Assessment of the Stocks of Sea Mullet in New South Wales and Queensland waters

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OBJECTIVES:

1. Preliminary comparison of the value of the total mullet catch in NSW and Qld under the present management regime and under alternate regimes that may be considered. What is the value of the "hardgut" run? What is the comparative value of mullet as a food fish and as a producer of roe?

2. Calculation of the potential social and biological impact of redirecting effort among the estuarine and oceanic components of the fishery as a result of alternate management regimes and, in the case of Qld, among ocean beach regions

To achieve these major objectives we need a more accurate description of the location of catches (freshwater, estuarine and oceanic) by individual fishers. Further the following gaps in our knowledge of sea mullet need to be filled:

1). What percentage of mullet spawn each year? In what area?
2). For how many years do individual mullet spawn (do they spawn only once)?
3). Does the age and size at first spawning differ among individuals from different estuaries.?
4). What is the appropriate legal size for mullet?

NON TECHNICAL SUMMARY

Introduction

The sea mullet (*Mugil cephalus*) is an important commercial fish species in New South Wales and Queensland. The catches of sea mullet are the largest amongst the commercially caught finfish species in both of these states. In New South Wales the total catch has increased from approximately 3000 tonnes to 4000 tonnes in the last 15 years. The estuary component has remained at approximately 2000 tonnes, but the ocean beach component has increased from approximately 500 tonnes to 2000 tonnes. The mullet caught on ocean beaches are mostly spawning run fish and their catches have increased as a result of a growing market for sea mullet roe. In Qld, catches have remained at approximately 2000 tonnes. Of this total, about 1500 tonnes of sea mullet are caught during the spawning period (May to August) by fishers in both the estuarine and ocean beach fisheries. The remainder are caught as fresh fish for local markets during the rest of the year in estuarine areas.

The main objectives of this study were to compare the value of the sea mullet catch under alternate management regimes and to examine the social and biological impacts of redirecting effort between components of the fishery. These objectives were addressed by examining the fisheries and aspects of the biology of sea mullet in both NSW and Qld. The methods used involved 1) the collation and analysis of fishery statistics, 2) biological sampling, 3) age estimation, 4) tagging and 5) a description of reproduction.

Fishery Statistics

The NSW fishery is valued at approximately $11.4 million per annum to approximately 870 fishers with ~387 taking 90% of the catch. The estuary sector of the NSW fishery is valued at ~$4.1 million and involves ~770 fishers. The ocean beach sector is valued at ~$7.3 million (1.8 times the estuary sector) and involves ~380 fishers (less than half the estuary sector). Almost half (~$5.2 million) of the value of the total fishery in NSW is from spawning run catches on ocean beaches in the central and mid north coast during April and May. The hardgut component of the ocean beach sector is valued at ~$100 thousand, which is only 0.9% of the total value of the NSW fishery.

The Qld fishery is valued at $7 to 8 million per annum. The non-spawning component of the catch is valued at ~$2.3 million and is taken in estuarine areas involving approximately 300 fishers. The spawning component is valued at ~$5m. Half of this is caught by the 70 fishers licensed in the ocean beach fishery with the other half caught by fishers in estuarine areas. While once a substantial part of the fishery, the value of the hardgut component has decreased to less than $0.2m in the last 15-20 years.

Ageing studies

Ageing studies indicated that opaque rings observed in thin sections of the otoliths in sea mullet were formed annually. This result was supported by 1) seasonal measurements of the interval between the last ring and the edge of the otolith and 2) by the use of chemical marks in the otoliths of sea mullet in tagging studies.

Catch composition

The ages of sea mullet in commercial catches range from 2 to 12 years and are dominated by ages 3 to 7 in NSW and 2 to 6 years in Qld. The estuary catches included higher proportions of younger fish and lower proportions of older fish than in spawning run catches on ocean beaches. On average, females were larger than males in the catches. This difference in the sizes of females compared to males is attributed more to a difference in size at age, than a difference in ages.

Reproductive studies

It appears that the proportion of sea mullet involved in spawning runs increases from ages 3 to 6. It is likely that spawning occurs over a range of latitudes on the east coast of Australia. This result was based on the observations of female and male sea mullet with advanced stages of reproductive development from a range of estuary and ocean beach sampling sites in NSW and Qld. It is also likely that spawning occurs in ocean waters since no running ripe females were found in samples from either the estuary or ocean beach sites both states.

Legal size

The minimum legal length for sea mullet in NSW and Qld is 30cm (total length). This minimum length potentially allows some males but very few, if any, females to spawn once. However this minimum length appears to have very little effect on the size of fish taken in commercial catches because most of the fish in catches are well above 30cm (TL).

Movement

The tagging study completed in NSW indicated that many mullet undertake both northern and southern coastal movements. Sea mullet tagged in estuaries were recaptured in the same estuary or north, but not south of the estuary of release. Those tagged on ocean beaches were recaptured both north and south of the area of release.

Redirection of effort

In New South Wales a large proportion of the sea mullet catch is comprised of non-roed fish from the estuaries while roed fish, taken mostly on ocean beaches, are of higher value. It can be argued that a redirection of effort to the higher valued roed fish may add value to the fishery. However, assessment of the full social, biological and economic impacts of such a policy is complex and its implementation likely to be difficult. Subsequent to the commencement of this project the commercial fisheries in New South Wales have been divided into 6 restricted and 2 share managed fisheries, each with separate management advisory committees. The commercial catches of sea mullet are now almost equally split between the Estuary General and the Ocean Haul Restricted Fisheries.

Future

It is recommended that the fish size and age structure of the commercial catches of sea mullet be monitored in the estuaries and on ocean beaches in both New South Wales and Queensland. Fish size and age information is important in fish stock assessment and would be an important addition to the fishery information collected by the New South Wales and Queensland Governments.

KEYWORDS: mullet, Mugilidae, Mugil, cephalus, fishery, ageing, reproduction, movement,

2. Background

The sea mullet (*Mugil cephalus*) is a major commercial fish species in Australia and many other parts of the world. In Australia the main commercial fisheries for sea mullet are in NSW (~4,000 tonnes per annum), Qld (~2,000 tonnes) and Western Australia (~500 tonnes).

In NSW, sea mullet comprises approximately 55% by weight of the total commercial finfish catch taken from estuaries and ocean beaches. They are caught on ocean beaches using beach seine nets mainly during their coastal spawning migrations, which occur in autumn and winter each year. Large catches are usually first recorded on the south coast of NSW in March, progressing to the north coast by about June. In the estuaries, sea mullet are taken by seine nets and gill nets throughout the year. Coastal movements of older juveniles can occur in the summer months. These migrating fish are sometimes referred to as 'hardgut' mullet.

Although catches of mullet in the estuaries have remained relatively constant during the last fifty or so years, catches in the ocean beach component of the NSW fishery have risen dramatically since the late 1970's, from an average of about 500 tonnes per annum to about 2000 tonnes in recent years. This increase in the oceanic catch may be attributed largely to the development of new markets for sea mullet roe. Mullet traditionally supplied the local fish and chip and fresh fish trade and were among the lowest priced species marketed. However, current prices for roe exceed $30 per kg, far greater than for the whole carcass.

In Qld, sea mullet sustain the largest single finfish fishery and are the mainstay of the fresh fish trade. There are 1039 licensed net fishers in Qld with 300 of these targetting sea mullet as one of their principal species (approx. 60 in Moreton Bay). The fishery extends from the NSW-Qld border to Townsville. Approximately 1800 t is caught annually between the border and the northern tip of Fraser Island with the remaining 200 t caught between Fraser Island and Townsville. The major sea mullet fishing areas are Fraser Island, the Sunshine Coast beaches, Moreton Island, North Stradbroke Island and Moreton Bay. The latter three account for about half of the total annual catch.

From September to December, no sea mullet are caught on ocean beaches. From December to March, depending upon environmental conditions (mainly rainfall) schools of non-reproductive fish ('hardgut') migrate from estuarine waters to ocean beaches. Although comparatively small in size, the 'hardgut' run was historically economically significant to net fishermen because of relatively higher prices at this time of the year, due to the scarcity of other fish species. The period May to August is the main run of spawning fish, with roed female fish being highly prized.

Sea mullet catches in Qld fluctuate from year to year. It is difficult to draw inferences about the population abundances from catch data as the demand can be market driven. Mullet are known to spawn at sea each year but the exact location remains unknown, even though the fishery targets pre- spawning fish on the ocean beaches. Mullet form large schools in the lower reaches of estuaries during winter and remain there in 'staging areas' before migrating to the ocean beaches with the onset of the winter westerly winds.

Although a great deal of work has been done on the biology of sea mullet in many parts of the world, few studies have been aimed at stock assessment. This is particularly so for Australia where sea mullet have been the subject of very little research since the pioneering work of Kesteven and Thomson in the 1940's and 1950's respectively and that of Grant and Spain in the 1970's. For example the age structure of spawning populations is not known, the role and importance of the "hardgut" component for the population is not understood and the appropriateness of the legal size is not clear.

The key point to be remembered about the ocean component of the sea mullet fishery is that it targets the mature and pre-spawning population. We are mindful of the collapse of similar fisheries in Australia (e.g. gemfish) brought about by increased fishing of pre-spawning aggregations. We do not have sufficient information to predict the consequences of the recent increases in the oceanic catch of sea mullet. Management and industry will become increasingly vulnerable to the problems associated with over exploitation if this trend in harvest continues without due regard to the conservation of the stock, and the maintenance of recruitment levels.

The effects of these increases in catches of spawning run fish may be manifest in changes in total return from the fishery (dollar per recruit) and/or changes in the annual yield. In the case of NSW , there is a need information to be able to advise the fishing industry on the optimal yield from the estuarine and oceanic components of the fishery. A large proportion of fishers in NSW derive income from the estuarine and ocean fisheries for mullet (791 fishers reported catches of mullet in 1990/91 and in that year 195 people derived > 50% of their total catch from mullet).

3. Need

The increases in catches of spawning run mullet give rise to several concerns in NSW. The first relates to the conservation of stocks of this very important species. We do not currently have sufficient information on the composition and movements of these spawning runs over the range of the fishery to determine whether current catch levels are sustainable. The second major concern is related to the optimal harvest strategies of the stock. Although it is clear that the unit prices of mullet from the spawning stock far exceed those from the estuarine and 'hardgut' components of the fishery, roe may be harvested only for only a short period each year. Whether the net gain to the whole fishery compensates for restricting access to any component will be an increasingly important question. Thirdly and stemming from the above, future management of sea mullet will require information on how many fishers are involved in each sector of the fishery and the levels of economic return to these fishers.

The fishery in Qld does not have the same clear demarcation between estuarine and ocean beach components as in NSW. The fishery supplies fresh fish for human consumption as well as roe to export markets. From a management view, several questions need to be answered. Firstly, what is the appropriate minimum legal size (currently 30 cm in Qld/NSW and 25 cm in Victoria)? If this size is appropriate, should it be varied seasonally (for the 'hardgut' run for example)? Second, as with NSW, managers have questioned the respective values of the estuarine and ocean beach fisheries. Finally, what is the age structure of the ocean run, and do spent females return to the estuaries?

Although the above issues differ between Qld and NSW, both groups of issues are complementary to a better understanding of the total fishery. The legal size is important if both components of the fishery (estuarine and ocean beach) are considered. Under Mutual Recognition Legislation agreed to by the States and Commonwealth, differences across borders (such as minimum size limits) need to be reconciled.

The value of the estuarine and ocean beach components of the fishery are of considerable economic importance in NSW (where separately managed estuarine and ocean beach fisheries are being implemented) and in Qld (where management of the ocean beach fishery through zoning has been introduced). Economic benefits are viewed as a way of comparing management scenarios and implicit in such an approach is the necessity for a measure of natural variation. Finally, the basic question of the impact of fishing spawning populations is important. Such practices combined with unfavourable environmental changes had dramatic consequences for the Peruvian anchovetta fishery and when combined with flawed assessment, had a similar consequence for North Sea herring.

This project is an important first step in increasing our knowledge of the biology of sea mullet and in initiating monitoring of the stocks. A greater understanding of the biology of this species and ongoing monitoring of commercial catch structure will help in the assessment of competing management strategies.

4. Objectives

1. Preliminary comparison of the value of the total mullet catch in NSW and Qld under the present management regime and under alternate regimes that may be considered. What is the value of the "hardgut" run? What is the comparative value of mullet as a food fish and as a producer of roe?

2. Calculation of the potential social and biological impact of redirecting effort among the estuarine and oceanic components of the fishery as a result of alternate management regimes, and, in the case of Qld, among ocean beach regions

To achieve these major objectives we need a more accurate description of the location of catches (freshwater, estuarine and oceanic) by individual fishers. Further the following gaps in our knowledge of sea mullet need to be filled:

1). What percentage of mullet spawn each year? In what area?
2). For how many years do individual mullet spawn (do they spawn only once)?
3). Does the age and size at first spawning differ among individuals from different estuaries.?
4). What is the appropriate legal size for mullet?

5. Methods

5.1 Introduction

The methods used in this study can be divided into 5 main components: 1) the collation and analysis of fishery statistics, 2) biological sampling, 3) age estimation, 4) tagging and 5) a description of reproduction. Information was drawn from each of these components to address the stated objectives. The sampling period commenced in January 1995 and allowed sampling of 2 full spawning and 'hardgut' seasons.

