whiting tagged in April through October could be found with the tetracycline mark and the opaque mark in close proximity. Otoliths from fish tagged early in the calendar year tended to have the tetracycline mark prior to the opaque mark and in fish tagged in spring and summer, the tetracycline mark followed the opaque mark (Figure A2).

The trends were similar for all species, including flathead and luderick, but there were differences between species in the variation in the relative position tetracycline and opaque marks. For example, the tetracycline marks in bream were spread among a wider range of positions relative to surrounding opaque marks compare to whiting (Figure A2).

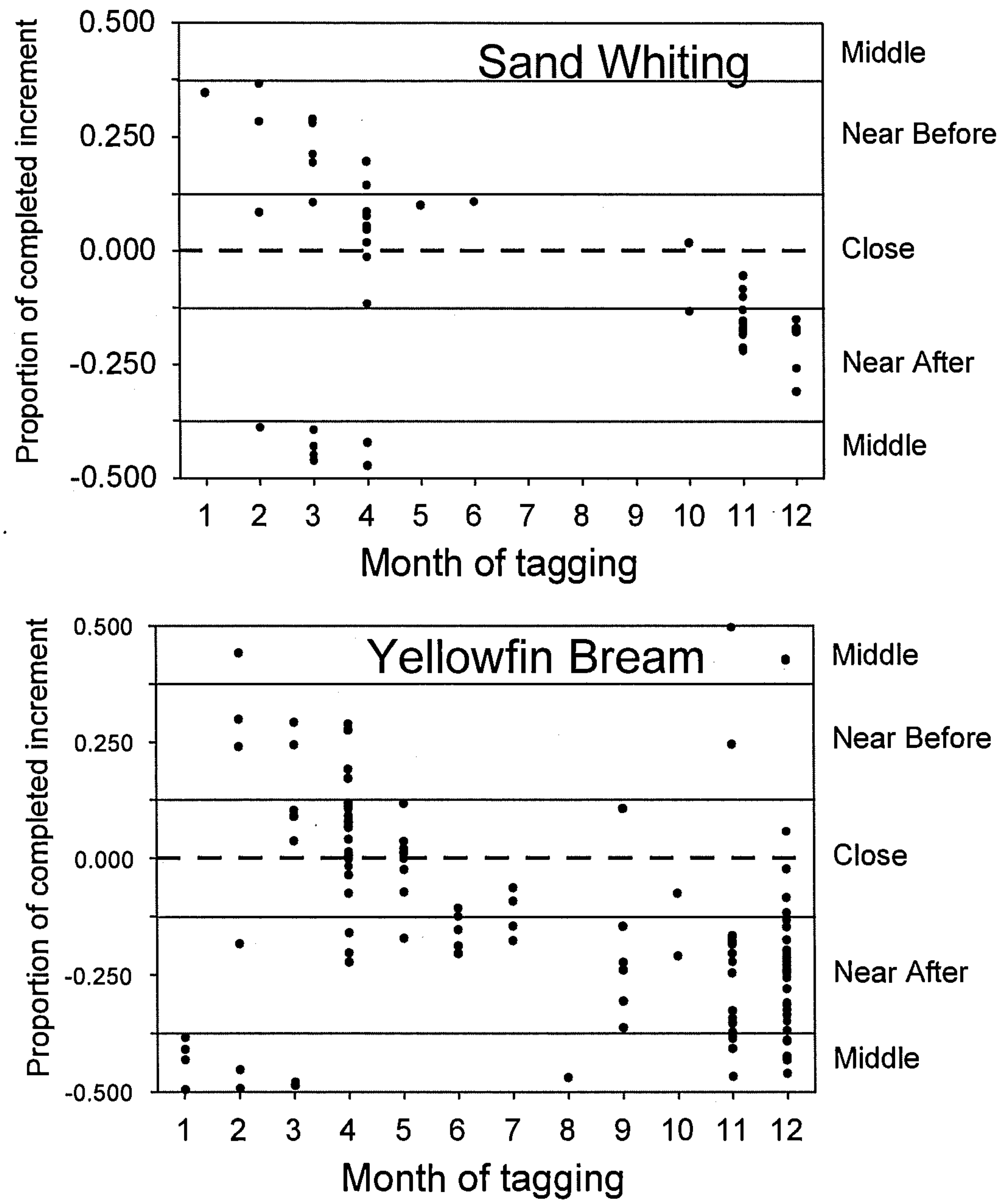


Figure A2. Position of the tetracycline mark relative to the nearest opaque mark in the otoliths of sand whiting and yellowfin bream. The units are fractions of the most recent completed increment, divided into quartiles with zero indicating that the tetracycline mark was coincident with the opaque mark (i.e. that the time of tagging was very close to the time the opaque increment formed.) Flathead and luderick not plotted due to small numbers of recaptures with sufficient time at large.

The formation of opaque marks in all species was consistent with annual deposition centered around the winter period (Figure A3). None of the errors came about because of over- or under-counts of opaque marks (Table A1). Errors all arose due to incorrect assessment of the otolith edge (Table A1). The rate of edge identification errors depended on the species and on the edge determination period (the months when a judgement was needed about the edge). There was a 15 % decrease in edge interpretation errors in whiting when edges were ignored in fish captured in August and September.

Table A1. Rates of errors made counting opaque zones in otoliths and assigning those zones to the correct year. The interpretation period is the months of the year when a judgement about the state of the otolith edge must be made before assigning the age. Age range is the range of capture ages that were included in the table. Numbers in brackets are sample size for each cell.

	Edge Interpretation errors		Zone Identification Errors	Age Range
Species	Interpretation Period			
	August to February	October to February		
Yellowfin Bream	8% (216)	3% (201)	0% (88)	2 to 15
Luderick	16% (19)	16% (19)	0% (4)	2 to 9
Dusky Flathead	0% (5)	0% (5)	0% (8)	2 to 8
Sand Whiting	20% (44)	5% (21)	0% (23)	2 to 9

Zone identification errors were all zero but sample sizes for luderick and sand flathead were low. This means the true probability of these errors is not zero. The binomial distribution can be used to calculate the maximum error rate given the number of trials. So, there is a 95% chance that the true zone identification error for sand flathead is less than 31%. Similarly, the true rate of errors for luderick is unlikely (at $p<0.05$) to exceed 56% and unlikely to exceed 11% for sand whiting. Likewise, the true error rate for yellowfin bream has only a 5% chance of being greater than 3%.

Edge interpretation errors appeared to be associated with otolith growth. For example, all 3 incorrectly assigned edges in luderick were fish captured in April. This was outside either period where edges were considered and in each case slow otolith growth meant that the terminal opaque zone was not from the previous winter, but from the one before. Had the interpretation period been moved to include March and April, no edge errors would have been made for this species.

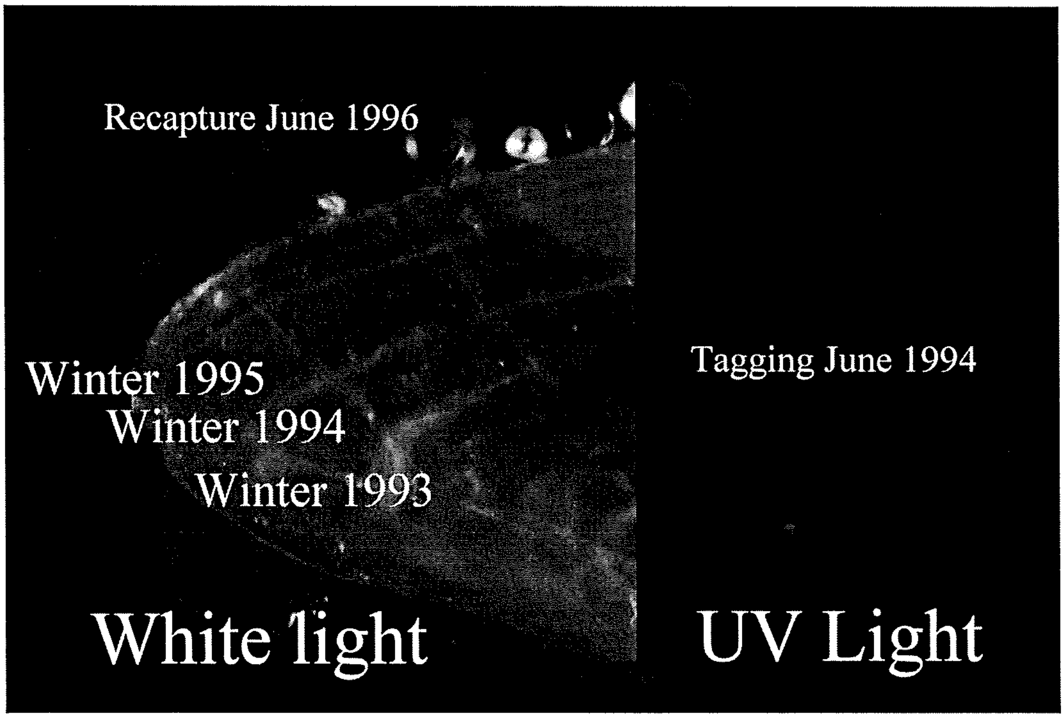


Figure A3. Cross section of flathead otolith with view frame split between incident white light and UV light. Fish was originally captured and tagged in June 1994 and recaptured almost exactly two years later in 1996. The opaque band from winter 1996 has either not formed or is not visible on the edge of the otolith.

A4. Discussion

Tagging and marking fish with tetracycline has again proved to be an important tool for describing the accuracy of age estimation in fish. Having tetracycline marks placed in otoliths throughout the year has provided insight into the timing of formation of the opaque and translucent bands commonly used to age fish. The results here demonstrate that opaque marks are formed, variably, but in winter and spring. These marks can often not be seen until later in the year and it is common in the literature to find references to opaque marks being formed in summer (reviewed in Beckman and Wilson, 1995).

Measurement error may partly explain the difference between bream and whiting in the amount of variation in the position of opaque mark relative to the tetracycline mark of fish tagged within the same month (Figure A2). The position of the opaque mark relative to the tetracycline mark was plotted as a proportion of the nearest completed increment. Average distances between opaque marks were much smaller in bream and the opaque marks themselves were more fuzzy and defuse in bream than in other species. These factors will both combine to increase measurement error in bream relative to whiting.

The error rates for ring identification are indicative of over-all aging accuracy in the sense used by Beamish and McFarlane (1983) and other subsequent authors. It is important to note that these rates (ignoring for the moment that they are all zero) are errors per ring, not errors per fish. This means that for old individuals, the probability of ring identification errors could still be high, even though the estimated rate per ring is very low.

The variation among individual fish in the apparent time of formation of opaque marks and the accuracy of the technique may seem initially out of step. After all, how could a process that varies so much give rise to overall error rates that are relatively low? It would seem that the reason lies with the need to only correctly identify the year in which an opaque mark formed. Much of the risk associated with incorrect assignments occurs during the period in the year when some judgement must be made about the edge of the otolith. Despite great variation in the season when the opaque marks form, it remains possible to routinely assign the year of formation correctly.

The variation in rates of edge identification errors, both among species and among models used to assess the edge, give rise to several responses. First, it should be noted that these errors are per fish and never exceed one year. In some situations, these errors will be trivial and could be ignored. For example, if the sampling only arises at a time of year when the edge does not need to be assessed, then edge identification will not be a problem. However, it is clear that the model used to decide about the condition of otolith edges must be clearly stated and, if possible, tested. It is not difficult to imagine a sampling scheme that caused bias in age estimation by collection of fish at a time when edges are likely to be incorrectly determined.

A5. References

Beamish, R. J. and McFarlane, G. A. (1983). The forgotten requirement for age validation in fisheries biology. Trans. Am. Fish. Soc. 112: 735-743

Beckman, D. W. and Wilson, C. A. (1995). Seasonal timing of opaque zone formation. Recent developments in fish otolith research (Eds. D. H. Secor, J. M. Dean and S. E. Campana.) pp. 27-43. (University of South Carolina Press: Columbia, South Carolina.)

Francis, R. I. C., Paul, L. J. and Mulligan, K. P. (1992). The ageing of adult snapper (*Pagrus auratus*) from otolith annual ring counts: validation using tagging and oxytetracycline injection. Aust. J. Mar. Freshw. Res. 43: 1069-1090

Appendix II. Daily logbooks

B.C. Pease, T.R. Walford

a. Daily logbook form used for north and central coast estuaries

b. Daily logbook form used for south coast estuaries

c. Back of daily logbook forms

NSW Estuarine Fishery Research Logbook

62078 575

NSW FISHERIES

Date: / /

Last Date Fished: / /

Sets/shots/hauls: Search time:

Total net length, Trap lifts, Hooks: Hours fished:

Gear used: O 1 O 2 O 3 O 4 O 5 O 6 O 7

Catch weights: O Landed or O Estimated

Choose one method and estuary only

Fishing Method:

- O Bait (seine)
- O Bullringing, garfish
- O Hauling, bait (anchovy, pilchard)
- O Hauling, fish (general)
- O Hauling, garfish
- O Hauling, trumpeter whiting
- O Lampara
- O Lift (hoop)
- O Mesh, bottom set
- O Mesh, flathead
- O Mesh, splashing
- O Mesh, top set
- O Pound
- O Purse seine (Jervis Bay)
- O Prawn, hauling
- O Prawn, running
- O Prawn, seine (snigger)
- O Prawn, set pocket
- O Prawn, trawl
- O Submersible lift net (bait)

NETS

- O Bait
- O Eel
- O Crab
- O Fish
- O Lobster

TRAPS

- O Hand held
- O Rod and reel

LINES

- O Handgathering
- O Skindiving
- O Other, please specify below

OTHER

Estuary Fished:

- O Tweed River
- O Richmond River
- O Clarence River
- O Bellinger River
- O Nambucca River
- O Macleay River
- O Hastings River
- O Camden Haven River
- O Manning River
- O Wallis Lake
- O Smiths Lake
- O Myall Lakes
- O Port Stephens
- O Hunter River
- O Lake Macquarie
- O Tuggerah Lakes
- O Hawkesbury River
- O Port Jackson
- O Botany Bay
- O Lake Illawarra
- O Shoalhaven River
- O Jervis Bay
- O St Georges Basin
- O Burrill Lake
- O Clyde River
- O Coila Lake
- O Tuross Lake
- O Brou Lake
- O Wallaga Lake
- O Other, Please specify below

Code: (see other side)

Other Species:

Processing	Weight (kg)	Species Code (other side)

Catch by species:

Processing	Weight (kg)	Species	
		Biddy, Silver	FINFISH
		Bream, Yellowfin & Black	
		Eel, Short-finned Conger	
		Eel, Short-finned River	
		Flathead, Dusky	
		Garfish, River	
		Garfish, Sea	
		Hairtail	
		Luderick	
		Mackerel, Blue	
		Mullet, Flattail	
		Mullet, Sand	
		Mullet, Sea	
		Mulloway	
		Pilchard	
		Tailor	
		Tarwhine	
		Trevally, Silver	
		Whitebait	
		Whiting, Sand	
		Whiting, Trumpeter	
		Yellowtail	
		Crab, Blue Swimmer	SHELLFISH
		Crab, Mud	
		Prawn, Eastern King	
		Prawn, Greasyback	
		Prawn, School	
		Cockle	
		Octopus	
		Species not listed on front or back of form	

Fax to: (02) 544-2071

50995 803

NSW Estuarine Fishery Research Logbook

NSW FISHERIES

Date: / /

Last Date Fished: / /

Sets/shots/hauls: Search time:

Total net length, Trap lifts, Hooks: Hours fished:

Gear used: O 1 O 2 O 3 O 4 O 5 O 6 O 7

Catch weights: O Landed or O Estimated

Choose one method and estuary only

Fishing Method:

NETS
- O Bait (seine)
- O Bullringing, garfish
- O Hauling, bait (anchovy, pilchard)
- O Hauling, fish (general)
- O Hauling, garfish
- O Hauling, trumpeter whiting
- O Lampara
- O Lift (hoop)
- O Mesh, bottom set
- O Mesh, flathead
- O Mesh, splashing
- O Mesh, top set
- O Pound
- O Purse seine (Jervis Bay)
- O Prawn, hauling
- O Prawn, running
- O Prawn, seine (snigger)
- O Prawn, set pocket
- O Prawn, trawl
- O Submersible lift net (bait)

TRAPS
- O Bait
- O Eel
- O Crab
- O Fish
- O Lobster

LINES
- O Hand held
- O Rod and reel

OTHER
- O Handgathering
- O Skindiving
- O Other, please specify below

Estuary Fished:

- O St Georges Basin
- O Swan Lake
- O Lake Conjola
- O Burrill Lake
- O Tabourie Lake
- O Meroo Lake
- O Durras Lake
- O Clyde River
- O Tomaga River
- O Moruya River
- O Congo Creek
- O Coila Lake
- O Tuross Lake
- O Lake Brunderee
- O Brou Lake
- O Dalmeny Lake
- O Wagonga Inlet
- O Nangudga Lake
- O Corunna Lake
- O Tilba Tilba Lake
- O Wallaga Lake
- O Bermagui River
- O Barragoot Lake
- O Cuttagee Lake
- O Murrah Lake
- O Wapengo Lagoon
- O Nelson Lagoon
- O Bega River
- O Wallagoot Lake
- O Other, Please specify below

Code: (see other side)

Other Species:

Processing	Weight (kg)	Species Code (other side)

Catch by species:

Processing	Weight (kg)	Species
		Biddy, Silver
		Bream, Yellowfin & Black
		Eel, Short-finned Conger
		Eel, Short-finned River
		Flathead, Dusky
		Garfish, River
		Garfish, Sea
		Hairtail
		Luderick
		Mackerel, Blue
		Mullet, Flattail
		Mullet, Sand
		Mullet, Sea
		Mulloway
		Pilchard
		Tailor
		Tarwhine
		Trevally, Silver
		Whitebait
		Whiting, Sand
		Whiting, Trumpeter
		Yellowtail
		Crab, Blue Swimmer
		Crab, Mud
		Prawn, Eastern King
		Prawn, Greasyback
		Prawn, School
		Cockle
		Octopus
		Species not listed on front or back of form

(Finfish: Biddy, Silver – Yellowtail; Shellfish: Crab, Blue Swimmer – Octopus)

Fax to: (02) 544-2071

Estuaries Not Listed on Front

Code	Short Name
2816	Cudgen Lake
2822	Cudgera Creek
2824	Mooball Creek
2833	Brunswick River
2837	Belongil Creek
2840	Tallow Creek
2842	Broken Head Creek
2907	Evans River
2913	Jerusalem Creek
2941	Sandon River
2953	Wooli Wooli River
2957	Station Creek
2959	Corindi River
3004	Arrawarra Creek
3005	Darkum Creek
3006	Woolgoolga Lake
3008	Hearns Lake
3013	Moonee Creek
3018	Coffs Harbour Creek
3021	Boambee Creek
3023	Bonville Creek
3032	Dalhousie Creek
3034	Oyster Creek
3036	Deep Creek
3053	South West Rocks Creek
3053	Saltwater Creek
3103	Korogoro Creek
3111	Killick Creek
3138	Camden Haven River
3201	Khappinghat Creek
3325	Wamberal Lagoon
3326	Terrigal Lagoon
3328	Avoca Lake
3330	Cockrone Lake
3344	Narrabeen Lake
3345	Dee Why Lagoon
3346	Harbord Lagoon
3347	Manly Lagoon
3404	Port Hacking
3425	Towradgie Creek
3428	Port Kembla Harbour
3434	Bensons Creek
3438	Minnamurra River
3440	Wrights Creek
3444	Werri Creek
3446	Crooked River
3457	Lake Wollumboola
3511	Swan Lake
3512	Berrara Creek
3414	Nerrindillah Creek
3516	Lake Conjola
3518	Narrawallee Inlet
3520	Mollymook Creek
3522	Ulladulla Harbour
3527	Touhouree Lake
3528	Termeil Lake
3529	Meroo Lake
3530	Willinga Lake
3533	Kioloa Lagoon
3545	Clyde River
3550	Tomaga River
3551	Candlagan Creek
3555	Moruya River
3557	Congo Creek
3559	Meringo Creek
3506	Lake Brunderee
3610	Dalmeny Lake
3612	Kianga Lake
3613	Wagonga Inlet
3615	Nangudga Lake
3617	Corunna Lake
3620	Tilba Tilba Lake
3621	Dry Lake

Estuaries Not Listed on Front

Code	Short Name
3625	Bermagui River
3628	Barragoot Lake
3629	Cuttagee Lake
3432	Murrah Lake
3633	Bunga Lagoon
3638	Wapengo Lagoon
3639	Middle Lake
3641	Nelson Lagoon
3642	Bega River
3647	Wallagoot Lake
3650	Bournda Lagoon
3653	Back Lake
3654	Merimbula Lake
3657	Pambula Lakeand River
3705	Twofold Bay
3715	Wonboyn River
3716	Merrica River
3720	Nadgee River
3728	Nadgee Lake
3730	Coastal Farm Dam

Fish Species Not Listed on Front

Code	Short Name
	Finfish:
ANCHOV	Anchovy
BATFIS	Batfish
BONITO	Bonito
BULLSE	Bullseye, Red
CARPCO	Carp, Common
CATFIE	Catfish, Estuary
CATFIF	Catfish, Forktail
CATFIL	Catfish, Longtail
CATFIS	Catfish, Striped
COBIA	Cobia
CODRED	Cod, Red Rock
DART	Dart
DOLPHI	Dolphinfish
DORYJO	Dory, John
DRUMME	Drummer
EELPIK	Eel, Common Pike
EELLFR	Eel, Longfin River
EELSC	Eel, Southern Conger
FLATHS	Flathead, Sand
FLOUND	Flounder
GARFIN	Garfish, No Bill
GOABLA	Goatfish, Blackspot
GOABLU	Goatfish, Blue-striped
HARDYH	Hardyhead
JACKMA	Jack, Mangrove
KINGFI	Kingfish, Yellowtail
KRILL	Krill
LEADEN	Leadenall
LEATHB	Leatherjacket, Bridled
LEATHF	Leatherjacket, Fanbelly
LEATHS	Leatherjacket, Six-spined
LEATHY	Leatherjacket, Yellow-finned
LONGTO	Longtom
MACJAC	Mackerel, Jack
MACSPA	Mackerel, Spanish
MACSPO	Mackerel, Spotted
MORRED	Morwong, Red
MORRUB	Morwong, Rubberlip
MULLFA	Mullet, Fantail
MULLPI	Mullet, Pink-eye
MULLRE	Mullet, Red
NANATA	Nanata
OLDMAI	Old Maid
PARROT	Parrotfish
PERCHP	Perch, Pearl
PIKE	Pike
SALMON	Salmon, Australian
SAMSON	Samson Fish

Fish Species Not Listed on Front

Code	Short Name
SHARAN	Shark, Angel
SHARBL	Shark, Black Tip
SHARBU	Shark, Bull
SHARCA	Shark, Carpet or Wobbegong
SHARDE	Shark, Dogfish Endeavour
SHARDG	Shark, Dogfish Greeneye
SHARFI	Shark, Fiddler
SHARGU	Shark, Gummy
SHARHA	Shark, Hammerhead
SHARSC	Shark, School or Snapper
SHARSH	Shark, Shovelnose
SNAPPE	Snapper
SNOOK	Snook
SOLEBL	Sole, Black
SOLELE	Sole, Lemon
STARGA	Stargazer
STINGR	Stingray
SURGEO	Surgeonfish
SWEEP	Sweep
TERAGL	Teraglin
TREVAB	Trevally, Black
TRUMPE	Trumpeter
TRUMPT	Trumpeter, Tasmanian
TUNAMA	Tuna, Mackerel
TUNANO	Tuna, Northern Bluefin
TUNASK	Tuna, Skipjack
WHITGR	Whiting, Grass
WHITSC	Whiting, School
WIRRAH	Wirrah
YELLOW	Yellowtail
	Molluscs:
CALAMA	Calamari, Southern
CUTTLE	Cuttlefish
MUSSEL	Mussel, Blue
PIPI	Pipi
SCALLO	Scallop
SHELLS	Shells
SQUID	Squid
	Crustaceans:
CRABCO	Crab, Coral
CRABHE	Crab, Hermit
CRABRE	Crab, Redspot
KRILL	Krill
LOBSTE	Lobster, Eastern Rock
NIPPER	Nipper
PRAWNT	Prawn, Tiger (Black or Leader)
SHRIMP	Shrimp, Mantis
	Other Shellfish:
BWORMS	Beachworms

List of Processing Types

Code	Processing
BA	Barrels (Shark)
CO	Cooked
FI	Fillets
FN	Fins (Shark)
FO	Fins off
GG	Gilled Gutted
GH	Gilled Head off
GI	Gilled
GR	Green
GS	Gutted Skin off
GU	Gutted
HE	Heads only
HO	Head off
HS	Head off Gutted Skin off
LI	Live (Eels)
OT	Other
RF	Ray Flaps
RO	Roe
SO	Skin off
TA	Tails only

Appendix III. Logbook instructions

B.C. Pease, T.R. Walford

Instructions for filling out daily logbook forms

Explanatory Notes for NSW Estuarine Fishery Research Logbook

Introduction

Assessments of the status of fish stocks in NSW estuaries have never been carried out and are urgently needed to assure the sustainability of this fishery. Scientists at the Fisheries Research Institute are conducting studies to develop techniques for assessing stocks of estuarine fish species. These studies will enable NSW Fisheries to start monitoring the status of estuarine fish stocks in association with changing management policies.

The research program is twofold:

1) biological sampling of catches will be carried out, both onboard fishing boats and at co-ops and market outlets at selected estuaries.
2) a voluntary daily logbook program will be developed to monitor details of catch and fishing effort in selected estuaries.

An important part of the logbook program is the testing of a new computer system which uses Optical Character Recognition techniques that allow us to collect logbook forms by fax and put the data directly into our computer database without manual data entry. It is very important that participants in this logbook program take the time to fill out the forms carefully and accurately so that the information can be collected and processed with a minimum number of errors.

Thank you for assisting in this important research by participating in the logbook program.

Instructions

Because the information on this logbook differs from the information requested on a Form 19 monthly catch return, you must continue to submit the mandatory Form 19 monthly catch returns during the time that you participate in this daily logbook program.

A log sheet should be filled out for each day fished, for each method and/or for each estuary. If more than one method or more than one estuary is fished ~~in any one~~ day, then separate log sheets must be filled out. You should lodge a log sheet for each day that you fished regardless of whether or not you caught any fish (zero catch for one day of fishing effort is valuable information).

You should lodge a log sheet for each day that you were in charge of a fishing operation, but not if you fished as crew or partner and your fishing activity has already been recorded on a daily log sheet by another fisher. Also ensure that none of your crew or partners are also filling out a daily log sheet for the same catches you are recording. Please do not split catches on log sheets. This information is for research purposes only and is strictly confidential.

To ensure that your information is understood by our computer system, please print all characters with a soft lead pencil eg. 2B, black ink pen or blue ink pen. Pencil is preferred so that you can erase mistakes. Print letters and numbers using upper case (capitol) block letters. Print only one character within a box and try to ensure that characters do not touch the side of the box they are printed within. Zero, seven and "Z" should not be crossed. All zeros in numbers, including those at the end, must be written in.

Like this: ZD 70 Not like this : ZD 7 7Ø

Selection bubbles should be completely darkened. Marking with a tick or a cross is acceptable but does not give the best results. Never circle a selection bubble.

Like this: Preferred Acceptable Not like this: Unacceptable

Fax your log sheets to NSW Fisheries at Cronulla Fax no. 02 544-2071 within 14 days. Keep the original log sheet for your information. If you do not have a fax machine please take the log sheets to your nearest District Fisheries Office and ask them to fax the sheets then return them to you. If you cannot fax the the sheets to us please mail them to: Estuarine Logbooks, PO Box 21, Cronulla 2230. A copy of the logs will be returned to you for your records. If you have any questions or need help, call the Estuarine Logbook Liason Officer at 02 527-8411.

The following numbered instructions refer to the sample log sheet provided:

1. Enter the date that the fishing activity was carried out. As: Day/Month/Year
2. Enter the date for the last day you fished and completed a log sheet. As: Day/Month/Year. If your last fishing day was as crew or partner with another fisher and you did not complete a log sheet, do not record this day as your last fishing day.
3. Enter the number of times your fishing gear was deployed during the day. It is the number of times you shot or hauled your haul, seine or trawl nets or set your mesh nets. If you used traps, lines, hand gathering or skindiving then leave these boxes blank.
4. Enter the number of traps you lifted on this day, if trap fishing, or the maximum number of hooks that were in the water at any time on this day if line fishing. If you used any method other than trap or line fishing then leave these boxes blank.
5. Enter the total number of hours spent searching for fish before putting your fishing gear in the water. Used primarily when hauling.
6. Enter the total number of hours fished. This is the total time that your fishing gear was in the water. If using traps this is the average soak time. Please round off minutes to the nearest hour. If you fished for anytime less than 1 hour it should be recorded as 1 hour. Do not include time spent searching for fish.
7. Fill in the bubble or bubbles identifying which gear you used. You may own several nets with different mesh sizes and dimensions that you use for one fishing method. These nets have been identified by us with a number. Please fill in the bubble for the identification number of the gear used on this day. We would prefer you to complete a separate log sheet for each gear. If this is not convenient, you may fill in multiple bubbles identifying each gear you used. For example, you might own three different nets that you use for bottom set meshing. If you use the net identified as bottom set meshing gear number 3, you fill in bubble number 3.
8. We prefer that you record catch weights that are measured when you land the catch. If you record measured weights upon landing your catch, fill in the bubble for "landed". We understand that there may be situations where it is not practical to wait until the catch is landed before recording catch weights. If you can only estimate the catch weights, fill in the bubble for "estimated".
9. Fill in the bubble for the fishing method you used. Please fill in the bubble for only one of the methods listed. If you used more than one method you must complete additional log sheets.
10. If the method you used is not listed on the log sheet, fill in the "Other" bubble and write in **capitals** the method you used in the space provided.
11. Fill in the bubble for the estuary you fished in. Please fill in the bubble for only one of the estuaries listed. If you fished in more than one estuary you must complete additional log sheets.
12. If the estuary you fished in is not listed on the front of the log sheet, fill in the "Other" bubble then refer to the back of the sheet for a complete list of estuaries and their codes. Enter the code for the corresponding estuary in the boxes provided. A complete list of estuaries with their tributaries and embayments etc. is also included following the sample log sheet.
13. If you process any of the species in your catch, for example gilled, gutted, etc., and the catch weights listed on the log sheet refer to landed weights after processing, enter the code listed on the back of the log sheet for the type of processing you carried out. If you record estimated weights, you do not have to enter processing codes because you should estimate whole weights only.
14. Enter the weight (in kilograms) for each species you caught. Please round all weights off to the nearest kilogram.

15. If you have caught a species not listed on the front of the log sheet, refer to the back of the sheet for a complete list of species and their codes. Enter the code in **capitals** for the corresponding species in the boxes provided. There are 3 places provided for further species not listed on the front of the log sheet. A complete list of species with their alternate names is also included following the sample log sheet.

16. This space is provided for the following information:

- If a species is not listed on the log sheet (front or back) you can write the name of the species in here.
- If the above 3 spaces provided for species listed on the back of the log sheet are already used and you have another species listed on the back to add, you can enter the species code here.
- If you have more than one species left to record and all the above spaces for other species are filled in, then write "OTHER" and add the weights of these species together. If you use this option, please ensure that the three weights listed above this space, for species not listed on the front of the sheet, are higher than any of the weights for species that are added together in the "OTHER" category.
- If you have any comments on the logbook itself or fishing conditions etc. and this space is not already used for species information you may place your comments here.

32752

NSW Estuarine Fishery Research Logbook

NSW FISHERIES

(1) Date: 14 / 8 / 95
(2) Last Date Fished: 12 / 8 / 95
(3) Sets/shots/hauls: 3
(4) Trap lifts or hooks:
(5) Search time: 5
(6) Hours fished: 5
(7) Gear used: O 1 ● 2 O 3 O 4 O 5
(8) Catch weights: ● Landed or O Estimated

Choose one method and estuary only

Fishing Method: (9)

- O Bait (seine)
- O Bullringing, garfish
- O Hauling, bait (anchovy, pilchard)
- ● Hauling, fish (general)
- O Hauling, garfish
- O Hauling, trumpeter whiting
- O Lampara
- O Lift (hoop)
- O Mesh, bottom set
- O Mesh, flathead
- O Mesh, splashing
- O Mesh, top set
- O Pound
- O Purse seine (Jervis Bay)
- O Prawn, hauling
- O Prawn, running
- O Prawn, seine (snigger)
- O Prawn, set pocket
- O Prawn, trawl
- O Submersible lift net (bait)

NETS

- O Bait
- O Eel
- O Crab
- O Fish
- O Lobster

TRAPS

- O Hand held
- O Rod and reel

LINES

- O Handgathering
- O Skindiving
- O Other, please specify below

OTHER

(10)

Estuary Fished: (11)

- O Tweed River
- O Richmond River
- O Clarence River
- O Bellinger River
- O Nambucca River
- O Macleay River
- O Hastings River
- O Camden Haven River
- O Manning River
- O Wallis Lake
- O Smiths Lake
- O Myall Lakes
- O Port Stephens
- O Hunter River
- ● Lake Macquarie
- O Tuggerah Lakes
- O Hawkesbury River
- O Port Jackson
- O Botany Bay
- O Lake Illawarra
- O Shoalhaven River
- O Jervis Bay
- O St Georges Basin
- O Burrill Lake
- O Clyde River
- O Coila Lake
- O Tuross Lake
- O Brou Lake
- O Wallaga Lake
- O Other, Please specify below

Code: (12) (see other side)

Catch by species:

Processing (13)	Weight (kg) (14)	Species
		Biddy, Silver
		Bream, Yellowfin & Black
		Eel, Short-finned Conger
		Eel, Short-finned River
GU	24	Flathead, Dusky
		Garfish, River
		Garfish, Sea
		Hairtail
	233	Luderick
		Mackerel, Blue
		Mullet, Flattail
		Mullet, Sand
	152	Mullet, Sea
		Mulloway
		Pilchard
		Tailor
	98	Tarwhine
		Trevally, Silver
		Whitebait
	57	Whiting, Sand
		Whiting, Trumpeter
		Yellowtail
CO	22	Crab, Blue Swimmer
		Crab, Mud
		Prawn, Eastern King
		Prawn, Greasyback
		Prawn, School
		Cockle
		Octopus
		Species not listed on front or back of form

FINFISH

SHELLFISH

Other Species:

Processing	Weight (kg)	Species Code (other side) (15)
	10	CATFIE

(16) Please send more forms

Complete List of Estuary Codes

Full Name	Short Name	Code
Tweed R, Cobaki Ck, Broadwater, Terranora	Tweed River	2810
Cudgen Lake	Cudgen Lake	2816
Cudgera Creek	Cudgera Creek	2822
Mooball Creek	Mooball Creek	2824
Brunswick River And Heads	Brunswick River	2833
Belongil Creek	Belongil Creek	2837
Tallow Creek	Tallow Creek	2840
Broken Head Creek	Broken Head Creek	2842
Richmond R, North Creek	Richmond River	2852
Evans River	Evans River	2907
Jerusalem Creek	Jerusalem Creek	2913
Clarence R, Wooloweyah L	Clarence River	2926
Sandon River	Sandon River	2941
Wooli Wooli River	Wooli Wooli River	2953
Station Creek	Station Creek	2957
Corindi R, Redbank Ck, Saltwater Ck	Corindi River	2959
Arrawarra Creek	Arrawarra Creek	3004
Darkum Creek	Darkum Creek	3005
Woolgoolga Lake	Woolgoolga Lake	3006
Hearns Lake	Hearns Lake	3008
Moonee Creek	Moonee Creek	3013
Coffs Harbour Creek	Coffs Harbour Creek	3018
Boambee Creek	Boambee Creek	3021
Bonville Creek	Bonville Creek	3023
Bellinger R, Kalang River	Bellinger River	3030
Dalhousie Creek	Dalhousie Creek	3032
Oyster Creek	Oyster Creek	3034
Deep Creek	Deep Creek	3036
Nambucca River	Nambucca River	3039
Macleay R, Spencers Creek	Macleay River	3052
South West Rocks Creek	South West Rocks Creek	3053
Saltwater Creek	Saltwater Creek	3053
Korogoro Creek	Korogoro Creek	3103
Killick Creek	Killick Creek	3111
Hastings River	Hastings River	3126
Lake Innes, Lake Cathie	Lake Innes, Lake Cathie	3133
Camden Haven R, Queens L, Watson Taylor L	Camden Haven River	3138
Manning River	Manning River	3153
Khappinghat Creek	Khappinghat Creek	3201
Wallis Lake	Wallis Lake	3211
Smiths Lake	Smiths Lake	3223
Myall Lakes and River	Myall Lakes	3226
Port Stephens, Karuah River	Lower Port Stephens	3243
Hunter River	Hunter River	3255
Lake Macquarie	Lake Macquarie	3305
Tuggerah Lakes, Munmorah, Budgewoi	Tuggerah Lakes	3321
Wamberal Lagoon	Wamberal Lagoon	3325
Terrigal Lagoon	Terrigal Lagoon	3326
Avoca Lake	Avoca Lake	3328
Cockrone Lake	Cockrone Lake	3330
Hawkesbury R, Broken Bay, Brisbane Water, Pittwater	Hawkesbury River	3334
Narrabeen Lake	Narrabeen Lake	3344
Dee Why Lagoon	Dee Why Lagoon	3345
Harbord Lagoon	Harbord Lagoon	3346
Manly Lagoon	Manly Lagoon	3347
Sydney Harbour, Parramatta River, Port Jackson	Port Jackson	3350
Botany Bay, Georges River	Botany Bay	3400
Port Hacking	Port Hacking	3404
Towradgie Creek	Towradgie Creek	3425
Port Kembla Harbour	Port Kembla Harbour	3428
Lake Illawarra	Lake Illawarra	3433
Bensons Creek	Bensons Creek	3434
Minnamurra River	Minnamurra River	3438
Wrights Creek	Wrights Creek	3440
Werri Creek	Werri Creek	3444

Complete List of Estuary Codes

Full Name	Short Name	Code
Crooked River	Crooked River	3446
Shoalhaven River, Crookhaven River	Shoalhaven River, Crookhaven River	3452
Lake Wollumboola	Lake Wollumboola	3457
Jervis Bay, Currambene Creek	Jervis Bay	3506
St Georges Basin, Sussex Inlet	St Georges Basin	3510
Swan Lake	Swan Lake	3511
Berrara Creek	Berrara Creek	3512
Nerrindillah Creek	Nerrindillah Creek	3414
Lake Conjola	Lake Conjola	3516
Narrawallee Inlet	Narrawallee Inlet	3518
Mollymook Creek	Mollymook Creek	3520
Ulladulla Harbour	Ulladulla Harbour	3522
Burrill Lake	Burrill Lake	3524
Tabourie Lake	Tabourie Lake	3527
Termeil Lake	Termeil Lake	3528
Meroo Lake	Meroo Lake	3529
Willinga Lake	Willinga Lake	3530
Kioloa Lagoon	Kioloa Lagoon	3533
Durras Lake	Durras Lake	3538
Batemans Bay, Clyde River, Cullendulla Creek	Clyde River	3545
Tomaga River	Tomaga River	3550
Candlagan Creek	Candlagan Creek	3551
Moruya River	Moruya River	3555
Congo Creek	Congo Creek	3557
Meringo Creek	Meringo Creek	3559
Coila Lake	Coila Lake	3603
Tuross Lake	Tuross Lake	3605
Lake Brunderee	Lake Brunderee	3506
Brou L, Birroul Lake	Brou Lake	3607
Dalmeny L, Mummaga L	Dalmeny Lake	3610
Kianga Lake	Kianga Lake	3612
Wagonga Inlet	Wagonga Inlet	3613
Nangudga L, Little L	Nangudga Lake	3615
Corunna Lake	Corunna Lake	3617
Tilba Tilba Lake	Tilba Tilba Lake	3620
Dry L, Little L	Dry Lake	3621
Wallaga Lake	Wallaga Lake	3622
Bermagui River	Bermagui River	3625
Barragoot Lake	Barragoot Lake	3628
Cuttagee Lake	Cuttagee Lake	3629
Murrah Lake	Murrah Lake	3432
Bunga Lagoon	Bunga Lagoon	3633
Wapengo Lagoon	Wapengo Lagoon	3638
Middle (Bega) L, Brow Lake	Middle Lake	3639
Nelson Lagoon	Nelson Lagoon	3641
Bega River	Bega River	3642
Wallagoot Lake	Wallagoot Lake	3647
Bournda Lagoon	Bournda Lagoon	3650
Back Lake	Back Lake	3653
Merimbula Lake	Merimbula Lake	3654
Pambula Lake and River	Pambula Lakeand River	3657
Twofold Bay, Curalo Lagoon, Nullica River, Towamba River, Fisheries Creek	Twofold Bay	3705
Wonboyn River	Wonboyn River	3715
Merrica River	Merrica River	3716
Nadgee River	Nadgee River	3720
Nadgee Lake	Nadgee Lake	3728
Coastal Farm Dam	Coastal Farm Dam	3730