5.2 The collection and analysis of fishery statistics

5.2.1 Background

Fishery statistics were collated and analysed to describe the different components of the sea mullet fisheries in each state. Reported catches by location and month were summarised in order to calculate the contribution of the various components of the fishery to total catch and value. Information on the numbers of fishers and their fishing operations in various components of the fishery were also assessed.

5.2.2 New South Wales

Fishery statistics were obtained from various sources including the catch/licensing computer database, catch summary cards from NSW Fisheries and summary data from the Australian Bureau of Statistics. These sources provide information for the period from 1956 to the present time and their primary source is the NSW Fisheries monthly fisher's return form. Information for years prior to 1956 was obtained from the NSW Fisheries annual reports.

The monthly fisher's return forms provide information from commercial fishers throughout the state. Fishers are required by law to complete and return these forms to NSW Fisheries. The catch statistics are recorded by estuary or by ocean zone which is based on degrees of latitude along the NSW Coast (Figure 1).

The return forms were introduced in the 1940s and with some changes in format their use has continued to the present time. Return form information for the period since 1984 has been entered onto computer and the original forms for this period have been stored. Most of the original forms prior to 1984 were lost during relocations or destroyed in a warehouse fire. However, summaries of the data prior to 1984 are available through secondary sources such as the departmental catch summary cards and annual reports.

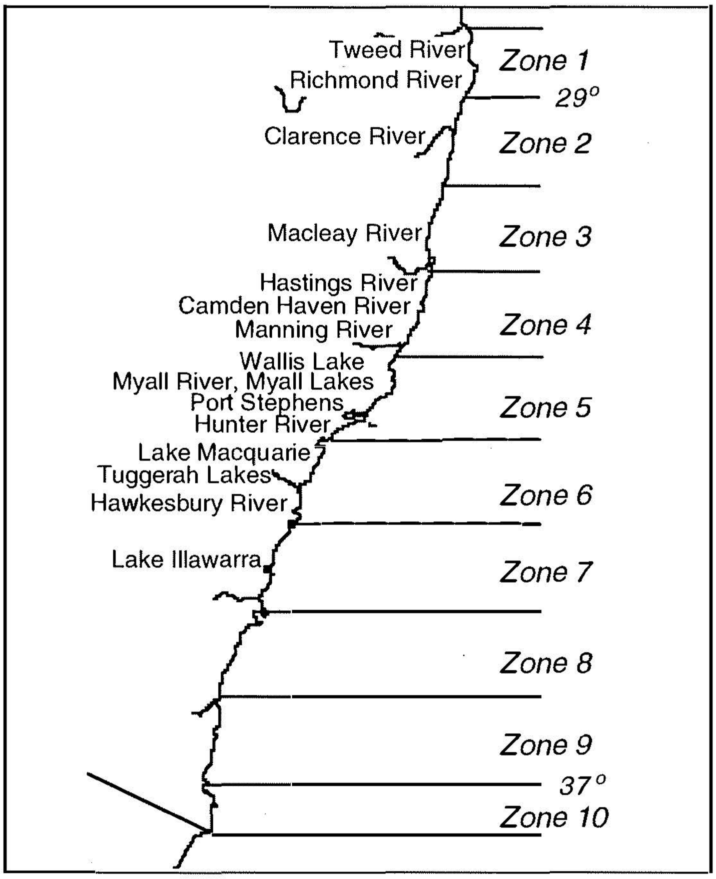

Figure 1 The New South Wales coast showing the zones used in catch statistics and the locations of important estuaries for catches of sea mullet.

To obtain a current view of the fishery, monthly catches for various components of the fishery during the last 5 years were summarised. The value of the fishery was estimated by applying 1996 prices to average catches for the 5 year period and the numbers of fishers involved in various components of the fishery were assessed for 1996. The fishery data for both the estuaries and ocean zones were grouped into intervals of two degrees latitude for many analyses used in this report.

Price information was obtained from the Sydney Fish Marketing Authority and the Clarence River Fishermen's Cooperative. Information from the Clarence River included prices for a range in the 'percentages return' of roe in catches. In calculations of the value of the catch,

$4.75 per kilogram of whole fish was used as the value, and 56% by weight as the proportion of roed females in the ocean spawning run fish (March to June). The value of $4.75 was the Clarence River price for roed females with a return (GSI) of 15% which was the average return for spawning run fish in this study. Also, 56% was the proportion by weight of females in the spawning run samples in this study. The weighted average of the monthly Sydney Fish Market prices for sea mullet were used in calculations for the rest of the catch (Table 1).

Some of the estuary catches during the spawning season are also sold for the roe market but the proportions of catches and the percentage return of roe in these catches were not obtained in this study and it would be difficult to do so. However an upper limit can be estimated. Based on the proportion by weight of females in the March to June component of the estuary catch (63%), $4.75 per kilogram of whole roed fish and Sydney Fish Market prices for the remainder of the estuary catch, a value of $5.8 million is obtained for the total estuary fishery. Only a proportion of estuary females would make it to the roe processors and it is doubtful whether an average of $4.75 per kilogram would have been obtained for these female fish. If half of the females were sold for roe and the average price of these fish was $3.00 per kilogram, a value of $4.1 million is obtained which is thought to be a more realistic figure. If none of the estuary fish were sold for the roe market a value of $3.6 million is obtained.

Table 1 Weighted average of monthly sea mullet prices (dollars)at the Sydney Fish Markets from January 1995 to June 1996.

Year/Month																	
1995						1996											
7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12
1.21	1.61	1.78	1.95	2.43	1.86	1.63	1.56	1.35	1.38	1.67	1.71	1.71	2.56	2.73	2.95	2.68	2.11

The number of fishers involved in catching mullet was determined by cross referencing skipper and crew information on the return forms. This cross referencing was necessary because skippers can be included as crew and individual fishers can be included on more than one form in a month. This cross referencing required coding of many crew records.

5.2.3 Queensland

Historical fishery statistics for sea mullet were extracted from the Qld Harbours and Marine Annual Reports for the years 1943 to 1969. An estimate of the percentage of the annual catch that was mullet is available for these years. Although all mullet species are included into this percentage it is assumed that sea mullet constituted the majority of the catch. The number of licences and the number of boats recorded in these Annual Reports apply to all finfish fisheries in Qld. These records provide limited effort data and cannot be used with any level of confidence to determine historical CPUE for the mullet fishery.

There are no fisheries catch statistics from 1970 to 1987 due to the closure of the Qld Fish Board and the cessation of the Boards' control over the fish markets in Qld

More recent catch and effort data from 1988 to 1995 were extracted from the Qld Fish Management Authority's CFISH database. This information provides estimates of the number of 'boat days' fished per year. Days when sea mullet were amongst the species caught were counted as 'mullet-fishing days'. The CFISH "boat day" does not distinguish between one haul of 20 t on an ocean beach, or 5 kg caught as byproduct in an estuary. It is also not possible to determine how many licences and boats were fishing together as amalgamated crews, or how many shots of a net occurred in the one day of recorded effort.

5.3 Biological sampling

5.3.1 General

Sampling of commercial catches in NSW and Qld was carried out at seven estuarine and seven ocean beach locations. The estuarine locations from south to north were: the Shoalhaven River, Lake Macquarie, Wallis Lake, the Clarence River, Moreton Bay, the Maroochy River and Tin Can Bay. The ocean beach locations from south to north were: Port Stephens, Port Macquarie, Coffs Harbour, Tweed Heads. North Stradbroke Island, Sunshine Coast beaches between Maroochydore and Noosa north shore and Fraser Island (Figure 2).

Generally, samples were collected bimonthly from the estuaries for 18 months and on two or three occasions during the winter spawning run of each year. Few hardgut run samples were obtained due to low commercial catches in this component of the NSW ocean haul fishery during the sampling period and no samples were obtained from this component of the fishery in Qld.

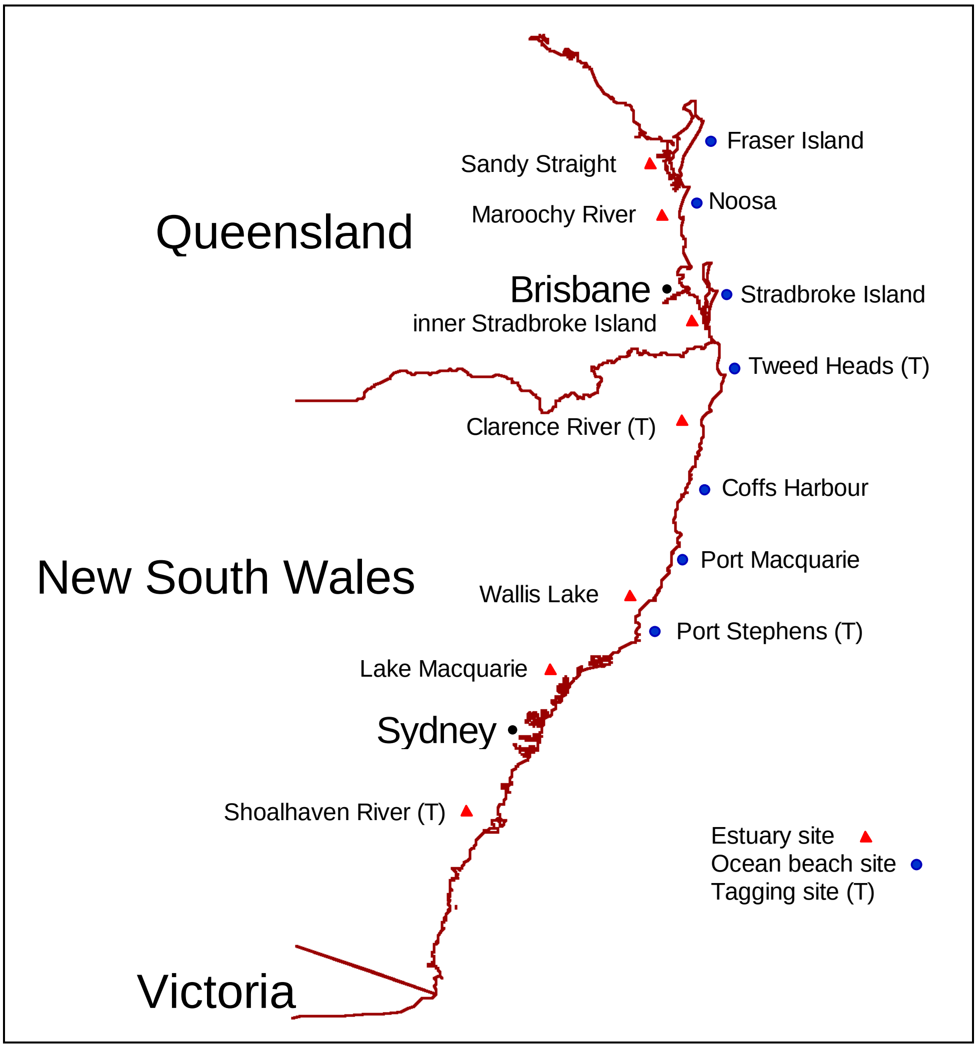

Figure 2 Map of the New South Wales and Queensland coasts showing the project sampling and tagging sites

5.3.2 New South Wales

On each sampling occasion biological information and tissue samples were collected from approximately 30 females and 30 males. For each fish, the length to the caudal fork (LCF) was measured in millimetres, the weight measured in grams and sex and gonad class determined macroscopically. Ovaries were removed and stored in plastic jars with 10% FAACC for at least 48 hours after which they were transferred to 70% alcohol. Both sagittal otoliths and approximately 6 scales from behind the left pectoral fin were removed and stored. Sex and length were recorded for any additional fish which were dissected to obtain the 30 females and 30 males. All the dissected fish were used to provide information on sex ratio. Additional fish length measurements also were made when catches were available. All ocean spawning run sea mullet for which length was recorded were sexed using the same method as that used by the fishers. The fish did not require dissection. They were softly squeezed near the abdomen with milt emerging if the fish was male.

5.3.3 Queensland

At each site, on each sampling occasion measurements of 300 sea mullet caudal fork lengths (FL) were taken from within a catch with every fifth fish being kept for biological sampling. In some cases, especially in the estuarine catches when less than 300 fish were caught, the samples were taken over two days or did not reach the desired levels. Actual numbers of fish from each sampling occasion at each of the locations throughout 1995 and 1996 are given in Appendix 2.

The 60 fish kept for biological sampling were placed on ice and returned to the laboratory. The fish were weighed (whole wet weight) to the nearest 1 g, measured to the nearest 5 mm (caudal fork length), their gonads removed and weighed, and their otoliths removed.

5.4 Age estimation

5.4.1 General

The primary method used to age sea mullet was the reading of sagittal otoliths. Sagittal otoliths were removed through a sub or supra-cranial incision. The otoliths were cleaned and stored in envelopes (NSW) or plastic vials (Qld) and left to dry. After drying for at least one week each otolith was weighed to the nearest 0.0001 of a gram. One of each pair was then set in a block of polyester resin. A transverse section approximately 300um thick was taken through the primordium of the otolith using a Buehler Isomet low-speed diamond saw. In NSW both sides of the section were then polished with 9µm polishing paper. Sections were mounted on microscope slides using Ultramount (NSW) or DPX mounting medium (Qld).

Otolith readings were done using a stereo dissecting microscope with reflected light on a black background. Most otolith sections showed a clear pattern of opaque (light) and translucent (dark) zones. The narrower opaque zones were counted to estimate age. Each reading was done without prior knowledge of capture date, size, or previous readings. Estimates of age were made by counting the number of opaque rings from the focus to the outer edge, usually along the line of the sulcus.