Complete List of Species Codes

Short Name	Alternate Names	Code
Finfish:	Fish	
Anchovy		ANCHOV
Batfish	Diamond Fish or Butterfish	BATFIS
Biddy, Silver		BIDDYS
Bonito	Bonito, Australian	BONITO
Bream, Black and Yellowfin		BREAMY
Bullseye, Red	Bigeye, Red	BULLSE
Carp, Common	Carp, Common, Koi or European	CARPCO
Catfish, Estuary		CATFIE
Catfish, Forktail		CATFIF
Catfish, Longtail		CATFIL
Catfish, Striped		CATFIS
Cobia	Black Kingfish	COBIA
Cod, Red Rock		CODRED
Dart		DART
Dolphinfish	Mahi Mahi	DOLPHI
Dory, John		DORYJO
Drummer	Rockfish, Black	DRUMME
Eel, Common Pike	Eel, Common Pike	EELPIK
Eel, Longfin River	Eel, Longfin	EELLFR
Eel, Shortfin Conger		EELSFC
Eel, Shortfin River	Eel, Shortfin	EELSFR
Eel, Southern Conger	Eel, Southern Conger	EELSTH
Flathead, Dusky or Black	Flathead, Black or River	FLATHD
Flathead, Sand	Flathead, Sand & Blue-spotted	FLATHS
Flounder	Flounder, Mixed	FLOUND
Garfish, No Bill	Garfish, Short Beaked or Snub-nosedl	GARFIN
Garfish, River		GARFIR
Garfish, Sea	Garfish, Southern Sea	GARFIS
Goatfish, Blackspot	Barbounia	GOABLA
Goatfish, Blue-striped	Barbounia	GOABLU
Hairtail		HAIRTA
Hardyhead	Silversides	HARDYH
Jack, Mangrove		JACKMA
Kingfish, Yellowtail		KINGFI
Krill		KRILL
Leadenall		LEADEN
Leatherjacket, Bridled		LEATHB
Leatherjacket, Fanbelly		LEATHF
Leatherjacket, Six-spined		LEATHS
Leatherjacket, Yellow-finned		LEATHY
Longtom	Needlefish	LONGTO
Luderick	Blackfish or Nigger	LUDERI
Mackerel, Blue or Slimy	Mackerel, Slimy or Common	MACBLU
Mackerel, Jack or Horse	Cowanyoung or Horse Mackerel	MACJAC
Mackerel, Spanish	Mackerel, Narrow-barred Spanish	MACSPA
Mackerel, Spotted		MACSPO
Morwong, Red		MORRED
Morwong, Rubberlip	Morwong, Grey	MORRUB
Mullet, Fantail or Flattail	Mullet, Flattail or Jumping	MULLFA
Mullet, Pink-eye		MULLPI
Mullet, Red	Goatfish, Blue-spot	MULLRE
Mullet, Sand		MULLSA
Mullet, Sea	Mullet, Bully or Hardgut	MULLSE
Mulloway	Jewfish	MULLOW
Nanata	Postlarval Fish	NANATA
Old Maid	Butterfish, Striped	OLDMAI
Parrotfish	Wrasse, Blue Throat & Purple	PARROT
Perch, Pearl		PERCHP
Pike	Seapike, Long-finned	PIKE
Pilchard	Sardine, Herring & Sprat	PILCHA
Salmon, Australian	Salmon, Eastern Australian	SALMON
Samson Fish		SAMSON

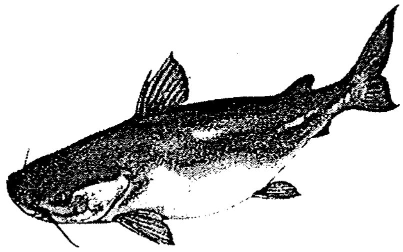
Complete List of Species Codes

Short Name	Alternate Names	Code
Shark, Angel	Ray, Angel	SHARAN
Shark, Black Tip		SHARBL
Shark, Bull		SHARBU
Shark, Carpet or Wobbegong	Shark, Wobbegong	SHARCA
Shark, Dogfish Endeavour	Shark, Dogfish Toughskin	SHARDE
Shark, Dogfish Greeneye		SHARDG
Shark, Fiddler	Ray, Fiddler or Banjo	SHARFI
Shark, Gummy		SHARGU
Shark, Hammerhead		SHARHA
Shark, School or Snapper	Shark, Snapper	SHARSC
Shark, Shovelnose	Ray, Shovelnose	SHARSH
Snapper	Cockney or Red Bream, Squire	SNAPPE
Snook	Seapike, Short-finned	SNOOK
Sole, Black		SOLEBL
Sole, Lemon		SOLELE
Stargazer		STARGA
Stingray	Ray or Ray Flaps	STINGR
Surgeonfish		SURGEO
Sweep		SWEEP
Tailor		TAILOR
Tarwhine		TARWHI
Teraglin	Trag	TERAGL
Trevally, Black	Happy Moments, Rabbitfish or Spinefoot	TREVAB
Trevally, Silver	Trevally, White	TREVAS
Trumpeter	Grunter, Eight-lined	TRUMPE
Trumpeter, Tasmanian	Trumpeter, Striped	TRUMPT
Tuna, Mackerel	Tuna, Eastern Little	TUNAMA
Tuna, Northern Bluefin	Tuna, Long-tailed	TUNANO
Tuna, Skipjack	Tuna, Striped or Stripey	TUNASK
Whitebait	Postlarval Fish	WHITEB
Whiting, Grass	Whiting, Rock	WHITGR
Whiting, Sand		WHITSA
Whiting, School or Red Spot	Whiting, Red Spot or Trawl	WHITSC
Whiting, Trumpeter		WHITTR
Wirrah	Wirrah, Eastern	WIRRAH
Yellowtail	Scad, Yellowtail	YELLOW
Molluscs:		
Calamari, Southern		CALAMA
Cockle		COCKLE
Cuttlefish		CUTTLE
Mussel, Blue	Mussel, Edible Blue	MUSSEL
Octopus		OCOTOP
Pipi		PIPI
Scallop	Scallop, Commercial	SCALLO
Shells		SHELLS
Squid		SQUID
Crustaceans:		
Crab, Blue Swimmer		CRABBS
Crab, Coral		CRABCO
Crab, Hermit		CRABHE
Crab, Mud or Black	Crab, Black	CRABMU
Crab, Redspot	Crab, Red-Spot	CRABRE
Krill	Very Small Crustaceans	KRILL
Lobster, Eastern Rock	Crayfish, Eastern	LOBSTE
Nipper	Yabby or Ghost Shrimp	NIPPER
Prawn, Eastern King		PRAWNK
Prawn, Greasyback		PRAWNG
Prawn, School		PRAWNS
Prawn, Tiger	Prawn, Black Tiger or Leader Tiger	PRAWNT
Shrimp, Mantis	Prawn Killer	SHRIMP
Other Shellfish:		
Beachworms	Worms	BWORMS

CATFISHES

CATFIF FORK-TAIL CATFISH

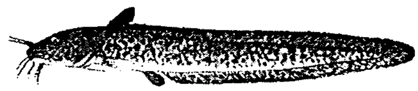
Max: 70cm
Nth NSW



- Inhabits estuaries and rivers and ascends above tidal limit into freshwater streams
- Purple-blue above with greenish reflections
- Fins have distinctly pinkish sheen
- Dorsal spine is shorter and weaker than pectoral spines

CATFIE ESTUARY CATFISH

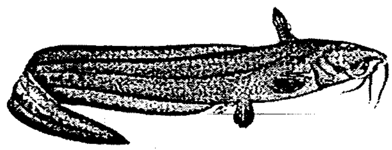
Max. 91cm
NSW



- Colour varies from blackish grey with pale mottling to black
- Small tentacle at rear of upper lip present

CATFIL EEL-TAIL or LONG-TAIL CATFISH

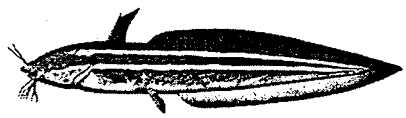
Max: 40cm
NSW



- Body uniformly greyish-brown or coppery brown, sometimes mottled on tail
- Dorsal and anal fins with slightly darker borders
- Eel-like tail

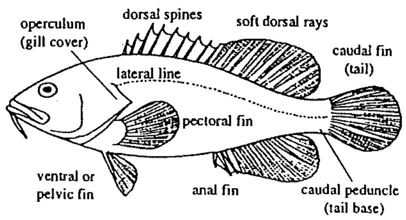
CATFIS STRIPED CATFISH

Max: 32cm
NSW



- Body black with creamy-white stripes running from head to tail
- Small juveniles form balls of closely packed individuals

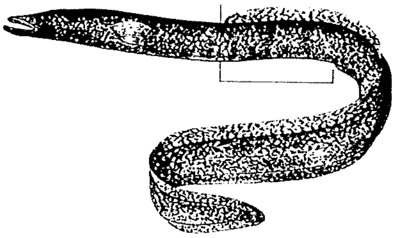
DIAGRAM OF FISH CHARACTERISTICS



EELS

EELLFR LONG-FINNED RIVER EEL

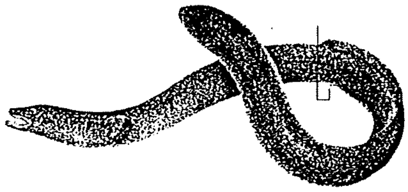
Max: 1.6m
NSW



- Dorsal fin begins well in front of anal fin
- Colour is olive-green to brownish becoming lighter ventrally, doral areas with darker blotches and mottling
- Pectoral fins yellowish, remaining fins dark brown

EELSFR SHORT-FINNED RIVER EEL

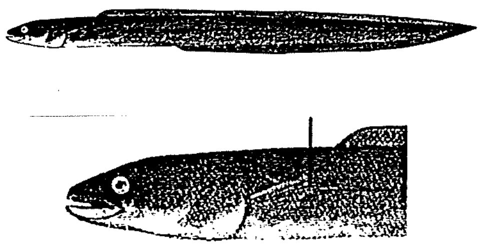
Max: 1.2m
NSW



- Dorsal fin begins slightly in front of anal fin
- Colour is olive green to olive brown with greyish white ventrally; lacks blotches and mottling

EELSFC SHORT-FINNED CONGER EEL

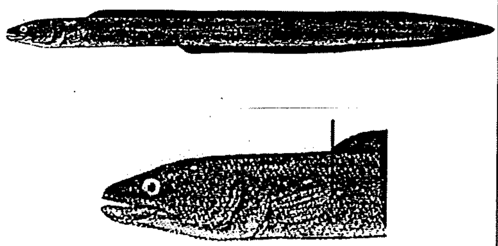
Max: 97cm
NSW



- Similar inappearance to Southern Conger Eel
- Dorsal fin begins behind tip of pectoral fin
- Colour varies from bluish grey to brownish grey

EELSTH SOUTHERN CONGER EEL

Max: 2m
Sth NSW



- Similar in appearance to Short-finned Conger Eel
- Dorsal fin begins over the pectoral fin
- Colour varies from bluish grey to blackish grey

EELPIK PIKE EEL

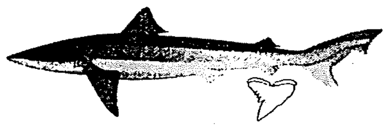
Max: 1.8m
NSW

- Similar in appearance to the Conger eels, but has longer jaws and large teeth
- Colour of back varies from silvery grey to brown
- Aggressive behaviour when captured

SHARKS AND RAYS

SHARSC SCHOOL SHARK

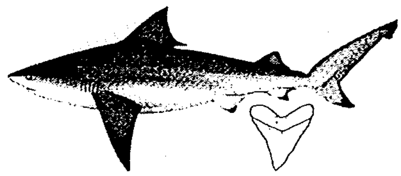
Max: 2m
NSW



- Teeth triangular having serrations on outer edge
- Upper lobe on caudal fin wide, giving 'double-tailed' appearance
- Head & body slate grey to bronze above, white below, no white spots

SHARBU BULL SHARK

Max: 4m
NSW

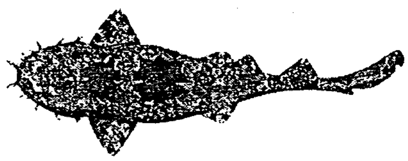


- Also known as Estuary or River Whaler or Black tip

Differs from the school shark by:
a) upper lobe of caudal fin not as wide
b) teeth with many fine serrations, these usually present on all tooth edges
c) dorsal fin tends to be higher

SHARCA WOBBEGONG SHARK

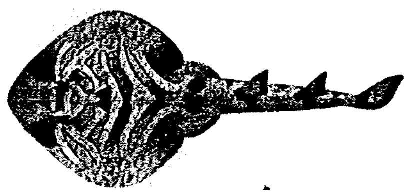
Max: 3m
NSW



- Also known as Carpet Shark
- No spines preceding dorsal fins
- Head & body brownish above with mottled patterns
- Numerous skin flaps around mouth

SHARFI FIDDLER RAY

Max: 1.2m
NSW

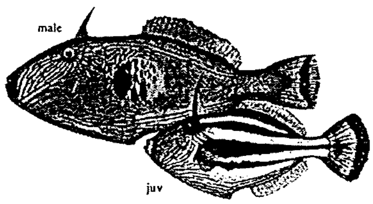


- Also known as Fiddler Shark or Banjo Shark or Shovelnosed Shark
- Lilac bands margined with dark brown over a light brown body

LEATHERJACKETS

LEATHS SIX-SPINED LEATHERJACKET

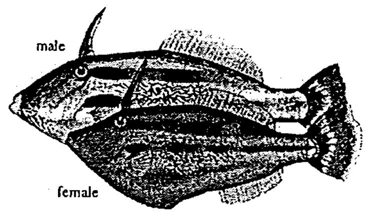
Max: 55cm
NSW



- 5 to 8 spines (usually six) on the caudal peduncle
- Smooth to velvety skin
- Maori-like pattern of bright blue to brown pattern on the head, extending onto the body
- Male: caudal peduncle spines large; distinctive yellow & blackish brown blotch (or blotches) on side
- Female & juvenile: smaller caudal peduncle spines; several dark stripes along the side; no yellowish/blackish blotch on side

LEATHY YELLOW-FINNED LEATHERJACKET

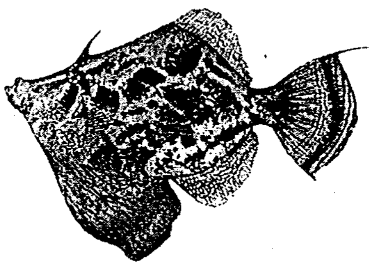
Max: 35cm
NSW



- 4 spines on caudal peduncle
- Very rough skin
- Maori-like patterning does not extend to lower body

LEATHF FAN-BELLIED LEATHERJACKET

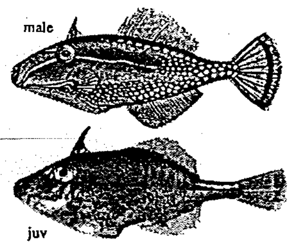
Max: 40cm
NSW



- Large fan-like flap on abdomen
- Large fish have a trailing filament on caudal fin
- 6 spines on caudal peduncle
- Colour ranges from green to yellowish/brown

LEATHB BRIDLED LEATHERJACKET

Max. 15cm
Sth NSW



- No spines on caudal peduncle
- Male: thin blue line from mouth to half way down body, black line in front of eye, yellowish stripe and blue spots on under side; caudal peduncle with vertical black line
- Female and juvenile: dark line in front of eye usually present, orange-brown poorly defined spots on sides

Appendix IV. Logbook newsletter

B.C. Pease, T.R. Walford

Newsletter and sample CPUE summary distributed for quarter ending November 1996.