Ages were estimated by adding 1 to the number of rings in the otolith section. This was regarded as a reasonable estimate of age because it appears that there is no observable ring in the 1st year of life and that the first ring is formed at approximately 18 months. This is based on the observation that there is usually a large interval from the focus to the first ring compared to intervals between later rings. This is supported by the recent work of Thompson (1991) on *Mugil cephalus* from Louisiana.

5.4.2 New South Wales

Each reading for each otolith section was given a readability ranking of 1 - 4. The rankings were 1) clear rings throughout section, 2) clear rings but not throughout the entire section, 3) some uncertainty about one ring, 4) more than one ring unclear, or no rings decipherable. Also the otolith edge was classified as being opaque (Figure 3a) or in the first, middle (Figure 3c), or last third of formation of the translucent zone.

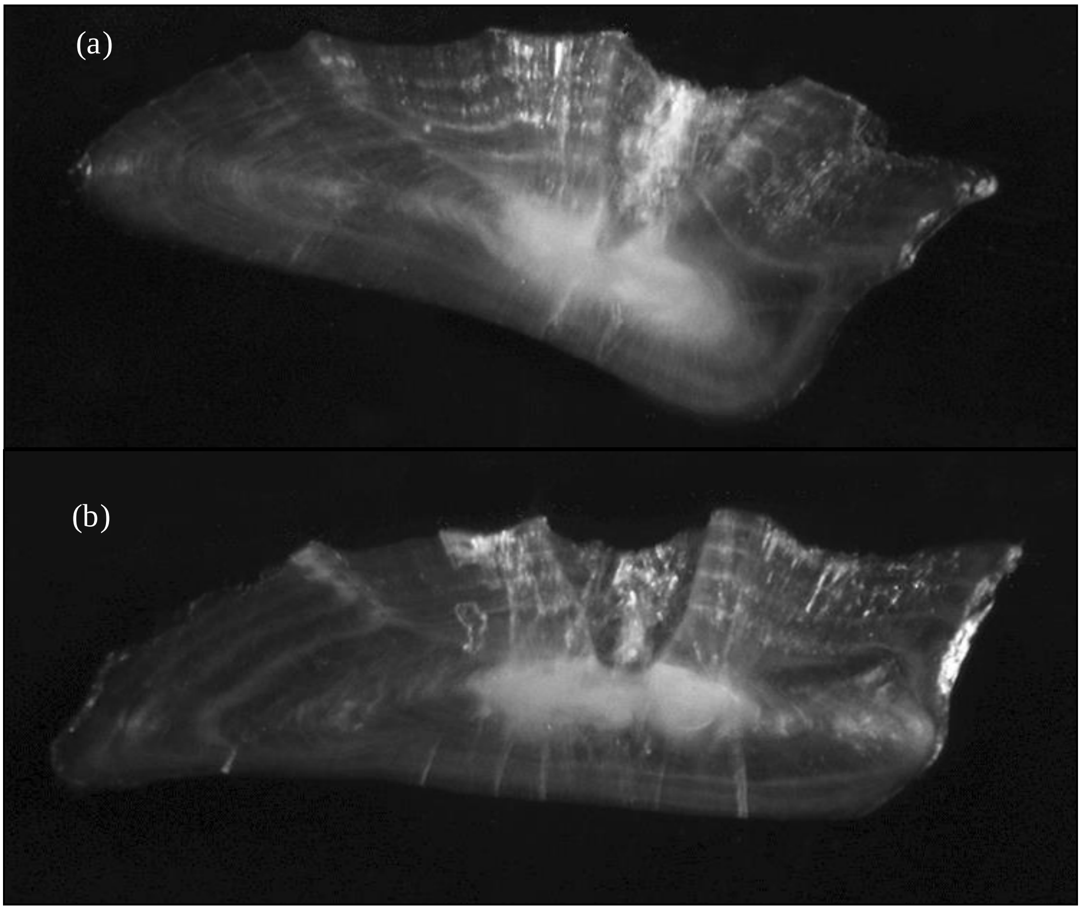

Figure 3 Otolith sections from sea mullet from New South Wales showing (a) an opaque edge forming a sixth ring and (b) the middle translucent phase of edge growth after the fourth ring.

5.4.3 Queensland

Otolith sections were read three times by at least two different readers The readings were classified into three groups; (a) all 3 age readings the same, (b) 2 of the 3 age readings the same and (c) all age readings different. Only fish for which at least two of the readings were consistent were used in the analysis of age.

Estimation of the amount of translucent growth on the outer edge of the otolith was done by readers when ageing the otoliths. One of three subjective rankings was given to the translucent growth on the outer edge of the otolith. These were; (1) no translucent growth, with the last annuli on the outer edge (Figure 3a), (2) partial translucent growth (Figure 3b), and (3) full translucent growth. The edge data were sorted into the same groups described above i.e. those with all 3 estimations the same, 2 estimates the same and all 3 readings different.

5.4.4 Otolith tissue exchange program

To check the consistency of aging technique between NSW and Qld researchers an otolith exchange program was developed. This involved the preparation of otoliths from 100 sea mullet from each state taken for biological sampling during the first year of the study. Fifty fish from summer and 50 from winter samples were examined. There were six readings on each of the sets of 100 otoliths. Three readings were made by three readers in NSW and three readings were made by two readers in Qld.

In addition to this exchange of otolith sections, an informal workshop on otolith reading was held with Prof. Bruce Thompson, and officers from Qld and NSW at the Southern Fisheries Centre, Deception Bay, Qld. Prof. Bruce Thompson is an ichthyologist from Louisiana State University, USA. He has studied striped/sea mullet in Louisiana and his work has included age estimation. There was good agreement between Prof. Bruce Thompson and officers from Qld and NSW in age estimates of otolith sections from the USA, Qld and NSW.

5.5 Tagging

5.5.1 Background

Tagging is a method commonly used to examine aspects of the biology of fish such as movements, growth and exploitation rates. In this study, tag and recapture techniques were used in conjunction with chemical tags to help validate ageing methods. Oxytetracycline was used to chemically mark the otoliths and other parts of the fish, producing a fluorescent mark that can be seen under ultraviolet light. The frequency of the rings since marking can be examined in recaptured fish to determine the periodicity of ring formation. The tagging study also was used to examine fish movements.

5.5.2 New South Wales

Sea mullet were tagged in estuary and ocean beach locations. The estuary locations were the Shoalhaven and Clarence Rivers and the ocean beach locations were at or near Port Stephens and Tweed Heads. The fish were obtained from the catches of commercial hauling crews in the estuaries and on ocean beaches.

All sea mullet that were tagged were also injected with oxytetracycline. Orange plastic dart tags were used to tag the fish. They were inserted into the dorso-lateral area of the fish slightly anterior to the second dorsal fin (Figure 4). After insertion, tags were given a slight tug to check that they were locked behind a neural spine. The application of dart tags was practiced and checked on dead fish before the field tagging commenced. Orange tags were used to indicate that the fish had been injected with oxytetracycline. This is consistent with other fish tagging studies in NSW. Oxytetracycline was administered by intraperitoneal injection (50mg/kg of fish weight) of a fish before their release.

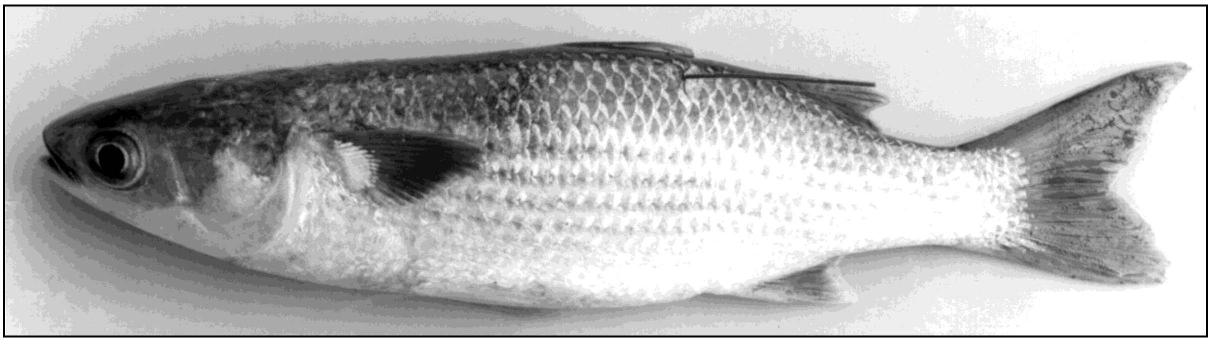

Figure 4 Photograph of a tagged sea mullet.

Prior to tagging, captured fish were held in large plastic tubs (each holding approximately 200 litres of water). After tagging they were held in smaller tubs and released in groups of about twelve to provide some degree of the school integrity.

The tagging study was advertised in the "New South Wales FISHERMAN" and "Queensland FISHERMAN" and tag reward posters (Appendix 5) were sent to sea mullet processors, Fishermen's Cooperatives and district fisheries offices.

5.5.3 Queensland

Ages were validated with oxytetracycline marking of tagged fish which were then held in captivity. A total of 278 sea mullet, ranging in size from 225 to 400 mm FL, were caught using a 2¾ inch stretch mesh gill net, tagged using plastic T-bar tags (Hallprint, 45 mm long and 0.5 mm in diameter) and injected intramuscularly with oxytetracycline at 0.1 ml/kg of body weight in March 1996. Oxytetracycline used was Tetravet 100 Injection with 92.7 mg of active ingredient per ml. These fish were released into a salt water dam at Novatel Twin Waters (Mudjimba)**.** This dam was 7.2 ha in size with an average depth of about 2 metres. Water exchange occurred through 90 cm diameter pipes linking the dam to the Maroochy River. The dam end of the pipes was covered by steel mesh to prevent the released fish from escaping. The dam has sand-mud bottom with areas of seagrass, rock walls and sand beaches surrounding the edge. No supplementary food was provided to the fish. Tagged fish were recovered from the dam between 14 and 16 months after release by catching them in 100 mm stretch mesh gill nets. All recaptured sea mullet from within the dam, whether tagged or not, were measured, weighed and their otoliths removed. Otoliths were sectioned and aged (as described above). Sections were then viewed for fluorescent rings under a compound microscope with an ultraviolet lighting source. Sections containing fluorescent rings were photographed to determine the position of fluorescent ring created by the oxytetracycline.

5.6 Reproduction

5.6.1 Staging

The protocol for the investigation into reproductive development classing and oocyte staging in sea mullet was based on West (1990). The protocol included techniques for the preservation, storage and sectioning the ovaries once removed from the fish (Appendix 6).

Gonads were removed from sea mullet returned to the laboratory for biological sampling, macroscopically staged, weighed (± 0.1 g) and stored in 10% FAACC (Appendix 6). After fixing, tissue sections (approx. 5 mm) were taken from within the central section of the ovary (Figure 5), placed in a tissue cassette, embedded in paraffin, sectioned and stained with haematoxylin/eosin. Sectioning and staining was carried out by the pathology laboratory at the University of Sydney in NSW and Sullivan Nicolaides pathology laboratories in Qld.

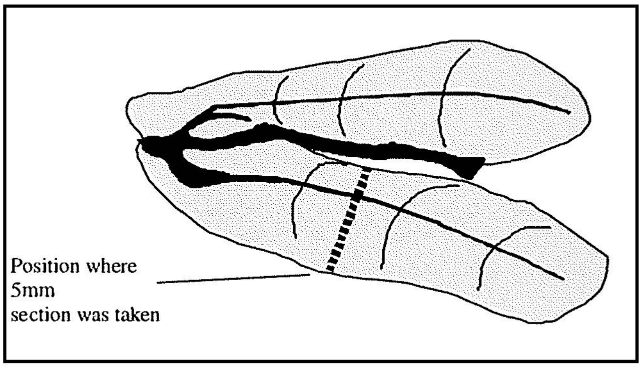

Figure 5 Diagram of sea mullet ovaries showing the position of histological sections.

Gonadosomatic Index (GSI) was calculated for each fish by the following formula:

GSI = $\frac{gw}{www} \times 100$ where *gw* = gonad weight, *www* = whole wet weight.

Gonads from juvenile fish and ovaries from females taken in estuaries during the non-spawning period were sectioned to determine sex and/or developmental class. Data recorded included the reproductive class (dominant oocyte stage or > 50% of the field of vision) and 10 maximum diameter measurements of the most advanced oocyte stage. Maximum diameter measurements were done using computer image analysis systems.

5.6.2 Ovary tissue exchange program

To check the consistency of staging ovary sections between NSW and Qld researchers an exchange program was developed. This involved the preparation of 100 ovary sections providing a range of developmental stages from each state taken from biological samples. The staging of oocytes by each state were then compared.

6. Achievement of objectives

6.1 New South Wales

Objective (1) Preliminary comparison of the value of the total mullet catch in NSW and Qld under the present management regime and under alternate regimes that may be considered. What is the value of the "hardgut" run? What is the comparative value of mullet as a food fish and as a producer of roe?

The values of different components of the fishery are estimated (Section 8.1.1) allowing assessment of the value of the fishery under alternate management regimes. The sea mullet fishery in NSW is valued at $11.4 million per annum. The ocean beach component of the fishery ($7.3 million) is valued at approximately 1.8 times that of the estuary component ($4.1 million). Within the ocean beach component of the fishery the value of the non-spawning run component, which includes the hardgut run fish , is approximately $0.1 million .

Objective (2) Calculation of the potential social and biological impact of redirecting effort among the estuarine and oceanic components of the fishery as a result of alternate management regimes, and, in the case of Qld, among ocean beach regions

The fishery is described in terms of catch, numbers of fishers and value for different components of the fishery (Section 7.1). The size and age structure of commercial catches (Section 7.2.2) and the reproductive biology of sea mullet have been examined (Section 7.3.1). This information will assist managers in assessing the potential social and biological impact of redirecting effort amongst components of the fishery. There appear to be possible economic and biological advantages in redirecting effort to ocean beaches but there are obviously many important social issues that would also need to be considered in any such comparison..

Question (1) What percentage of mullet spawn each year? In what area?

The percentage of mullet which spawn each year and the areas in which they spawn are discussed in Section 8.1.3.1. It appears that the proportion of fish spawning increases from ages 3 to 6 years. It is likely that spawning occurs in ocean waters at a range of latitudes in NSW.

Question (2) For how many years do individual mullet spawn (do they spawn only once)?

The number of years during which mullet might spawn is discussed in Section 8.1.3.2. The available evidence suggests that sea mullet are likely to spawn for more than one year, but may not commence spawning until their 3rd, 4th, 5th or 6th year of life.

Question (3) Does the age and size at first spawning differ among individuals from different estuaries.?

The size and age at first spawning is discussed in Section 8.1.3.3 The youngest age at which spawning occurs is 3 however this age group represents less than 5% of the catches. The smallest size at which spawning occurs is 33 cm (TL) for females and 30 cm (TL) for males. There does not appear to be a latitudinal difference in the size and age when sea mullet begin spawning. Larger sample sizes would be required to confirm this.

Question (4) What is the appropriate legal size for mullet?

The appropriate legal size is discussed in Section 8.1.3.4 The current minimum legal length (30cm TL, 26.5cm LCF) appears to have very little effect on the size of fish taken in the estuaries and virtually no effect on spawning run fish. The sizes taken are larger than the minimum legal size. It does have an effect on the hardgut fish but these only represent a very small proportion of the fishery (1.4%). The minimum legal size would have to be approximately 30cm (LCF) for males and 33cm (LCF) for females before it had the effect of excluding young spawning run fish from the catches.

6.2 Queensland

Objective (1) Preliminary comparison of the value of the total Mugil cephalus catch in New South Wales and Queensland under the present management regime and under alternate regimes that may be considered. What is the value of the 'hardgut' run? What is the comparative value of Mugil cephalus as a food fish and as a producer of roe?

Under the current management regimes in Qld the sea mullet fishery is valued at about $7 - 8 m p.a. to the fishers. The hardgut component of this is small with a maximum value of $200,000 p.a. The importance of the hardgut run in terms of dollars to the fishers has decreased dramatically in the last 15-20 years because of competition from imported frozen products. Changing management to develop a "meat only fishery" and protect pre-spawning aggregations would decrease the value of the fishery to about $2.3 m p.a. to the fishers on the basis of today's prices for mullet flesh. This would have an adverse economic effect on the 70 ocean beach licence holders and their associated crews as well as on local seasonal employment created by the processing of roe fish. The development of a roe only fishery i.e. by restricting catch to the ocean beach fishery and increasing catches from the pre-spawning aggregations, could create a fishery valued at between $7.5 to $12 m to the fishers. This depends greatly on the increased catch that may occur by not taking sea mullet as a food fish. This type of management policy would have a adverse economic effect on the ~300 net fishers that catch sea mullet as a primary or secondary target species.

Objective (2) Calculation of the potential social and biological impact of redirecting effort among the New South Wales estuarine and oceanic components of the fishery as a result of alternate management regimes, and, in the case of Queensland, among ocean beach regions.

The effect of the introduction of zoning to the ocean beach fishery in Qld is extremely difficult to determine as the log book data provided by CFISH does not allow this scale of reporting to be identified. It is known that there are a number of social aspects that the zoning is trying to address. The zoning will alleviate conflict between locally based and transient fishers. It also restricts that numbers of vehicles accessing beaches throughout the mullet spawning season as there is a limited number of fishermen in each of the zones.

Question (1) What percentage of Mugil cephalus spawn each year? In what area?

a: The percentage of mullet that spawn each year could not be answered in this study. This study did not have a fishery independent component to determine the numbers of fish remaining in estuaries during the winter spawning run, a time when those estuarine fishers still catching mullet are using large mesh nets to catch fish congregating in staging areas before moving onto ocean beaches.

b. Spawning occurs along the length of the east coast fishery with mullet in spawning condition occurring in all areas. Spawning appears to occur offshore away from the surf zone, with the possibility of some minor spawning in estuaries or in areas close to ocean beaches.

Question (2) For how many years do individual Mugil cephalus spawn (do they spawn only once)?

Sea mullet are isochronal spawners i.e. they have one batch of eggs that are released over a short period of time. Spawning takes place in a restricted winter reproductive season with no evidence of spawning outside this season. Spent female fish occurred in samples collected from estuarine catches, during the winter months, indicating that female fish do return to estuaries and therefore may spawn more than once in their lifetime.

Question (3) Does the age and size at first spawning differ among individuals from different estuaries?

There are large variations in the size at age of sea mullet within an estuary making the variations between fish from different estuaries difficult to determine. This is further confounded by the summer "hardgut" that allows fish to move between estuaries before reaching maturity From tagging studies it appears that sea mullet from Fraser Island to NSW form a single stock, however, the influence that environmental characteristics of each particular estuary have on juvenile growth rates and subsequent maturation could not be determined.

Question (4) What is the appropriate legal size for Mugil cephalus?

The legal size of mullet in Qld is 300 mm total length. This is less than the estimated size at first maturity for both male and female sea mullet. Length frequency data collected from commercial catches shows that 1.4% of the total ocean beach catch and 3.4% of the estuarine catch would be expected to be immature female fish. This should also be weighed against the fact that the ocean beach fishery targets spawning run females and therefore there is the possibility that although females are reaching maturity they are being caught before they actually spawn for the first time. The low proportion of immature female sea mullet represented in the catch when considered along with other management measures in the fishery indicates that the current size limit is appropriate.

7. Results

7.1 Fishery structure

7.1.1 New South Wales

7.1.1.1 Trends in catch

In NSW, the catches of sea mullet are the largest among finfish species taken in the estuary (47%) and ocean beach (62%) fisheries (Figure 6). Other important species in the estuary are luderick (11%), bream, (10%) and dusky flathead, (4%). In the ocean, other important species include Australian salmon (23%), bream (5%) and luderick (3%). Sea mullet fishers often catch these other species.

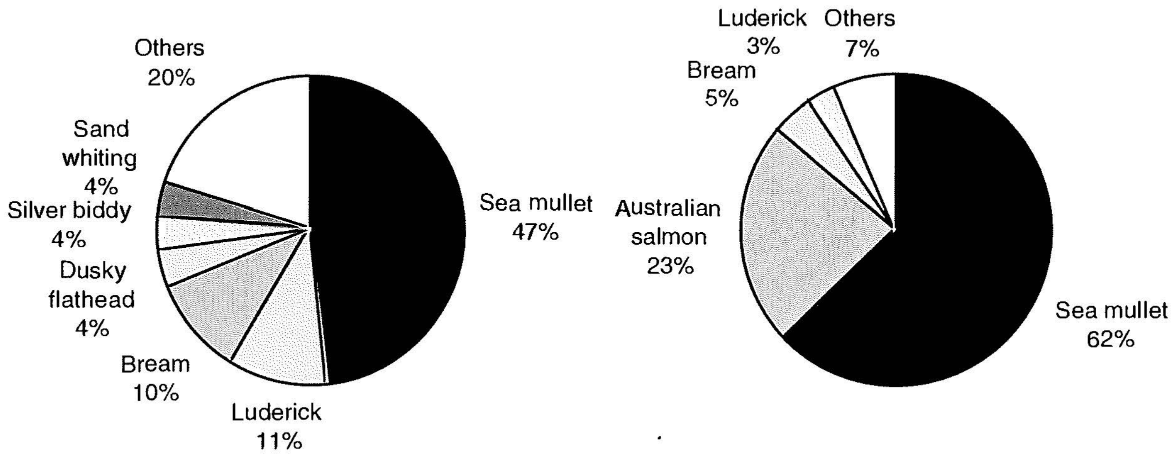

Figure 6 Average catches of important commercial finfish species from the estuaries and ocean beach locations in New South Wales for the 5 year period from 1992 to 1996.

While the estuary catch has remained stable at approximately 2000 tonnes per annum for many years, the ocean beach catch has increased substantially from approximately 500 tonnes to 2000 tonnes over the last 15 years (Figure 7).

The estuary catches (Figure 8) have remained approximately the same for all seasons except for a small increasing trend in the autumn catches. The highest catches are in autumn (~800 tonnes) followed by summer(~600 tonnes) winter (~400 tonnes) and spring (~300 tonnes).

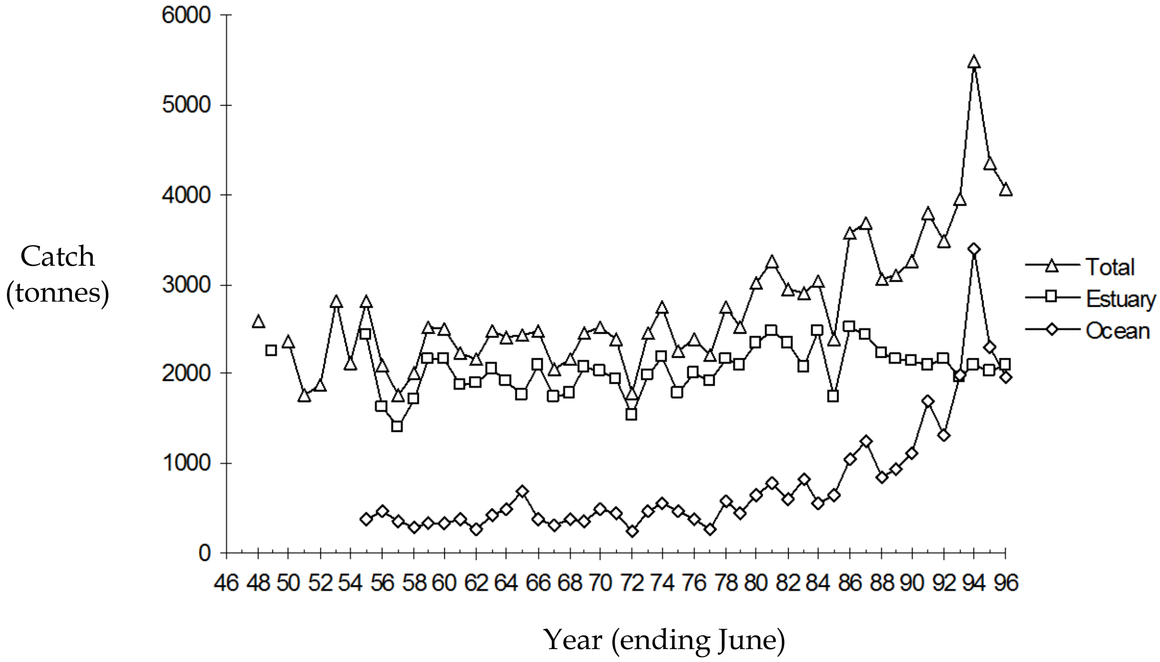

Figure 7 Commercial catches of sea mullet from New South Wales showing the ocean beach and estuary catches from 1955/56 to 1995/96 and total catch from 1947/48 to 1995/96.

The ocean beach catches (Figure 9) have been low in all seasons except autumn. This component of the catch has increased from less than 500 tonnes to approximately 2000 tonnes during the last 15 or so years and is therefore almost solely responsible for the increases in total catch (Figure 7**).** Catches in the other seasons on ocean beaches have generally been below 200 tonnes.

7.1.1.2 Components of the fishery

During recent years (1991/92 to 1995/96) the average catch of sea mullet has been approximately the same in the estuary (2075 tonnes) and ocean beach (2190 tonnes) sectors of the fishery. Most (90%) of the estuary catches have been made north of Sydney in zones 1 to 6 (Figure 10). The main areas were on the central north coast in locations such as Port Stephens and the Myall River and Lake system, Tuggerah Lakes, Wallis Lake and Lake Macquarie, and on the far north coast from the Clarence River (Figure 11). The Clarence River was the highest ranking river accounting for 20% of the states estuary catches of sea mullet. The 10 highest ranking estuaries accounted for 75% of the estuary catch and the 15 highest ranking estuaries accounted for 90% of the estuary catch (Figure 11). A high proportion (79%) of the ocean beach catch of sea mullet was taken on the central and mid north coast (Figure 10).