(Fisher name with-held; note black and white copies of original colour graphs)

ESTUARINE LOGBOOK NEWSLETTER

Fisheries Research Institute
PO Box 21, Cronulla, 2230
Phone: (02) 527-8411 Fax: (02) 527-8576

No. 4
Sept-Nov 1996

Hello Everyone,

Congratulations! The logbook programme has now been operating for over one year. As promised in our previous newsletter, we are able to provide some graphs summarising catch per unit of effort over the past year and a summary table of your annual fishing activity, along with the usual summary tables for this (Spring 1996) quarter.

In order to minimise the volume of information for your review, we are only providing annual summary graphs for estuaries where you fished most often and for methods which you used most frequently. The quarterly periods in the annual summaries are as follows: 96Q1 = 1 December 1995 - 29 February 1996; 96Q2 = 1 March 1996 - 31 May 1996; 96Q3 = 1 June 1996 - 31 August 1996; 96Q4 = 1 September 1996 - 30 November 1996. Also please note that annual summaries only include your hauling and meshing activity.

We hope you find this information useful for providing an increased understanding of your personal fishing activity and helps to put your catch and effort into perspective with that of the other fishers in your area. Please check to make sure our summaries correspond with your records. If you find any errors please contact us as soon as possible so that we can correct the information in our database.

We are planning to get out fishing with some of you again during this next year to continue our observations of your fishing techniques.

Thanks for your co-operation and please keep up the good work.

Bruce Pease & Trudy Walford
26 February 1997

In this newsletter

1. Catch per unit of effort of main fish species by gear type for your area for the spring quarter.
2. Catch per unit of effort of main fish species (including eels and shellfish if applicable) by gear type for your individual fishing activity for the spring quarter.
3. Graphs of catch per unit of effort of main fish species by main gear types for your area during the year 1996.
4. Graphs of catch per unit of effort of main fish species by main gear type and estuary for your individual fishing activity during the year 1996.
5. Table summarising the number of log sheets for hauling and meshing activity that we have received during the year 1996.

Catch per Unit of Effort (CPUE) of Finfish for the Spring period - 1/9/96 to 30/11/96
Wallis Lake

Fishing Method: Fish Hauling Net (general) — Mesh Size (mm): — Number of Samples: 12

	Bream	Dusky Flathead	Luderick	Sea Mullet	Sand Whiting
Average CPUE (kg/hr)	17.64	0.03	8.19	4.18	5.97
Min - Max CPUE (kg/hr)	3.80 - 46.83	0.00 - 0.50	0.00 - 30.33	0.00 - 18.17	0.00 - 17.50

Fishing Method: Mesh Net, Bottom Set — Mesh Size (mm): 80 — Number of Samples: 5

	Bream	Dusky Flathead	Luderick	Sea Mullet	Sand Whiting
Average CPUE (kg/hr)	1.33	0.00	0.00	5.93	3.73
Min - Max CPUE (kg/hr)	0.67 - 1.67	0.00 - 0.00	0.00 - 0.00	0.00 - 11.00	0.00 - 10.67

Fishing Method: Mesh Net, Bottom Set — Mesh Size (mm): 100 — Number of Samples: 9

	Bream	Dusky Flathead	Luderick	Sea Mullet	Sand Whiting
Average CPUE (kg/hr)	5.56	0.00	3.70	0.00	0.00
Min - Max CPUE (kg/hr)	2.67 - 9.33	0.00 - 0.00	0.00 - 10.00	0.00 - 0.00	0.00 - 0.00

Fishing Method: Mesh Net, Flathead — Mesh Size (mm): 70 — Number of Samples: 7

	Bream	Dusky Flathead	Luderick	Sea Mullet	Sand Whiting
Average CPUE (kg/hr)	0.01	1.45	0.00	0.00	0.05
Min - Max CPUE (kg/hr)	0.00 - 0.08	0.50 - 2.92	0.00 - 0.00	0.00 - 0.00	0.00 - 0.17

Fishing Method: Mesh Net, Splashing — Mesh Size (mm): 80 — Number of Samples: 4

	Bream	Dusky Flathead	Luderick	Sea Mullet	Sand Whiting
Average CPUE (kg/hr)	0.63	0.31	0.88	37.75	0.00
Min - Max CPUE (kg/hr)	0.25 - 1.25	0.00 - 1.00	0.00 - 1.50	9.00 - 76.75	0.00 - 0.00

Catch per Unit of Effort (CPUE) of Finfish for the Spring period - 1/9/96 to 30/11/96

Name: Bloggs

Hawkesbury River

Fishing Method: Mesh Net, Bottom Set | Mesh Size (mm): 80 | Number of Samples: 1

	Bream	Dusky Flathead	Luderick	Sea Mullet	Sand Whiting
Average CPUE (kg/hr)	4.33	2.00	2.67	5.00	4.33
Min - Max CPUE (kg/hr)	4.33 - 4.33	2.00 - 2.00	2.67 - 2.67	5.00 - 5.00	4.33 - 4.33

Manning River

Fishing Method: Fish Hauling Net (general) | Mesh Size (mm): | Number of Samples: 1

	Bream	Dusky Flathead	Luderick	Sea Mullet	Sand Whiting
Average CPUE (kg/hr)	2.00	0.00	4.17	11.67	0.67
Min - Max CPUE (kg/hr)	2.00 - 2.00	0.00 - 0.00	4.17 - 4.17	11.67 - 11.67	0.67 - 0.67

Myall Lakes

Fishing Method: Fish Hauling Net (general) | Mesh Size (mm): | Number of Samples: 8

	Bream	Dusky Flathead	Luderick	Sea Mullet	Sand Whiting
Average CPUE (kg/hr)	6.35	0.00	12.40	15.38	0.00
Min - Max CPUE (kg/hr)	0.83 - 13.33	0.00 - 0.00	0.00 - 56.50	0.00 - 76.67	0.00 - 0.00

Fishing Method: Mesh Net, Bottom Set | Mesh Size (mm): 100 | Number of Samples: 4

	Bream	Dusky Flathead	Luderick	Sea Mullet	Sand Whiting
Average CPUE (kg/hr)	2.25	0.17	3.58	0.33	0.00
Min - Max CPUE (kg/hr)	1.00 - 3.33	0.00 - 0.67	0.00 - 8.33	0.00 - 0.67	0.00 - 0.00

Catch per Unit of Effort (CPUE) of Finfish for the Spring period - 1/9/96 to 30/11/96

Tuggerah Lakes

Fishing Method: Mesh Net, Bottom Set | Mesh Size (mm): 80 | Number of Samples: 1

	Bream	Dusky Flathead	Luderick	Sea Mullet	Sand Whiting
Average CPUE (kg/hr)	4.67	1.67	2.33	4.33	8.67
Min - Max CPUE (kg/hr)	4.67 - 4.67	1.67 - 1.67	2.33 - 2.33	4.33 - 4.33	8.67 - 8.67

Wallis Lake

Fishing Method: Mesh Net, Bottom Set | Mesh Size (mm): 80 | Number of Samples: 5

	Bream	Dusky Flathead	Luderick	Sea Mullet	Sand Whiting
Average CPUE (kg/hr)	1.33	0.00	0.00	5.93	3.73
Min - Max CPUE (kg/hr)	0.67 - 1.67	0.00 - 0.00	0.00 - 0.00	0.00 - 11.00	0.00 - 10.67

Fishing Method: Mesh Net, Bottom Set | Mesh Size (mm): 100 | Number of Samples: 9

	Bream	Dusky Flathead	Luderick	Sea Mullet	Sand Whiting
Average CPUE (kg/hr)	5.56	0.00	3.70	0.00	0.00
Min - Max CPUE (kg/hr)	2.67 - 9.33	0.00 - 0.00	0.00 - 10.00	0.00 - 0.00	0.00 - 0.00

Fishing Method: Mesh Net, Flathead | Mesh Size (mm): 70 | Number of Samples: 4

	Bream	Dusky Flathead	Luderick	Sea Mullet	Sand Whiting
Average CPUE (kg/hr)	0.00	1.08	0.00	0.00	0.00
Min - Max CPUE (kg/hr)	0.00 - 0.00	0.50 - 1.67	0.00 - 0.00	0.00 - 0.00	0.00 - 0.00

Catch per Unit of Effort (CPUE) of Shellfish and Eels for the Spring period - 1/9/96 to 30/11/96

Name: Bloggs

Smiths Lake

Fishing Method: Crab Trap

Number of Samples: 1

	School Prawn	Greasyback Prawn	King Prawn	Blue Swimmer Crab (per 10 traps)	Mud Crab (per 10 traps)	Shortfinned River Eels (per 10 traps)
Average CPUE (kg/hr)	0.00	0.00	0.00	0.00	0.31	0.00
Min - Max CPUE (kg/hr)	0.00 - 0.00	0.00 - 0.00	0.00 - 0.00	0.00 - 0.00	0.31 - 0.31	0.00 - 0.00

Fishing Method: Prawn Seine Net (snigger)

Number of Samples: 3

	School Prawn	Greasyback Prawn	King Prawn	Blue Swimmer Crab (per 10 traps)	Mud Crab (per 10 traps)	Shortfinned River Eels (per 10 traps)
Average CPUE (kg/hr)	0.00	6.56	0.00	0.00	0.00	0.00
Min - Max CPUE (kg/hr)	0.00 - 0.00	3.17 - 8.40	0.00 - 0.00	0.00 - 0.00	0.00 - 0.00	0.00 - 0.00

Fishing Method: Prawn Set Pocket Net

Number of Samples: 1

	School Prawn	Greasyback Prawn	King Prawn	Blue Swimmer Crab (per 10 traps)	Mud Crab (per 10 traps)	Shortfinned River Eels (per 10 traps)
Average CPUE (kg/hr)	0.00	0.00	12.40	0.00	0.00	0.00
Min - Max CPUE (kg/hr)	0.00 - 0.00	0.00 - 0.00	12.40 - 12.40	0.00 - 0.00	0.00 - 0.00	0.00 - 0.00

Catch per Unit of Effort (CPUE) of Shellfish and Eels for the Spring period - 1/9/96 to 30/11/96

Wallis Lake

Fishing Method: Crab Trap — **Number of Samples:** 3

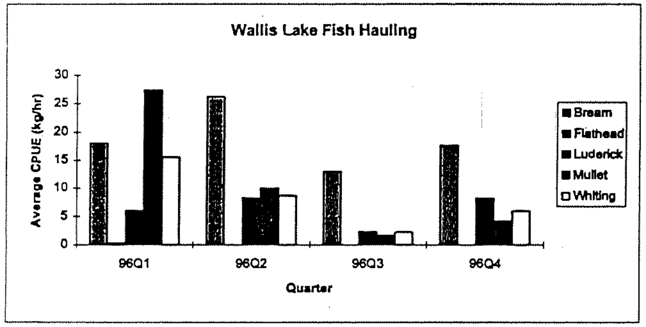
	School Prawn	Greasyback Prawn	King Prawn	Blue Swimmer Crab (per 10 traps)	Mud Crab (per 10 traps)	Shortfinned River Eels (per 10 traps)
Average CPUE (kg/hr)	0.00	0.00	0.00	0.16	0.08	0.00
Min - Max CPUE (kg/hr)	0.00 - 0.00	0.00 - 0.00	0.00 - 0.00	0.11 - 0.19	0.05 - 0.11	0.00 - 0.00

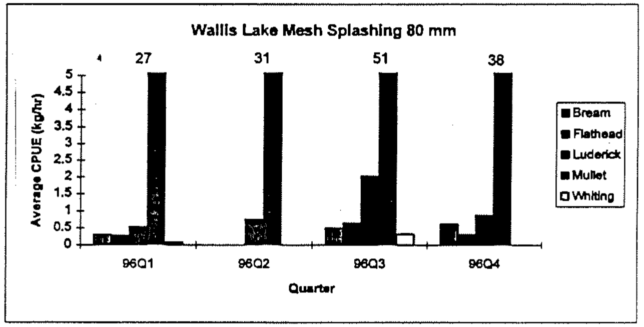
Fishing Method: Prawn Seine Net (snigger) — **Number of Samples:** 2

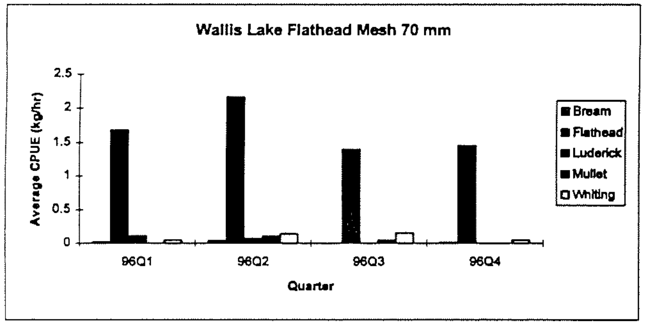
	School Prawn	Greasyback Prawn	King Prawn	Blue Swimmer Crab (per 10 traps)	Mud Crab (per 10 traps)	Shortfinned River Eels (per 10 traps)
Average CPUE (kg/hr)	0.00	4.90	0.00	0.00	0.00	0.00
Min - Max CPUE (kg/hr)	0.00 - 0.00	4.40 - 5.40	0.00 - 0.00	0.00 - 0.00	0.00 - 0.00	0.00 - 0.00

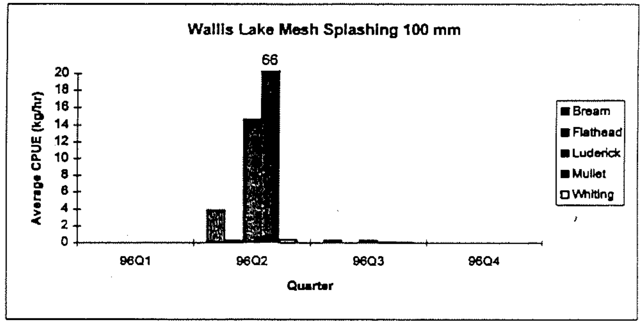
Fishing Method: Prawn Set Pocket Net — **Number of Samples:** 5

	School Prawn	Greasyback Prawn	King Prawn	Blue Swimmer Crab (per 10 traps)	Mud Crab (per 10 traps)	Shortfinned River Eels (per 10 traps)
Average CPUE (kg/hr)	6.53	0.00	0.00	0.00	0.00	0.00
Min - Max CPUE (kg/hr)	1.67 - 14.33	0.00 - 0.00	0.00 - 0.00	0.00 - 0.00	0.00 - 0.00	0.00 - 0.00