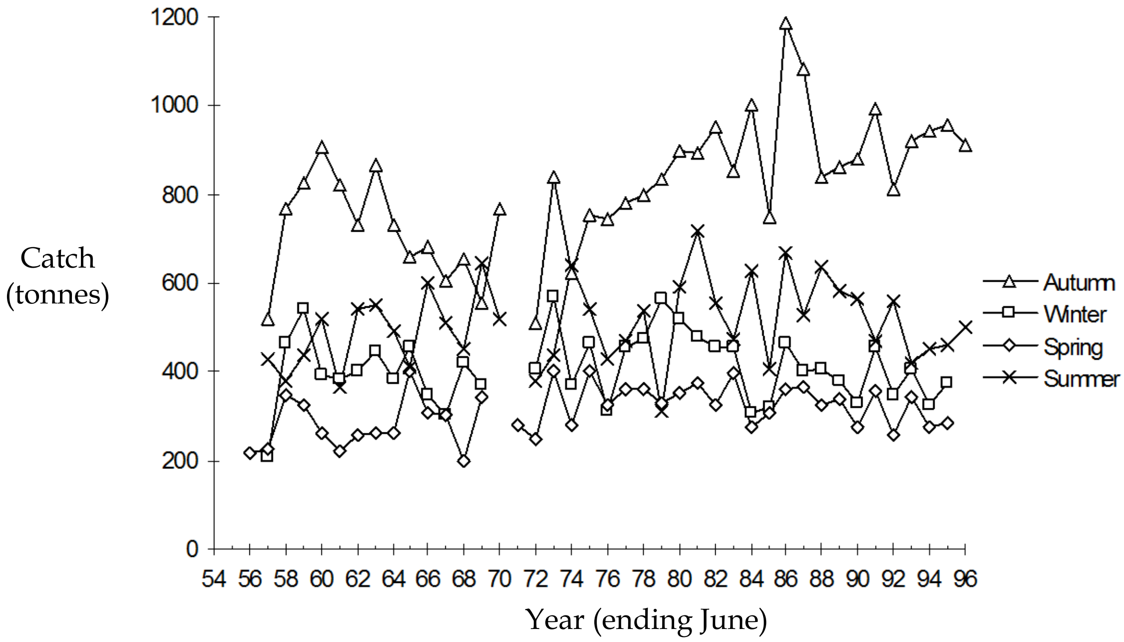

Figure 8 Commercial catches of sea mullet from estuaries in New South Wales for each season from 1956 to 1996

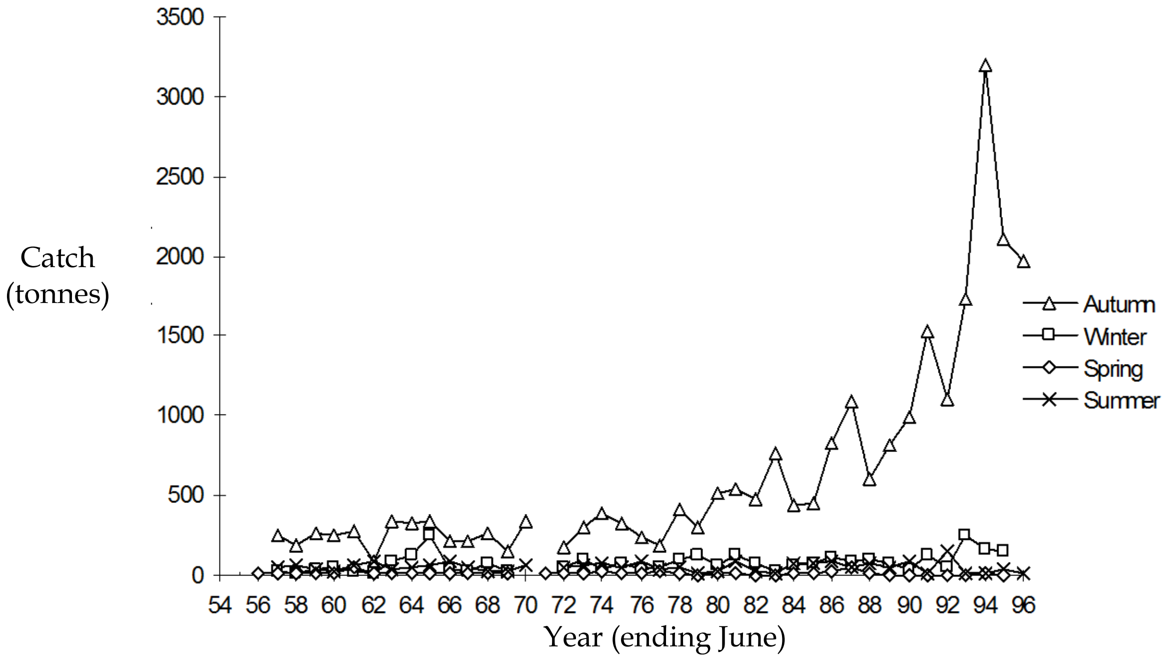

Figure 9 Commercial catches of sea mullet from ocean beaches in New South Wales for each season from 1956 to 1996.

The ocean beach catches were much more seasonal than the estuary catches. In the estuaries the catches are made throughout the year with peaks in April on the central north coast and May on the far north coast (Figure 13). On the ocean beaches nearly all the catches are made in the months from March to June inclusive (Figure 14). There is a chronological progression in the peak period of catches from March on the south coast to May on the north coast.

The hardgut component of the fishery occurs outside the spawning run season during spring and summer. Catches for this component of the fishery averaged 47 tonnes in the years from 1992 to 1996 and accounted for only 2% of the total NSW sea mullet catch.

A total of 871 fishers reported catches of sea mullet in 1995/96 (Figure 12). Approximately twice as many fishers (772) recorded catches of sea mullet in the estuary than on ocean beaches (380) with an overlap of 281 recording catches from both sectors. For both sectors of the fishery 90% of the catch was taken by slightly less than half of the fishers. Catch per fisher in the ocean is approximately twice that in the estuary (Figure 12).

The geographical distribution of fishers is similar to the distribution of catches. Thus, in the estuaries, the highest numbers of fishers work in the central and far north coast while in the ocean sector the highest numbers of fishers work in the central and mid north coast (Figure 10).

7.1.1.3 Value estimation

The value of the NSW sea mullet fishery in terms of the price paid to commercial fishers is estimated at around $11.4 million. Although the estuary and ocean beach catches of sea mullet are approximately the same (~2,000 tonnes), the value of the ocean beach fishery ($7.3 million) is approximately 1.8 times that of the estuary fishery ($4.1 million) due to higher proportions of spawning run fish in the ocean beach sector and the higher prices paid for roed sea mullet (Figure 10).

On the ocean beaches most of the value of the fishery is in the central and mid north coast during April and May. This component of the fishery alone is valued at approximately $5.2 million which is nearly half the total value for sea mullet in NSW for the year.

In the estuaries, most of the value comes from the central coast (~$2.7 million) and the far north coast (~$1.4 million), which together account for approximately 85% of the estuary sector ($4.1 million).

The hardgut component of the fishery is valued at approximately $0.100 million or 0.9% of the total value of the NSW fishery.

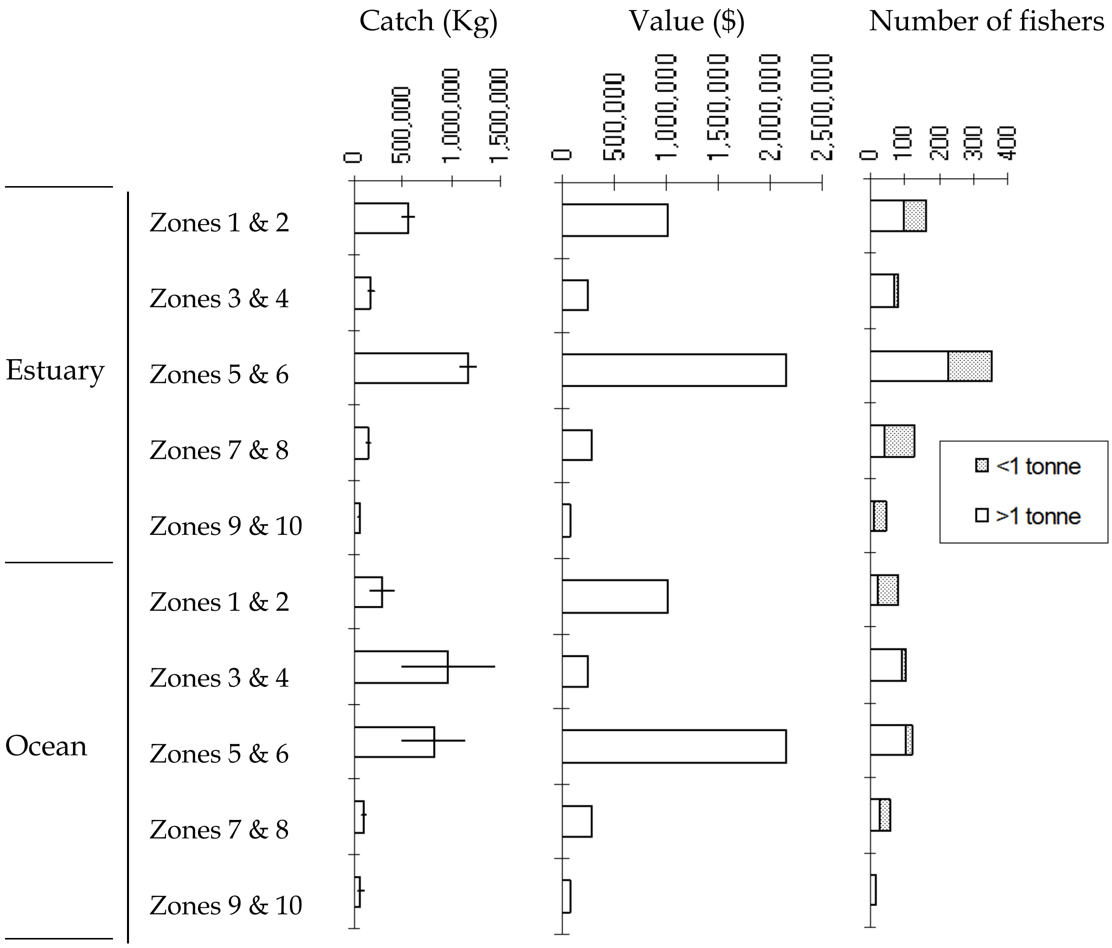

Figure 10 The (a) average catch (± SD) (1992/3 - 1995/6), value (b) and numbers of fishers (c) recorded catching sea mullet in various components of the commercial fishery in New South Wales. The number of fishers recording catches less than 1 tonne per annum is shown in the shaded areas.

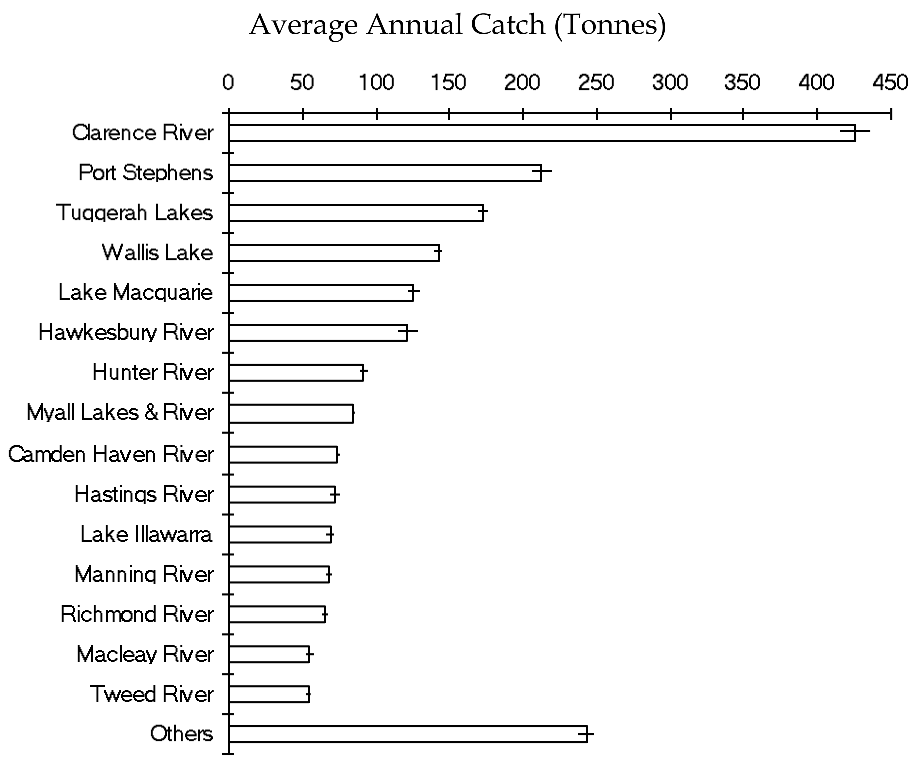

Figure 11 Average annual catches (± SD) of sea mullet in the main estuaries in New South Wales for the years 19991/92 to 19995/96.