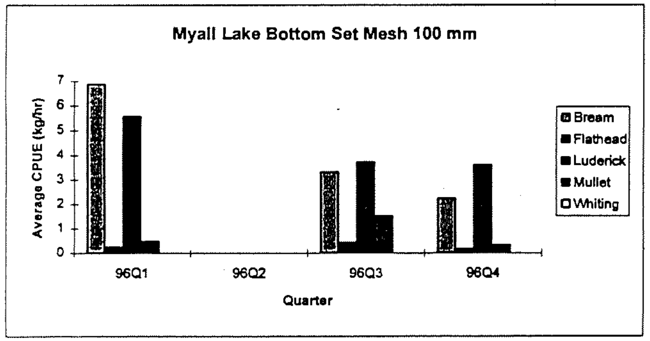

Wallis Lake Fish Hauling
Average CPUE (kg/hr)
30
25
20
15
10
5
0
96Q1
96Q2
96Q3
96Q4
Quarter
Bream
Flathead
Luderick
Mullet
Whiting

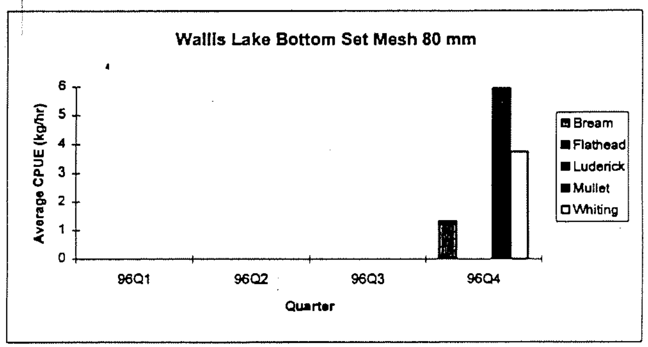

Wallis Lake Mesh Splashing 80 mm
27
31
51
38
Average CPUE (kg/hr)
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
96Q1
96Q2
96Q3
96Q4
Quarter
Bream
Flathead
Luderick
Mullet
Whiting

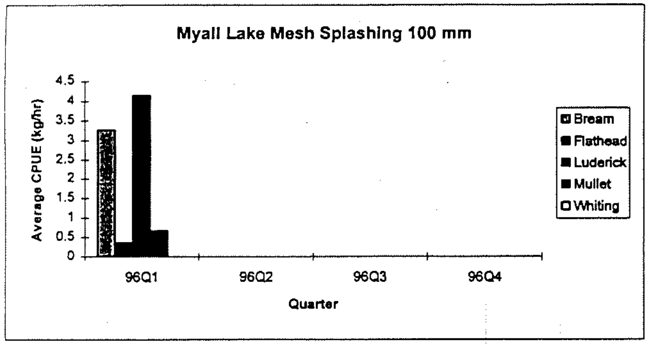

Wallis Lake Flathead Mesh 70 mm
Average CPUE (kg/hr)
2.5
2
1.5
1
0.5
0
96Q1
96Q2
96Q3
96Q4
Quarter
Bream
Flathead
Luderick
Mullet
Whiting

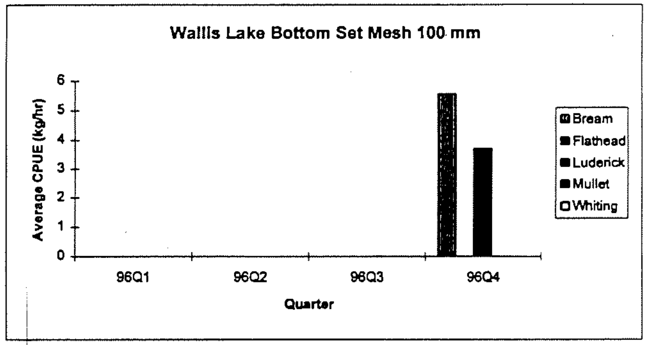

Wallis Lake Mesh Splashing 100 mm
66
Average CPUE (kg/hr)
20
18
16
14
12
10
8
6
4
2
0
96Q1
96Q2
96Q3
96Q4
Quarter
Bream
Flathead
Luderick
Mullet
Whiting

Bloggs


Myall Lake Bottom Set Mesh 100 mm
Average CPUE (kg/hr)
0
1
2
3
4
5
6
7
96Q1
96Q2
96Q3
96Q4
Quarter
Bream
Flathead
Luderick
Mullet
Whiting


Wallis Lake Bottom Set Mesh 80 mm
Average CPUE (kg/hr)
0
1
2
3
4
5
6
96Q1
96Q2
96Q3
96Q4
Quarter
Bream
Flathead
Luderick
Mullet
Whiting


Myall Lake Mesh Splashing 100 mm
Average CPUE (kg/hr)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
96Q1
96Q2
96Q3
96Q4
Quarter
Bream
Flathead
Luderick
Mullet
Whiting


Wallis Lake Bottom Set Mesh 100 mm
Average CPUE (kg/hr)
0
1
2
3
4
5
6
96Q1
96Q2
96Q3
96Q4
Quarter
Bream
Flathead
Luderick
Mullet
Whiting

Summary of Fishing Activity for the Year 1996

Name	Estuary	Nets:	Mesh	No. of daily logs received				Grand Total
				96Q1	96Q2	96Q3	96Q4	
Bloggs	Hawkesbury River	Mesh Net, Bottom Set	80	0	0	0	1	1
	Manning River	Fish Hauling Net (general)		0	0	0	1	1
	Myall Lakes	Fish Hauling Net (general)		0	0	2	8	10
		Mesh Net, Bottom Set	80	0	0	2	0	2
			100	7	0	23	4	34
		Mesh Net, Splashing	80	3	0	0	0	3
			100	13	0	0	0	13
		Mesh Net, Top Set	100	1	0	2	0	3
	Tuggerah Lakes	Mesh Net, Bottom Set	80	0	0	0	1	1
	Wallis Lake	Mesh Net, Bottom Set	80	0	0	0	5	5
			100	0	0	0	9	9
		Mesh Net, Flathead	70	5	37	18	4	64

Appendix V. Sample size determination for estimating the age compositions of commercial catches of estuarine fish species

G.N.G. Gordon, C.A. Gray, G.W. Liggins

A1. Introduction

The determination of appropriate sample size (for the intended use of the data) is an important aspect of any fisheries-related study. Knowledge of the size and age compositions of fish stocks is valuable for stock assessments and provides the basis for age structured stock assessment models, which have been used in managing many fisheries resources throughout the world. Few studies, however, have considered the determination of appropriate sample sizes for estimating the size and age distributions of populations, even though several analytical techniques are available (see Smith and Sedransk 1982, Baird 1983, Chen 1996, Andrew and Chen 1997).

The objective of this study was to assess the likely effects of different sample sizes (numbers of aged fish) on estimating the precision of age composition estimates of commercial landings of 3 species of estuarine fish; bream (*Acanthopagrus australis*), sand whiting (*Sillago ciliata*) and dusky flathead (*Platycephalus fuscus*). We limited our analyses to consideration of age. We did not consider length because length is not a good indicator of age in these species and future assessment methodologies for these stocks will need to be age-based (see Chapters 4-7). We assumed simple random sampling of fish to be aged using age data from previous samples collected across several estuaries as indicative of the actual age structures of populations.

A2. Methods

The data used in our analyses came from the age data from commercial landings described in Chapters 4 -7. We compared the likely effects of various sample sizes on the precision of age composition estimates of each species from several estuaries for data collected in 1997. We limited our analyses to data from just one year because age compositions were similar across years. The sampling of fish was assumed to be a simple random sampling process, which implied that the proportions of fish sampled in the various age classes followed a multinomial distribution. A number of criteria for precision were considered based on the theory of multinomial distributions. The logic and assumptions of these analyses are as follows.

Suppose that a simple random sample of size n is drawn from a population, and that each element of the sample can be categorised as belonging to one of c mutually exclusive categories, $A_1, A_2, \ldots A_c$. Let the probability that the i th element belongs to the category A_i be $p_i = \Pr(A_i)$. Then $p_1 + p_2 + \ldots + p_c = 1$. Then the numbers $(X_1, X_2, \ldots, X_c)$ in the various categories has a multinomial distribution, where

$$\Pr(X_1 = k_1, X_2 = k_2, \ldots, X_c = k_c) = \frac{n!}{k_1!k_2!\ldots k_c!} p_1^{k_1} p_2^{k_2} \ldots p_c^{k_c},$$

where $k_1 + k_2 + \ldots + k_c = n$.

The expectation, variances and covariances are

$$E(X_i) = np_i\ ,\ Var(X_i) = np_i(1-p_i)\ ,\ Cov(X_i, X_j) = -np_ip_j\ ,\ i \neq j\ ,$$

for i,j, = 1, ... c.

If fish can be considered to be sampled independently from a well defined population, then the numbers of fish from a simple random sample of size n which are in the c age categories will be jointly distributed according to a multinomial distribution, as above. If we further suppose that the p_i are known, (as, for instance from a very large sampling experiment), then confidence intervals for the individual X_i can be constructed, as for a binomial distribution, in the usual way, since for each X_i, the remaining categories can be combined to form a single category. Note that the covariances are all negative, because of the constraint that the probabilities should sum to 1 ; there are in fact only c - 1 independently assignable probabilities p_i.

The problem of simultaneous confidence intervals is discussed in Miller (1966, 1980). Two basic methods are given. The first uses a quadratic form in the observed proportions to generate a confidence ellipsoid in c dimensions centred on the vector **p** of the population proportions, the vector of the probabilities p_i. The size of the ellipsoid is determined by the appropriate percentage point of a chi-squared distribution with c-1 degrees of freedom for the desired degree of confidence. This ellipsoid is then projected onto the individual coordinate axes to give simultaneous confidence intervals for the p_i centred on the observed proportions $\hat{p}_i$.

$$p_j \in \hat{p}_j \pm (\chi^{2,\alpha}_{c-1})^{\frac{1}{2}} \left[\frac{\hat{p}_j(1-\hat{p}_j)}{n} \right]^{\frac{1}{2}} \qquad j=1, \ldots c.$$

This projection method was originally due to Scheffé, and the approach developed by Gold (1963) and Quesenberry and Hurst (1964).

An alternative approach is to use Bonferroni intervals, which were introduced by Goodman (1965). These are given (in the notation of Miller) by

$$p_j \in \hat{p}_j \pm g^{\alpha/2c} \left[\frac{\hat{p}_j(1-\hat{p}_j)}{n} \right]^{\frac{1}{2}} \qquad j = 1, \ldots c.$$

for a 100(1-α) confidence interval, where g^p is the quantile of order 1-p of a standard normal distribution, (i. e with tail probability p),

$$1-p=\frac{1}{\sqrt{2\pi}}\int_{-\infty}^{g^p} e^{-y^2/2}\,dy.$$

Goodman (1965) found that for the usual values of c and α, the Bonferroni intervals are shorter than those obtained using the Scheffé projection method . Calculation of intervals of both types for typical age class distributions for several estuarine species has confirmed this finding in the current context.

By calculating the widths of the above intervals (or, more conveniently, their semi-intervals) for putative values of $\hat{p}_j$ chosen on the basis of past samples, for various combinations of n, c and α, one can decide on acceptable sample sizes for future sampling, and possibly also on the desirability or otherwise of combining categories to reduce c. If a researcher is chiefly interested in the proportion of fish above a certain age, which might correspond to the onset of sexual maturity, for instance, the number of class intervals can be reduced by combining age classes, thus allowing smaller Bonferroni confidence intervals. As usual, the more detail one wants to know with some degree of certainty, the greater the penalty which must be paid in terms of sample size.

Goodman (1965) also discusses confidence intervals of another type, due to Quesenberry and Hurst (1964) and also gives an improved Bonferroni version of them as well. These Bonferroni intervals, as also discussed in Miller (1966, 1980), are

$$p_j \in \frac{\chi_1^{2\alpha/c}+2n_j \pm \sqrt{\chi_1^{2\alpha/c}[\chi_1^{2\alpha/c}+4n_j(n-n_j)/n]}}{2(n+\chi_1^{2\alpha/c})} \quad \text{for } j=1, \ldots, c.$$

where n_j is the frequency observed in the j category, and n is the sum of the n_j for all categories. These intervals are asymptotically equivalent to the simpler Bonferroni intervals given previously. The previous simpler intervals are obtained by substituting the observed proportions $\hat{p}_j$ for the underlying probabilities p_j in the more complex version. As we are assuming for our sample size determinations that the data are proxies for the underlying population proportions, that is, we are assuming that the observed proportions are the underlying frequencies, we have calculated the simpler intervals given previously. When calculating confidence intervals for any particular data set, as when presenting data rather than looking at hypothetical situations, as we are here, however, the intervals just given in terms of actual frequencies might be preferable. In most situations, the difference between confidence intervals of the two types would be very small.

A3. Results

Figures 1-3 show the underlying age distributions used in each analysis and the relationships between sample size and precision. The results for the semi-interval width of confidence intervals for individual cells as a percentage of the assumed p value are shown graphically for sample sizes ranging from 50 to 800 ages. In all analyses, the greater the sample size the smaller the confidence intervals, but note however, that by doubling the sample size (e.g. from 200 to 400) an approximate increase in precision of only about 40% is achieved. Further, the semi-interval widths for any given sample size are much smaller for the most abundant cells (age classes). A far greater sample size is required to achieve the same level of precision in the least abundant age classes as in the most abundant age classes. The semi-interval width of confidence intervals as a percentage of the assumed p value is dependent not only on sample size but on relative age class abundance and p.

For each species, the semi-interval widths for any given sample size varied slightly between estuaries, due to the differing underlying age distributions. For example, the semi-interval widths of confidence intervals as a percentage of the assumed p value for the 3 most abundant age classes based on 200 ages for dusky flathead varied between 15.5 - 43.8 in the Clarence River, 16.1 - 28.8 in Wallis Lake, 19.5 - 31.2 in Lake Macquarie and 13.2 - 54.6 in St. Georges Basin. Despite this variation between estuaries, the analyses showed that a sample size of 400 for bream and sand whiting and 200 for dusky flathead would generally be sufficient for estimation of each age distribution to achieve a nominal level of 20% for semi-interval width as a percentage of cell probability across the major age groups in each distribution (equivalent to the criteria suggested by Baird 1983, see below).