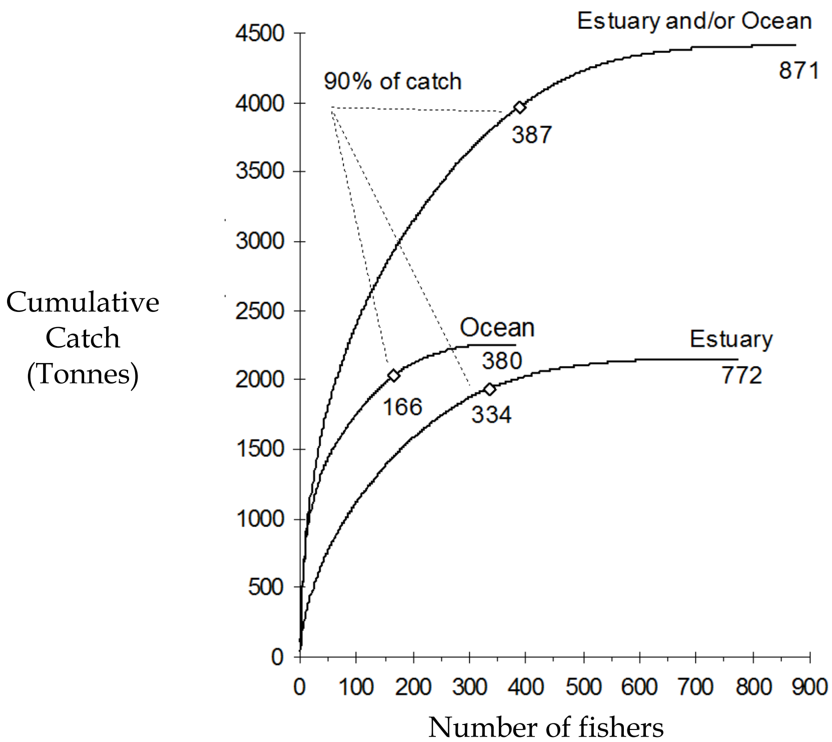

Figure 12 Cumulative catch of sea mullet for New South Wales fishers ranked from highest to lowest catch during 1995/96. The point on the curve representing 90% of the total catch is shown.

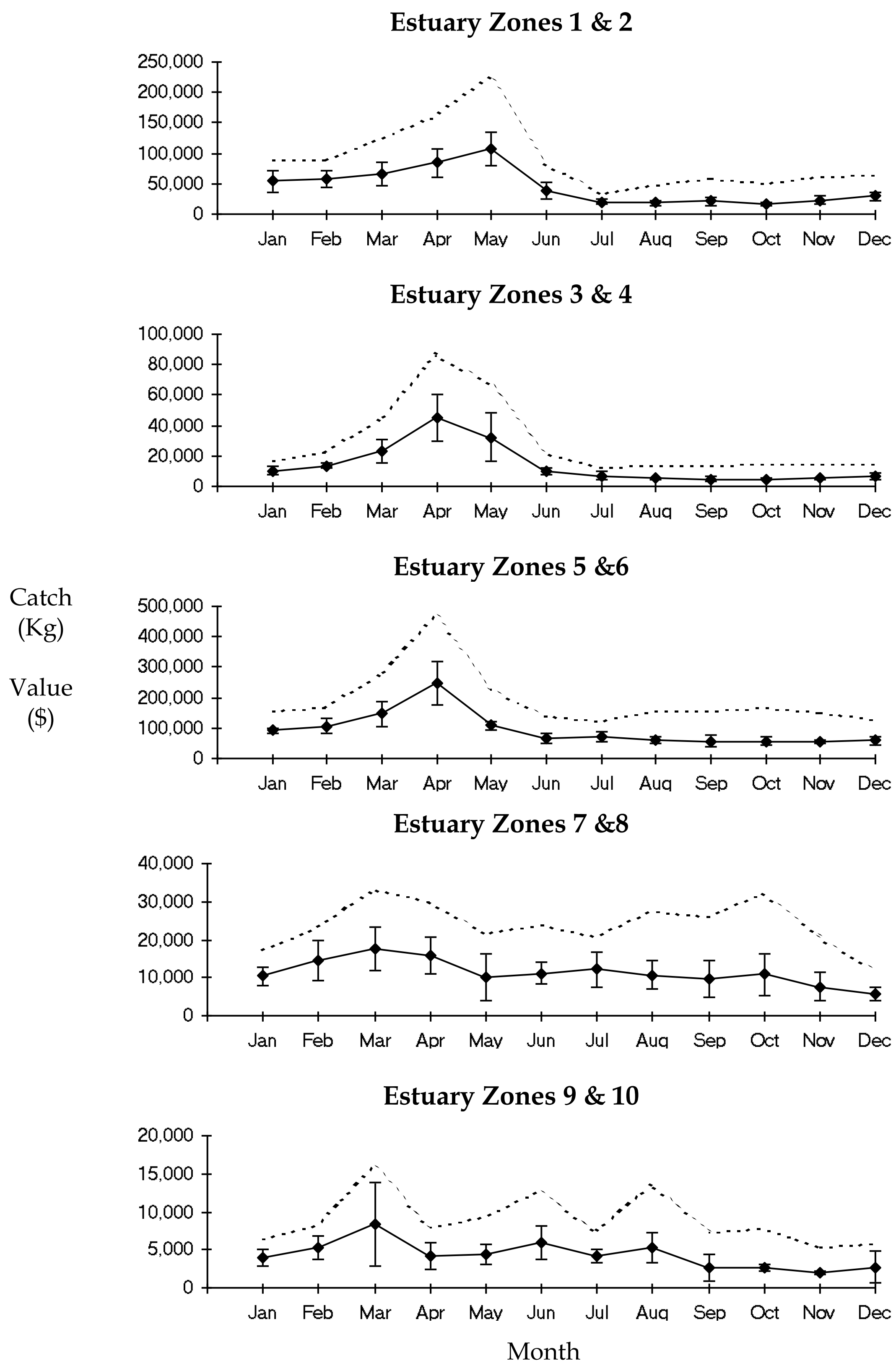

Figure 13 Average monthly catches (± SD) of sea mullet from the estuaries for the 5 year period from 1992 to 1996 for geographic intervals of 2deg latitude on the New South Wales coast. Dashed lines show monthly values of catch based on the 1996 prices applied to the five year average (Note the difference in scales amongst zones).

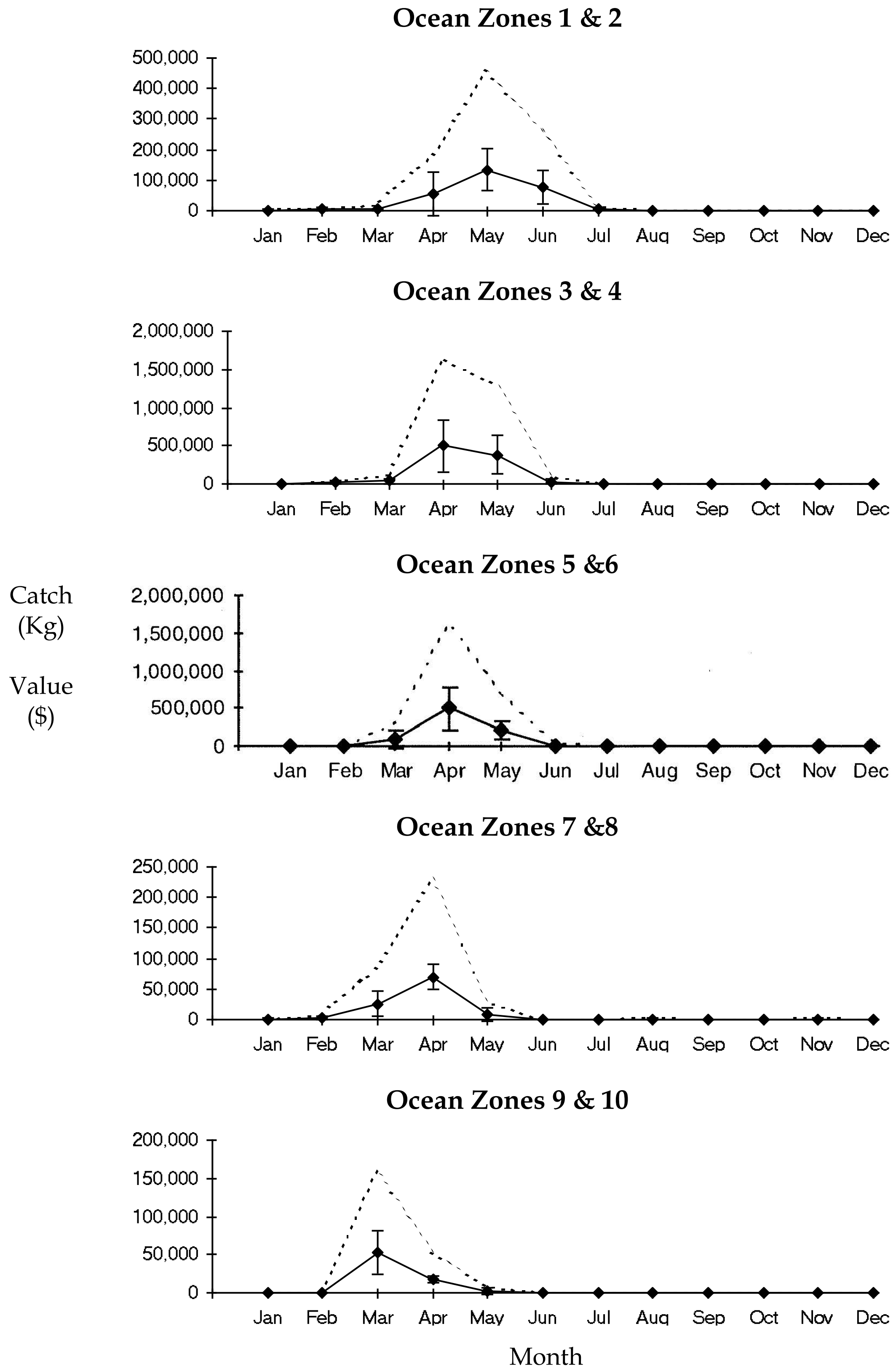

Figure 14 Average monthly catches (± SD) of sea mullet from the ocean spawning run sector for the 5 year period from 1992 to 1996 for geographic intervals of 2deg latitude on the New South Wales coast. Dashed lines show monthly values of catch based on the 1996 prices applied to the five year average (Note the difference in scales amongst zones).

7.1.2 Queensland

7.1.2.1 Trends in catch

Excluding the period from 1970 and 1987 the annual sea mullet catch from 1943 to 1995 has ranged from 1241 t in 1960 to 2686 t in 1988, with a mean and S.D. of 1886 +/- 367 t **(**Figure 15**).**

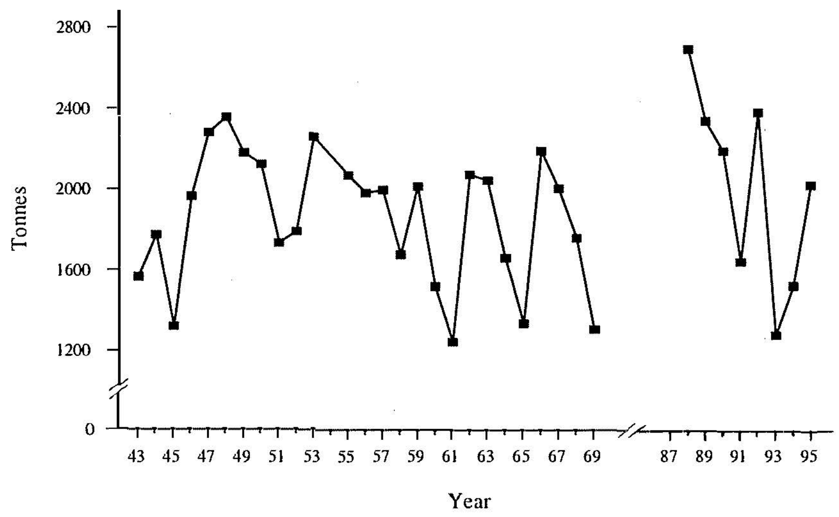

Figure 15 Total commercial catch of sea mullet in Queensland waters**.**

Fluctuations in annual catches have been partially attributed to environmental factors such as high numbers of jellyfish (1943); heavy rains during late summer (1951); south-easterlies combined with low summer rainfall; a small hardgut catch (1961) and severe drought (1965). During the war years factors such as scarcity of fishing gear (1945) may have resulted in lower than average catches. Market driven factors such as a severe reduction in effort due to fear of 'kerosene taint' in 1969 are also valid explanations for fluctuations in annual catch. Comments corresponding to good catch years were good size and condition of mullet caught (1948); a good hardgut season (1953, 1959, 1962) and a marked increase in rainfall (1966). The variable hardgut mullet run in summer has become of lesser importance in recent years as the demand for this fish for local markets has decreased in the last 15-20 years with the advent of imported frozen fish fillets. There has been no indication of increasing ocean beach catches even though hardgut fish are no longer targeted as much as they used to be.

7.1.2.1.1 Effort.

Effort in the Qld sea mullet fishery has decreased slightly in the period 1988-95 from a high of 11 260 days in 1988 to 8 000 - 8500 days in the years 1992 - 1995 (Figure 16). This decrease in effort was not a result of new management measures but may be due to a number of factors which include: low mullet prices during the non-spawning period forcing fishers to target different species; fishers not reporting catches; fishers amalgamating licences and reporting catches on only one logbook; and that days spent looking for fish but not actually catching fish are not being reported as effort. This data is difficult to interpret due to the combined effect of factors mentioned above and the lack of observer validation of the logbook data.

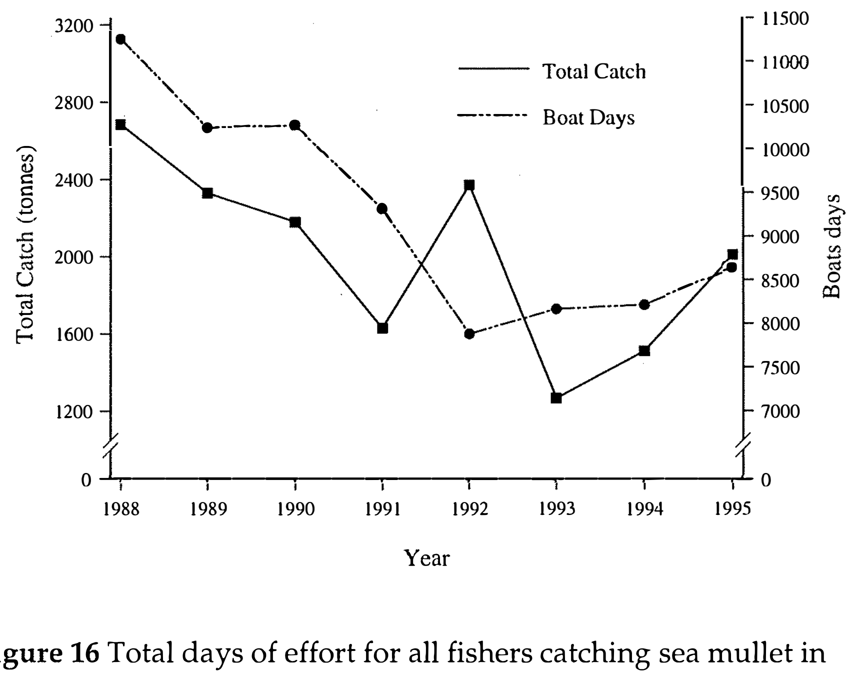

Figure 16 Total days of effort for all fishers catching sea mullet in Queensland waters from 1988 to 1995.

7.1.2.1.2 Catch per unit of effort (CPUE)

The decreasing trend in total annual catch over the last seven years and the corresponding decrease in effort has resulted in catch per unit effort remaining relatively stable at about 250 kg per boat per day (Figure 17). This is probably an under estimation for the fishers that target sea mullet, as log book data shows about half the fishers catching sea mullet take less than 500 kg per year, which indicates that their sea mullet catch is a byproduct of other fishing operations.

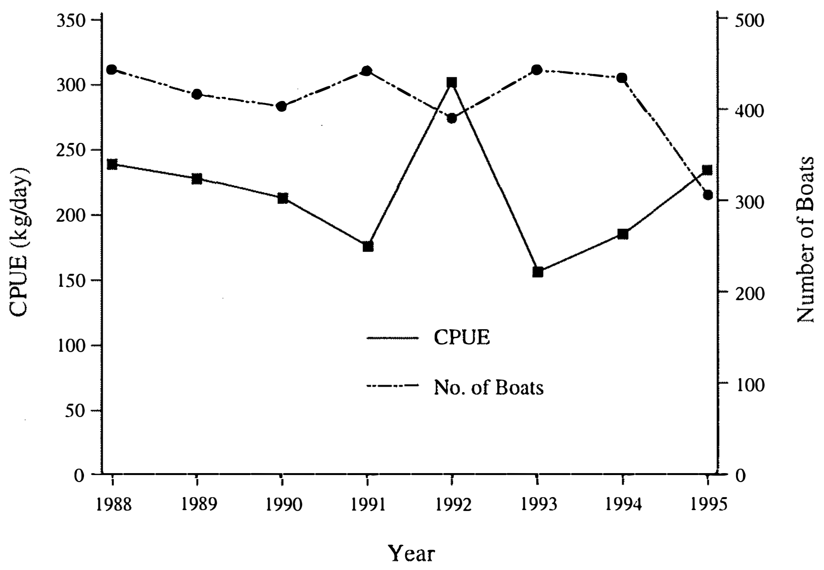

Figure 17 CPUE for the Queensland sea mullet fishery from 1988 to 1995.

7.1.2.2 Components of the fishery

The Qld mullet fishery is divided into two component fisheries. The ocean beach fishery targets sea mullet in spawning condition during their winter spawning run and the estuarine fishery which targets sea mullet for local fresh fish markets throughout the rest of the year.

7.1.2.2.1 The ocean beach fishery

The Ocean Beach Fishery is a special, designated fishery, under different management from the rest of the east coast fisheries in Qld. It is a limited entry fishery with 70 licences endorsed to fish on the ocean beaches between the Qld - NSW border and the northern tip of Fraser Island (Figure 18) from the 1st April - 30th August each year. This fishery primarily targets the spawning run of sea mullet.

Peak catches in the ocean beach fishery occur during June. Approximately 70-80% of the total sea mullet catch for Qld is taken during the ocean beach season from April to August (Figure 19) with 33% of the total catch taken during June (Figure 20). About half the catch during the ocean beach season is taken in estuaries, rivers and areas outside the designated ocean beach fishery. Most of the latter is in spawning condition, and is sold for roe at prices similar to those received by the ocean beach fishers.

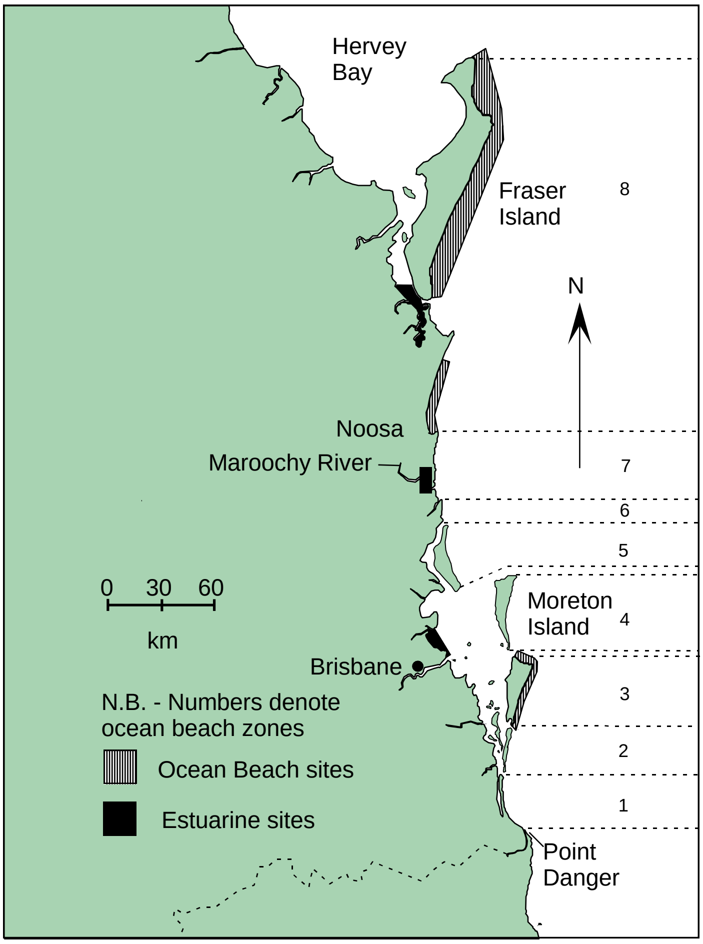

Figure 18 Sampling sites and zoning of the Queensland ocean beach fishery.

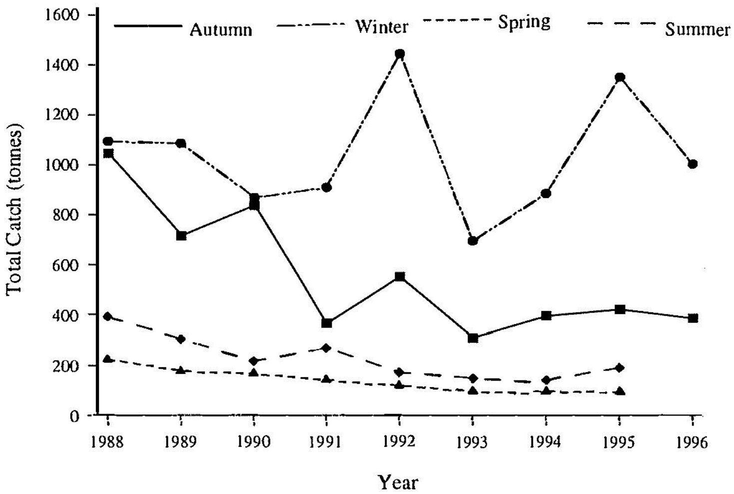

Figure 19 Seasonality of commercial sea mullet catches in Queensland.

7.1.2.2.2 The estuary fishery

The estuary fishery for sea mullet catches about 25% of the total sea mullet catch in Qld. Fishers in this fishery often are small operators working as individuals or in pairs to take mullet in gill and tunnel nets. This provides about 78 tonnes of meat to local markets throughout Qld in all months other than in the spawning season. Catches from estuaries immediately after the winter spawning run are usually lowest with increasing catches throughout summer and into autumn (Figure 19). There are currently 1039 fishers eligible to participate in this fishery with 300 of these recording catches of sea mullet in log books.

7.1.2.3 Value estimation

During the 1995 season, the sea mullet fishery in Qld was estimated to have been worth between $7 and 8 million to the fishers. This estimate was achieved by converting monthly catches from kgs landed into the number of male and female fish in the catch. The number of each sex was estimated by determining from average weight of male and female fish taken during each month (Table 2). Male and female sea mullet grow at different rates but are represented in a 1:1 sex ratio in the catch. Therefore a conversion of 50% of weight for each sex is not appropriate. As the average weight of male and female sea mullet varies monthly, proportional representation needs to be calculated separately for each month. During the sampling programme sea mullet were not sampled in March, September or December and therefore the estimated average weight was determined from the mean of the previous and following months (Table 2).

Between January and April, and September to December mullet were considered to be in non- spawning condition. The price paid for these fish is usually between $1 and $2.20/kg fluctuating daily in response to supply and demand. As male and female fish are of equal value at this time, a value of $1.50/kg was used to estimate the value of the fishery during these months. During the remaining months (May - August) female fish caught in the ocean beach and estuarine fisheries were considered to be in spawning condition. This results in a price of $6/kg (the average price received by fishers for whole female fish). In contrast, the price paid for male fish during this period remained at $1.5/kg.

Table 2 Calculations of the 1995 $ value to the fisher of sea mullet.

Month	1995 (kg)	Average Male (g)	Average Female (g)	% Male/kg	% Female/kg	Total Males in Catch (kg)	Total Females in Catch (kg)	Male Value ($)	Female Value ($)
January	36874	428	503	0.46	0.54	16944	19930	25,416	29,895
February	68869	465	450	0.51	0.49	35025	33845	52,537	50,767
March	113402	468[a]	506[a]	0.48	0.52	54458	58943	81,688	88,415
April	86071	470	563	0.45	0.55	39159	46912	58,739	70,368
May	222403	531	756	0.41	0.59	91702	130701	137,552	784,208
June	858431	537	844	0.39	0.61	333734	524697	500,601	3,148,183
July	388034	499	775	0.39	0.61	151876	236157	227,815	1,416,944
August	102283	484	811	0.37	0.63	38228	64055	57,342	384,332
September	27286	474[a]	650[a]	0.42	0.58	11505	15781	17,257	23,672
October	29755	463	488	0.49	0.51	14483	15272	21,725	22,908
November	38546	423	409	0.51	0.49	19610	18936	29,415	28,404
December	36825	425[a]	456[a]	0.48	0.52	17775	19050	26,662	28,575
Total Value								1,236,748	6,076,671

[a] = estimated average weights interpolated from data.

7.1.2.3.1 Value of mullet as a meat and roe fishery.

A number of management options have been suggested to achieve the highest dollar value to the fishermen and maintain the sustainability of the mullet fishery. The two options considered here are the value of the mullet fishery as solely a food fish and solely as a roe producer.

The total catch data for 1995 was used to determine the value of mullet as a food fish and as a roe producer. The value of the fishery is calculated in prices paid to the fishermen. Figure 20 shows the average monthly catches in Qld for the period 1988-94. This indicates that the 1995 catch tended to be lower than the average for most months giving a lower estimate of the total value than if the average catch was used.

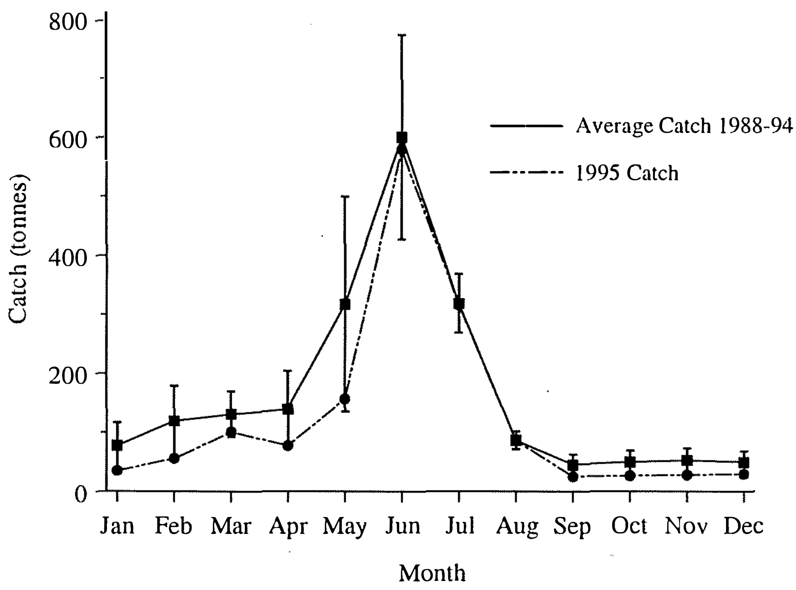

Figure 20 Average monthly catch (± S.D) of sea mullet in from1988 to 1994 compared with total monthly catch for 1995.