A4. Discussion

Firstly, it should be noted that the above approach to the sampling of fish assumes simple random sampling, in which fish are completely independently sampled. Fish sampled for age determination are sometimes sampled through a two-stage sampling process, with initial sampling by length. There may sometimes be sampling efficiencies to be gained to compensate for the additional complexity of the sampling process. This possibility is discussed in Fournier (1983), which suggests the taking of three separate and independent catch samples - (i) a random sample for which only lengths are taken, (ii) a random sample for which lengths and ages are taken; and (iii) a sample stratified by length for which ages are taken. This approach amounts to inverting the length at age key with assumed error distribution to obtain a conditional probability distribution for age given length. This method is shown to be more efficient when length information alone provides effective separation of some age classes. This is likely to be the case when there are few age

Figure A1. Age composition and the semi-interval width of confidence intervals for individual cells as a percentage of the cell probability for bream in 4 estuaries in 1997. Note the interval widths are greatest at n = 50 ages and least at n = 800 ages in all graphs.

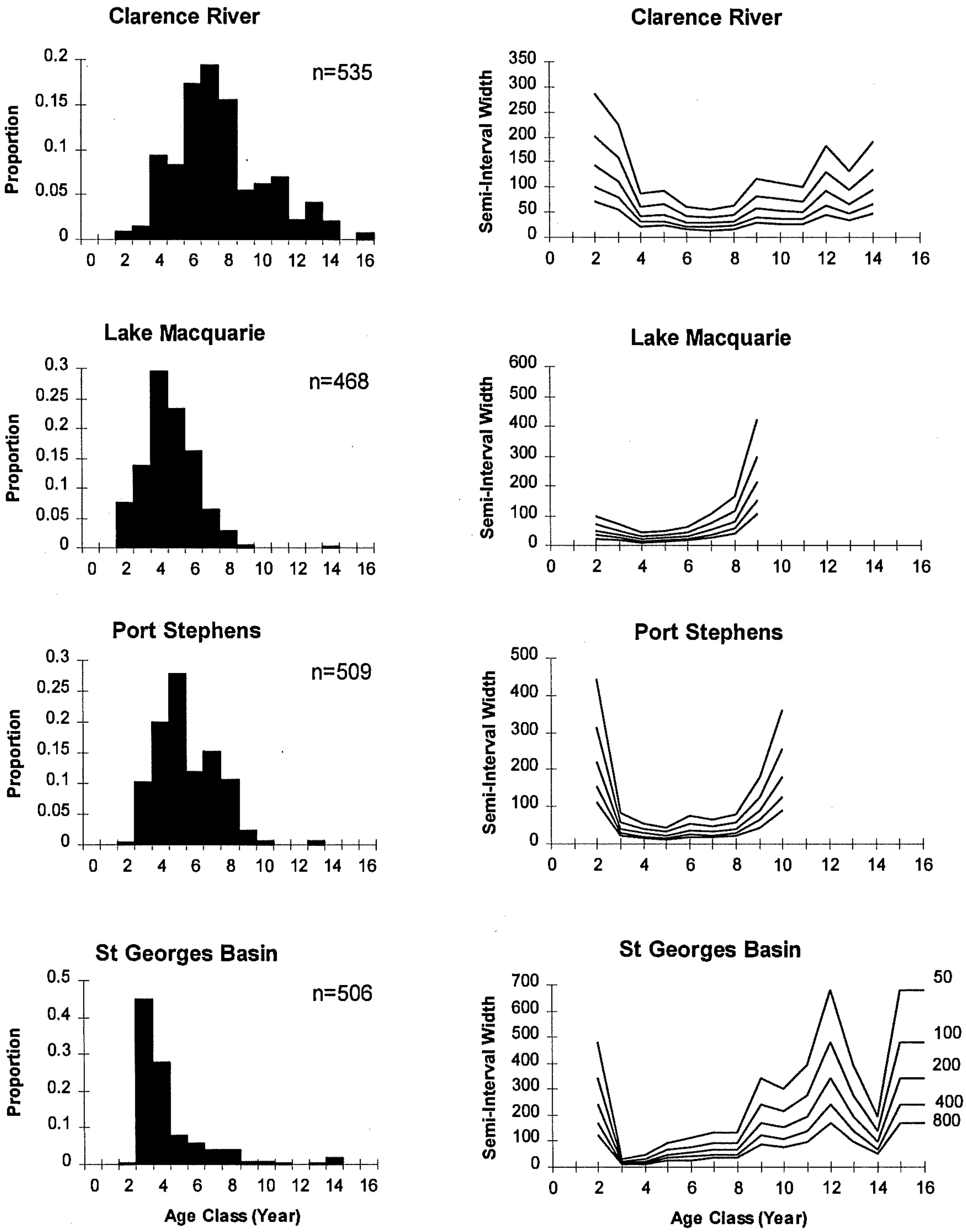


Figure A2. Age composition and the semi-interval width of confidence intervals for individual cells as a percentage of the cell probability for dusky flathead in 4 estuaries in 1997. Note the interval widths are greatest at n = 50 ages and least at n = 800 ages in all graphs.

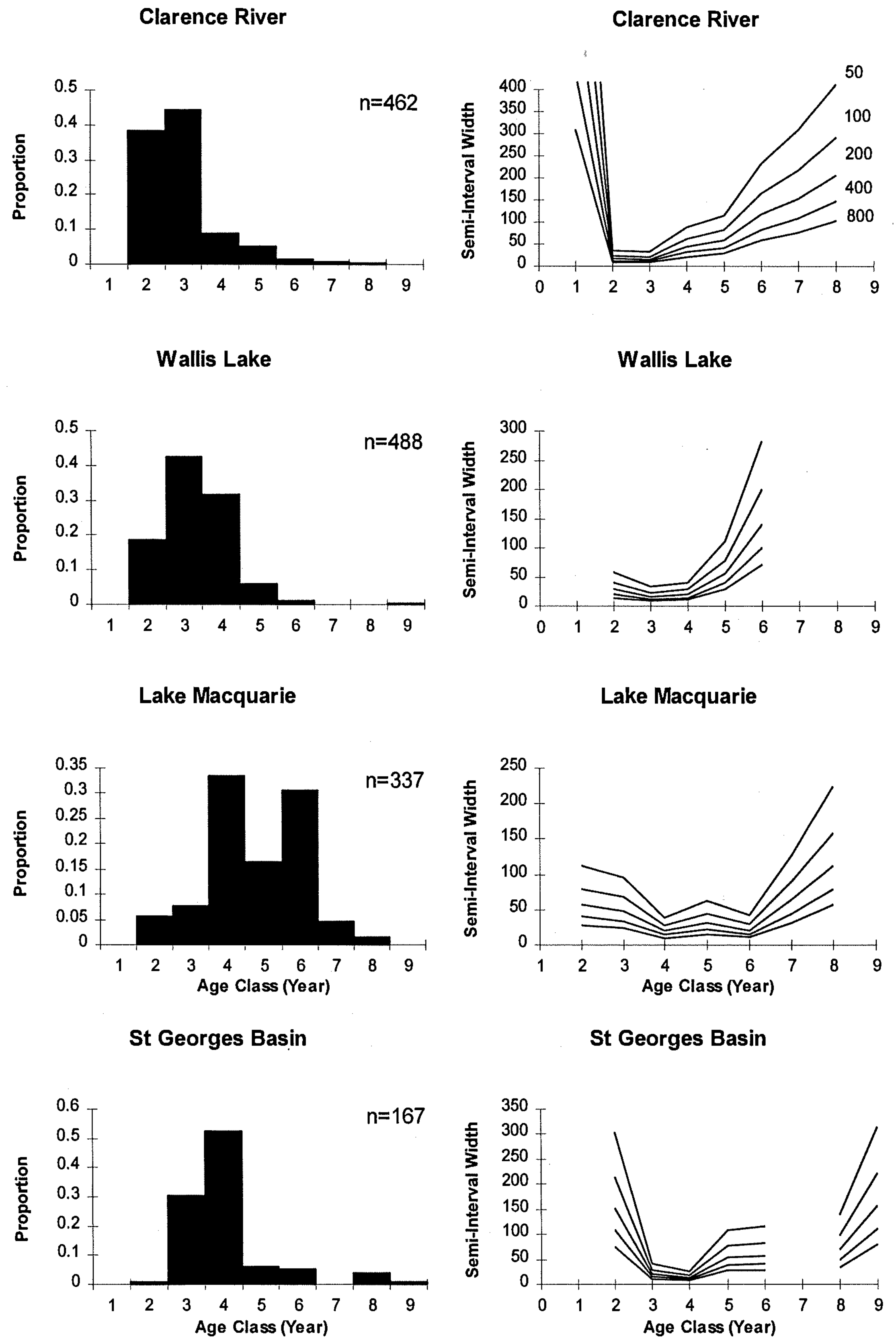
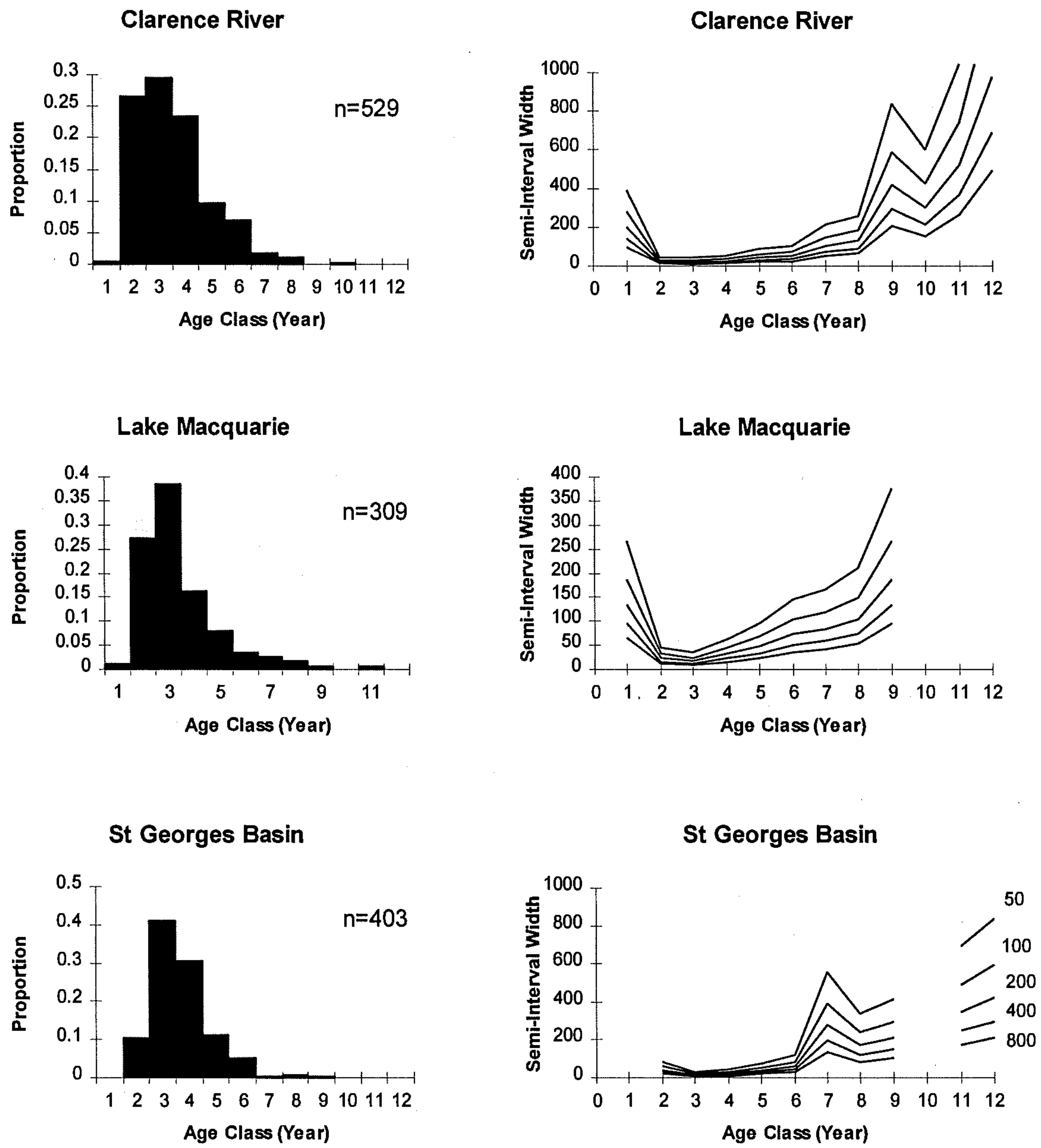


Figure A3. Age composition and the semi-interval width of confidence intervals for individual cells as a percentage of the cell probability for sand whiting in 3 estuaries in 1997. Note the interval widths are greatest at n = 50 ages and least at n = 800 ages in all graphs.



classes in the fishery and when there are consistent and obvious differences between the lengths in some age classes, especially the lower age classes in the fishery. In this case simple random sampling may choose too many young fish, for which age information is not needed to separate classes. The approach is however more complicated, conceptually requiring sample sizes to be determined for three types of sample. It also requires assumptions to be made, including assumptions about the age-length relationship and the errors around it, which would require investigation and validation. Because of the high degree of variability in the age-length relationships that have been found for bream and other estuarine species among estuaries and years (so that length information is not strongly indicative of age), and because of the relatively large number of age classes for these species, a length-stratified sampling approach is not advocated at present, though further investigation of this approach as more data become available would be appropriate.

The age sampling method discussed above depends on the strict assumptions of a simple random sampling process. In practice, the requirements of simple random sampling may not be strictly met. For instance, instead of sampling each fish with a probability of 1 in 10, say, every tenth fish might be chosen for aging as the catch is being measured. If there is no sequential dependence in the order with which fish are selected for measurement, this sampling scheme would be equivalent to a simple random sampling scheme for practical purposes. So we might say that if the sampling process used can be reasonably considered as having generated a simple random sample, then the use of the methods discussed to determine confidence intervals when something is known of the ranges of p values to be encountered should give reasonable approximate results for appropriate sample sizes.

A practical problem to be faced is the determination of the precision needed, that is, the determination of the appropriate widths of confidence intervals prior to sample size determination. In any applied context, this determination will depend on the use which is made in a model of the age structure information. Sensitivity analyses of the role the age information plays in the determination of acceptable risk, TAC, (or whatever is of interest in the model) ultimately determine the acceptable widths of confidence intervals, and hence sample sizes. (The constraint of available resources for sampling might also play a role, of course). In some modeling contexts, it could be that differences among the proportions in the various age classes is of chief interest. If this is so, the above Bonferroni approach may be extended to obtain simultaneous confidence intervals for the $\binom{c}{2}$ differences among the proportions, as is also discussed in Miller (1966, 1980) and Goodman (1965).

As a tentative rough rule of thumb for stock assessment purposes, Baird (1983) suggests that sample sizes should be such as to give coefficients of variation of less than 10% for all age classes which contribute substantially to a fishery, i. e. which together make up 70-80% of the fishery, and of around 20% or so for the age classes making up the remaining 20-30% of the fishery. (The coefficient of variation, or 'C. V.' of an estimate is the standard error of the estimate divided by its expected value). Baird (1983) also suggests that appropriate allowance be made for possible variation in the underlying population p_j. It is for this reason that several sets of data have been considered in our calculations for several estuarine species, so that robust recommendations for appropriate sample sizes can be made. The use of a criterion such as the semi-interval width as a percentage of the estimated cell probability for simultaneous confidence intervals rather than a criterion based on the coefficient of variation would seem to potentially provide some improvement, as the semi-interval width criterion for confidence intervals builds in some allowance for the total number of cells. The semi-interval width of a confidence interval for an individual cell (i. e. a non-simultaneous confidence interval) is twice the standard error, roughly. So a translation between the rule of thumb given by Baird (1983) to a rule of thumb in terms of confidence intervals for individual cells would be to require the semi-interval widths of confidence intervals for individual cells to be less than about 20% for age classes contributing substantially to a fishery, and about 40% for the remaining age classes. This translation would of course be too conservative if applied directly to simultaneous confidence intervals, as simultaneous confidence intervals are much wider than the corresponding intervals for individual cells. Such a translation of the rough C. V. based rule of thumb would depend on the number of age classes considered, and would involve further relaxation of the percentages quoted. For instance in many situations on an ad hoc basis one might be able to give roughly equivalent rule of thumb guidelines based on simultaneous confidence intervals, such as semi-interval widths of 30% of estimates for important age classes, and 60% for less important age classes. Such guidelines would have to evolve in comparison with existing ones as experience is gained. Nonetheless, the analyses presented indicated that a substantial number of samples (400 for bream and sand whiting and 200 for dusky flathead) would be required to achieve the recommended 20% semi-interval width as a percentage of cell probability across the dominant ages groups for each species in each estuary.

When interpreting simultaneous confidence intervals, it should be remembered that simultaneous confidence intervals must be interpreted as a set of intervals. A 95% set of simultaneous confidence intervals means that for a large number of repeated samplings, in at least 95% of occasions all the statements in the set will be correct (i. e. correct simultaneously). That is, in less than 5% of occasions there will be at least one statement which will be incorrect - that is, the true value will lie outside the estimating interval for at least one of the intervals. In general, with an error rate of α, and c age classes, one can expect that "in the long run" a proportion of $1-\alpha$ of the sets of confidence intervals will be correct, and a proportion α will have at least one statement wrong. The expected number of incorrect statements, on a per interval basis, (assuming α is fairly small, so the chance of two incorrect intervals in a set is negligible) will thus be about $\alpha\, c$. If there are 20 age classes, and $\alpha = 0.05$, then on average we can expect 1 of the c confidence intervals to be incorrect. If we were happy for this to be so, when considering a fishery with only 10 age classes, we might be happy to take relax α to be 0.1, as on average again only one of our confidence intervals will be in error. Thus the error rate as a proportion α of incorrect sets of simultaneous statements gives differing numbers of expected incorrect statements on a per statement basis, depending on the number of simultaneous statements that are made in a set, (i. e. depending on the number of confidence intervals in a set, or the number of age classes c).

Goodman(1965) notes that more general sets of Bonferroni confidence intervals can be generated than the sets given above, by allocating unequal probabilities β_i to the c statements in each set of simultaneous confidence intervals, where $\sum_{i=1}^{c} \beta_i = \alpha$, rather than allocating equal probabilities $\beta_i = \alpha / c$ to each statement. The sets given are thus only special cases. It might thus be possible in some cases to widen confidence intervals for age classes which are likely to be shorter than required under an equal allocation scheme by reducing the β_i allocated to those intervals to values less than α / c. In return confidence intervals which are likely to be wider than required can be shortened. For a given set of p_i, some appropriate measure of the differences among the relative widths of the confidence intervals as a percentage of the corresponding point estimates within a set could be perhaps be formulated, and the problem posed of minimising this measure. This would amount to solving a non-linear programming problem, that is, an optimisation problem, in which a (non-linear) objective function is minimised by allocating the β_i to the various categories subject to non-negativity constraints $\beta_i \geq 0$ and the linear constraint $\sum_{i=1}^{c} \beta_i = \alpha$. It should also be noted that when a set of generalised simultaneous confidence intervals are not all true, the individual statements will have different probabilities of being incorrect. In the long run, those with a larger β_i will be false more often than those with a smaller β_i. We have not investigated the possible advantages of trade-offs among the individual statements in a set of simultaneous confidence intervals. We have used the equal allocation scheme $\beta_i = \alpha / c$ given above, as at this stage we do not have good a priori grounds for allocating unequal error rates to the individual age classes in our confidence statements. However, the possibility of generalising the intervals we have used does perhaps provide some further justification for adopting semi-interval widths from sets of simultaneous confidence intervals rather than simple C.V. s as a basis for deciding sample sizes, although in many practical situations the choice of criterion will not be important. This is because the semi-interval widths of confidence intervals for single cells, for simultaneous confidence intervals, and the values of C. V. s all depend in a similar way on the inverse square root of the sample size. However, even if some other criterion is adopted for choosing a sample size, such as using a rule of thumb based on past experience, for instance, simultaneous confidence intervals should always be calculated as they give a very useful interpretation of the degree of confidence one can expect to have when extrapolating from sample proportions to underlying population proportions, and they provide a better way of making comparisons among data sets.

More recent work on simultaneous confidence intervals for multinomial proportions is reported in Fitzpatrick and Scott (1987) and Thompson (1987). The latter paper uses the age class determination problem in fish as an example, and gives a table which can be used to determine the sample size for which one can have specified confidence (e. g. 95%) that all proportions in the sample are within a certain 'distance' d from the true value. For instance, one can say that with 95% confidence, all proportions in the sample are within 0.05 of the true population value for all age classes, if the sample size is 510. The remarkable result of this paper is that such probability statements can be made independently of the number of age classes, as worst case scenarios are dealt with which will occur with particular numbers of classes. (These worst case scenarios are analogous to the case $p = 0.5$ in the case of binomial sampling). It should be noted however that absolute differences between sample proportions and the underlying probabilities are discussed in this paper as criteria for choosing sample size rather than the relative precisions which have been discussed above. Information on absolute distances from underlying population proportions could, however, be interpreted in relative terms when the likely probabilities for important age classes are known.

Thompson (1987) mentions the possibility discussed further by Cochran (1977) and Angers (1984) of using a sequential sampling method when nothing is known of the underlying proportions in the population, in order to reduce the sample size needed. In our exercise we had good preliminary data, and therefore such an approach was not required.

A5. Conclusions

The determination of optimum sample size is an ongoing iterative process. Sample size determination depends on the aims of the sampling exercise and also the costs of collecting and processing samples (something we have not considered in this study). For example, age samples may be collected to feed an age structured stock assessment model or to determine spatial and temporal changes in age structures of populations, and thus the optimal number of samples required may differ for each exercise. Further, the level of precision achieved in sample collection and processing may be limited by funding. Based on Baird's suggestion, for stock assessment purposes, the analyses presented suggest that it would be wise to take sample sizes of 400 for bream and sand whiting and 200 for dusky flathead at the spatial and temporal scale of primary interest until age structured stock models are developed for these species. For example, the analyses imply that for an assessment based on the whole coast covering 1 year, 400 bream would be required to be aged annually. Following the development of age structured models, the level of precision required for future age-based sampling of these species will be determined.

A6. References

Andrew, N.L., Chen, Y. (1997). Optimal sampling for estimating the size structure and mean size of abalone caught in a New South Wales fishery. Fishery Bulletin 95: 403-413.

Angers, C. (1984) Large Sample Sizes for the estimation of Multinomial Frequencies From Simulation Studies. *Simulation* October, 175-178.

Baird, J.W. (1983) A method to select Optimum Numbers for Aging in a Stratified Approach, *Canadian Special Publication of Fisheries and Aquatic Sciences* No 66, edited by W. G. Doubleday and D. Rivard, Dept. of Fisheries and Oceans, Ottawa, pp 161-164.

Chen, Y. (1996). A Monte Carlo study on the impacts of the size of subsample catch on estimation of fish stock parameters. Fisheries Research 26: 207-225.

Cochran, W.G. (1977) Sampling Techniques (3rd edn.), John Wiley, New York.

Fitzpatrick, S., Scott, A. (1987) Quick Simultaneous Confidence Intervals for Multinomial Proportions" *Journal of the American Statistical Association*, 82: 875-878.

Fournier, D.A. (1983) Use of Length and Age data for estimating the Age Structure of a Collection of Fish, *Canadian Special Publication of Fisheries and Aquatic Sciences* No 66, edited by W. G. Doubleday and D. Rivard, Dept. of Fisheries and Oceans, Ottawa, pp206-208.

Gold, R. Z. (1963) Tests auxiliary to χ^2 tests in a Markov chain, *Annuals Mathematics Statistician.,* 34:56-74.

Goodman, L. A. (1965) On simultaneous confidence intervals for multinomial proportions,

Miller, R.G., Jr. (1966) Simultaneous Statistical Inference, McGraw-Hill, New York.

Miller, R.G., Jr. (1980) Simultaneous Statistical Inference (2nd edn.), Springer-Verlag, New York.

Quesenberry, C. P., Hurst, D. C. (1964) Large sample simultaneous confidence intervals for multinomical proportions, *Technometrics,* 6:191-195.

Smith, P.J., Sedransk, J. (1982) Bayesian optimization of the estimation of the age composition of a fish population. *Journal of the American Statistical Association* 77: 707-713.

Technometrics, 7:247-254.

Thompson, S.K. (1987) Sample Size for Estimating Multinomial Proportions. *The American Statistician*, 41: 42 - 47.

Other titles in this series:

ISSN 1440-3544

No. 1 Andrew, N.L., Graham, K.J., Hodgson, K.E. and Gordon, G.N.G., 1998. Changes after 20 years in relative abundance and size composition of commercial fishes caught during fishery independent surveys on SEF trawl grounds. Final Report to Fisheries Research and Development Corporation. Project no. 96/139.

No. 2 Virgona, J.L., Deguara, K.L., Sullings, D.J., Halliday, I. and Kelly, K., 1998. Assessment of the stocks of sea mullet in New South Wales and Queensland waters. Final Report to Fisheries Research and Development Corporation. Project no. 94/024.

No. 3 Stewart, J., Ferrell, D.J. and Andrew, N.L., 1998. Ageing Yellowtail (*Trachurus novaezelandiae*) and Blue Mackerel (*Scomber australasicus*) in New South Wales. Final Report to Fisheries Research and Development Corporation. Project no. 95/151.

No.4 Pethebridge, R., Lugg, A. and Harris, J., 1998. Obstructions to fish passage in New South Wales South Coast streams. Final report to Cooperative Research Centre for Freshwater Ecology.

No. 5 Kennelly, S.J. and Broadhurst, M. K., 1998. Development of by-catch reducing prawn-trawls and fishing practices in NSW's prawn-trawl fisheries (and incorporating an assessment of the effect of increasing mesh size in fish trawl gear). Final Report to Fisheries Research and Development Corporation. Project no. 93/180.

No. 6 Allan, G.L., and Rowland, S.J., 1998. Fish meal replacement in aquaculture feeds for silver perch. Final Report to Fisheries Research and Development Corporation. Project no. 93/120-03.

No. 7 Allan, G.L., 1998. Fish meal replacement in aquaculture feeds: subprogram administration. Final Report to Fisheries Research and Development Corporation. Project no. 93/120.

No. 8 Heasman, M.P., O'Connor, W.A., O'Connor, S.J., 1998. Enhancement and farming of scallops in NSW using hatchery produced seedstock. Final Report to Fisheries Research and Development Corporation. Project no. 94/083.

No. 9 Nell, J.A., McMahon, G.A., and Hand, R.E., 1998. Tetraploidy induction in Sydney rock oysters. Final report to Cooperative Research Centre for Aquaculture. Project no. D.4.2.

No. 10 Nell, J.A. and Maguire, G.B., 1998. Commercialisation of triploid Sydney rock and Pacific oysters. Part 1: Sydney rock oysters. Final Report to Fisheries Research and Development Corporation. Project no. 93/151.

No. 11 Watford, F.A. and Williams, R.J., 1998. Inventory of estuarine vegetation in Botany Bay, with special reference to changes in the distribution of seagrass. Final Report to Fishcare Australia. Project no. 97/003741.

No. 12 Andrew, N.L., Worthington D.G., Brett, P.A. and Bentley N., 1998. Interactions between the abalone fishery and sea urchins in New South Wales. Final Report to Fisheries Research and Development Corporation. Project no. 93/102.

No. 13 Jackson, K.L. and Ogburn, D.M., 1999. Review of depuration and its role in shellfish quality assurance. Final Report to Fisheries Research and Development Corporation. Project no. 96/355.

No. 14 Fielder, D.S., Bardsley, W.J. and G.L. Allan., 1999. Enhancement of Mulloway (*Argyrosomus japonicus*) in intermittently opening lagoons. Final Report to Fisheries Research and Development Corporation. Project no. 95/148.

No. 15 Otway, N.M. and Macbeth, W.G., 1999. The physical effects of hauling on seagrass beds. Final Report to Fisheries Research and Development Corporation. Project no. 95/149 and 96/286.

No. 16 Gibbs, P., McVea, T. and Louden, B., 1999. Utilisation of restored wetlands by fish and invertebrates. Final Report to Fisheries Research and Development Corporation. Project no. 95/150.

No. 17 Ogburn, D. and Ruello, N., 1999. Waterproof labelling and identification systems suitable for shellfish and other seafood and aquaculture products. Whose oyster is that? Final Report to Fisheries Research and Development Corporation. Project no. 95/360.

No. 18 Gray, C. A., Pease, B.C., Stringfellow, S.L., Raines, L.P., Rankin, B.K. and Walford, T.R., 2000. Sampling estuarine fish species for stock assessment. Final Report to Fisheries Research and Development Corporation. Project no. 94/042.