7.1.2.3.2 Food fish only (value estimated from the 1995 catch)

To create a food only fishery, fishers would only be allowed to catch enough mullet to supply fresh fish markets with roe from females in spawning condition sold to export markets.

The majority of mullet caught in Qld is consumed by the local market. To estimate the quantity of mullet that would be absorbed by local markets during the winter months, the average annual catches for the non-spawning months (January to April, and September to December) were determined for the period 1988 - 94. The average monthly catch from these months was 78,087 kg. If sea mullet were fished solely for their meat the average yearly value of the fishery would be about $1.4 m. An additional $857,000 could be gained from the sale of the roe taken from female fish caught during the spawning season. This would give an overall production of the meat fishery of $2.26 m p.a.

7.1.2.3.3 Value as a roe fishery alone

A roe only fishery would mean that meat from the mullet fishery would be sold on the local market only from catches targetting spawning fish. The calculations assumed that fishing for mullet would be banned for 8 months of the year outside the spawning run.

Under this scenario it is necessary to calculate the quantity of fish that would not be caught during other times of the year, and the probability that they would be caught during the spawning season. Fishers currently catch as many fish as possible during the spawning season with the technology available to them. Catches are limited by restrictions on the number of licences in the fishery, where the fishermen may use their nets, and by sea conditions. By not allowing mullet to be taken during the non-spawning period the number of fish available to be caught during the spawning period should increase. To determine the numbers of fish that may become available to the ocean beach fishermen under this type of management regime, and again using the 1995 catch data as a basis, we determined the quantity of mullet taken outside the winter spawning season and apportioned the weight to male and female fish. This was done on a monthly basis with some interpolation of the average weight of males and females taken during each month (determined from the biological sampling).

Under an optimistic scenario, 95% of all sea mullet not caught under this arrangement could take part in the spawning run. Considering that females are larger than males and they occur in a 1:1 sex ratio over the year as a whole it is possible to increase the overall roe production of the fishery. From an average production from 1988-1995 an estimated 760 tonnes more of female fish could be caught during the spawning season. This added to the average level of catch of females of 1014 tonnes would increase the value of the fishery to $10.5 m annually, an increase of about $3.5 m from the current harvest (assuming a $6/kg price). Males caught in this fishery would be worth little as they would be put on the market floor during the glut created by the high catches during the spawning season.

If 80% of the fish where caught by the roe fishery, an additional 640 tonnes of female fish could be expected to be caught with an increasing the fishery value to about $10 m p.a., a increase of $3 m on current levels. If 50% entered the fishery the value would be $9 m p.a. with an increase of 480 tonnes of female fish and if 20% entered the fishery the value would be $6.4 m p.a. with an increase of 52 tonnes of female fish, similar to the current value of the catch.

7.2 Catch structure

7.2.1 Otolith exchange program

There was good agreement between the six readings of the 100 otolith sections from NSW and Qld. Agreement was higher for the sections from NSW where 4 or more readings were the same for 99% of the time compared to 87% of the time for the sections from Qld (Table 3).

Table 3 Results of otolith exchange program showing the numbers of samples having various levels of agreement between readers.

	Number of samples with:			Total
	4 out of 6 readings in agreement	5 out of 6 readings in agreement	6 out of 6 readings in agreement	number of samples
New South Wales	99	95	55	100
Queensland	87	66	39	100

7.2.2 New South Wales

7.2.2.1 Size structure

The average size of sea mullet in the ocean spawning run catches was larger than in the estuary catches (Figure 21a). Females were larger than males in the estuary and to a greater degree in the ocean spawning run catches (Figure 24a). Fish in the hardgut component of the fishery were much smaller than in the other components and were similar in size for males and females (Figure 24a).

Sea mullet in the estuary samples were slightly larger in the 1st half of 1996 than in the 1st half of 1995 and were smaller in the 2nd half of 1996 than in the other periods (Figure 22). These differences in catches appear to be influenced by the sizes of females. (Figure 27). Sea mullet in the spawning run catches were on average slightly larger in the 1996 season than in 1995 (Figure 23).

Females were generally larger than males in all estuary (Figure 25) and ocean spawning run locations (Figure 26). In samples from spawning run catches, females at the Port Stephens site were slightly larger than females at the more northern sites (Figure 26).

7.2.2.2 Age structure

Of approximately 3,000 otolith sections examined, 82% were regarded as acceptable with a readability of 3 or less.

The length frequency distributions of the aged fish were plotted to evaluate how representative they were of the of the total length frequencies. Generally, the length frequencies of the aged samples mirror the total length frequencies (Figure 21b & Appendix 3) indicating that the aged samples were reasonably representative of the total samples.

Ages in the commercial catch samples ranged from 2 to 12 years (Figure 21c). In the estuary samples the dominant ages were 3 to 7 years and the age frequency distributions were similar for females and males (Figure 24). In the samples from the ocean spawning run the dominant ages were 4 to 8 years. The dominant ages for females were 5 to 8 years and for males were 4 to 7 years (Figure 24). The ocean non-spawning samples (hardgut samples from Port Stephens) were mostly comprised of fish aged 3 years for males and females (Figure 24).

When examined by time the age frequency distributions of sea mullet in the estuary samples were similar between the 1st and 2nd half of 1995 an the 1st half of 1996 (Figure 22). In females there were peaks at 3 and 5 years of age in the first half of 1995 carrying on to 4 and 6 years of age in the second half of 1996 (Figure 27). In the first half of 1996 the year 4 peak is still present but the year 6 peak somewhat diminished. Males follow the same pattern except there is no 3 year peak in the 1st half of 1995 (Figure 27). In the ocean spawning run samples the proportion of older fish was slightly higher in 1996 than in 1995 (Figure 23). The female and male peaks are one year apart (6 and 5 respectively) in 1995 while in 1996 there is a high proportion of year 4 males and the female and male peak ages are 2 years apart (6 and 4 respectively) (Figure 28).

When examined by area the female and male age frequency distributions were similar within estuaries but varied between estuaries (Figure 25). Higher ages were more dominant in the Shoalhaven River than in the more northern estuaries. In the ocean spawning run samples, female and male age frequency distributions were similar in the Tweed samples (Figure 26). Males were generally younger in the southern sites than in the northern sites.

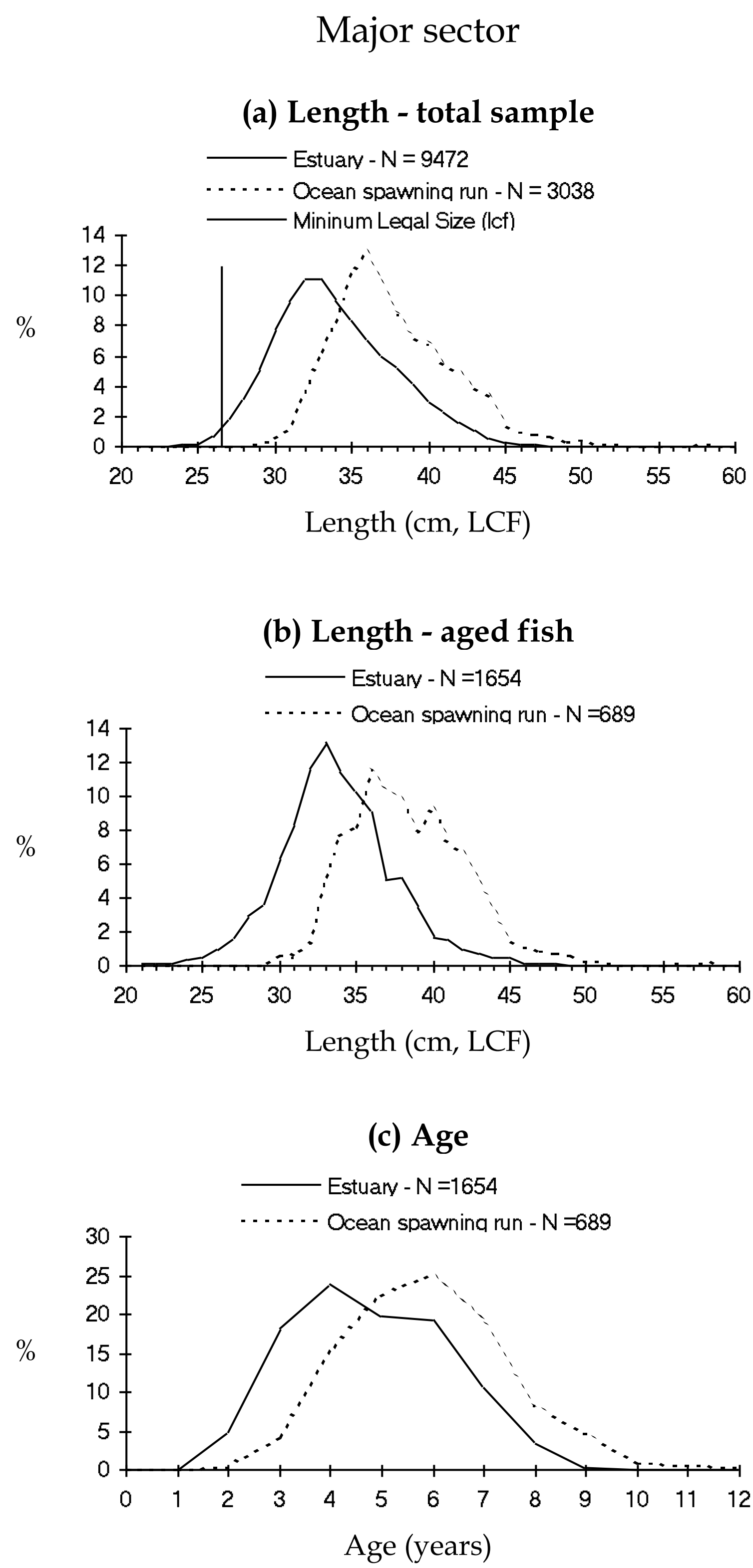

Figure 21 Length (a) and age (c) frequency distributions of commercial catches of sea mullet from the estuary and ocean spawning run sectors of the fishery. The middle chart (b) shows the length frequency distribution of the aged subsample. The estuary data is for the period from January 1995 to June 1996 and the ocean data is for the 1995 and 1996 spawning runs.

Estuary sector by time

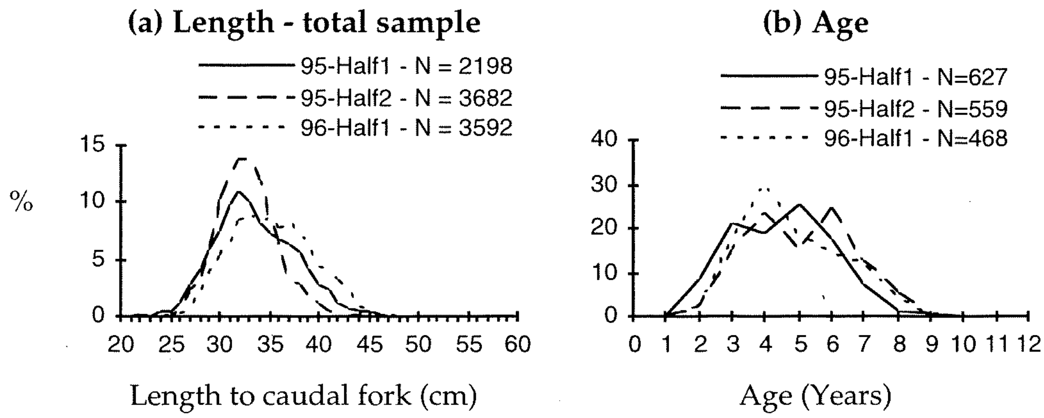

Figure 22 Length (a) and age (b) frequency distributions of commercial catches of sea mullet from the estuary sector of the fishery for the 1st half of 1995, 2nd half of 1995 and the 1st half of 1996.

Ocean spawning run sector by time

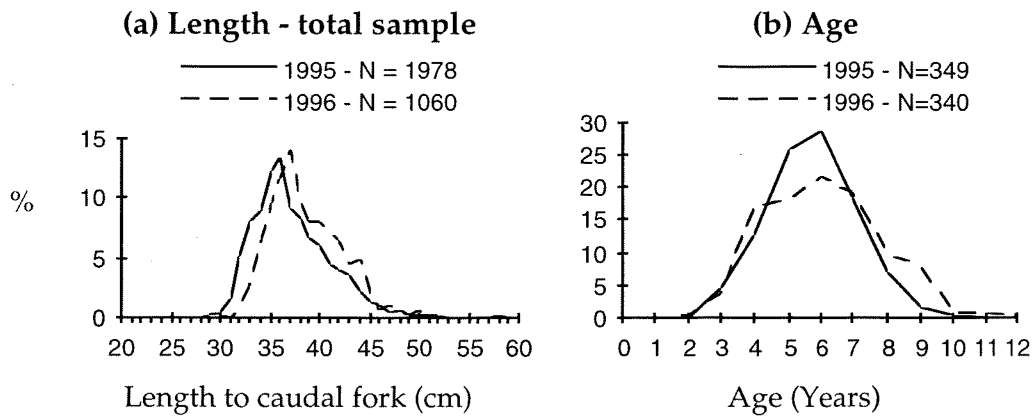

Figure 23 Length (a) and age (b) frequency distributions of commercial catches of sea mullet from the ocean spawning run sector of the fishery for the years 1995 and 1996.

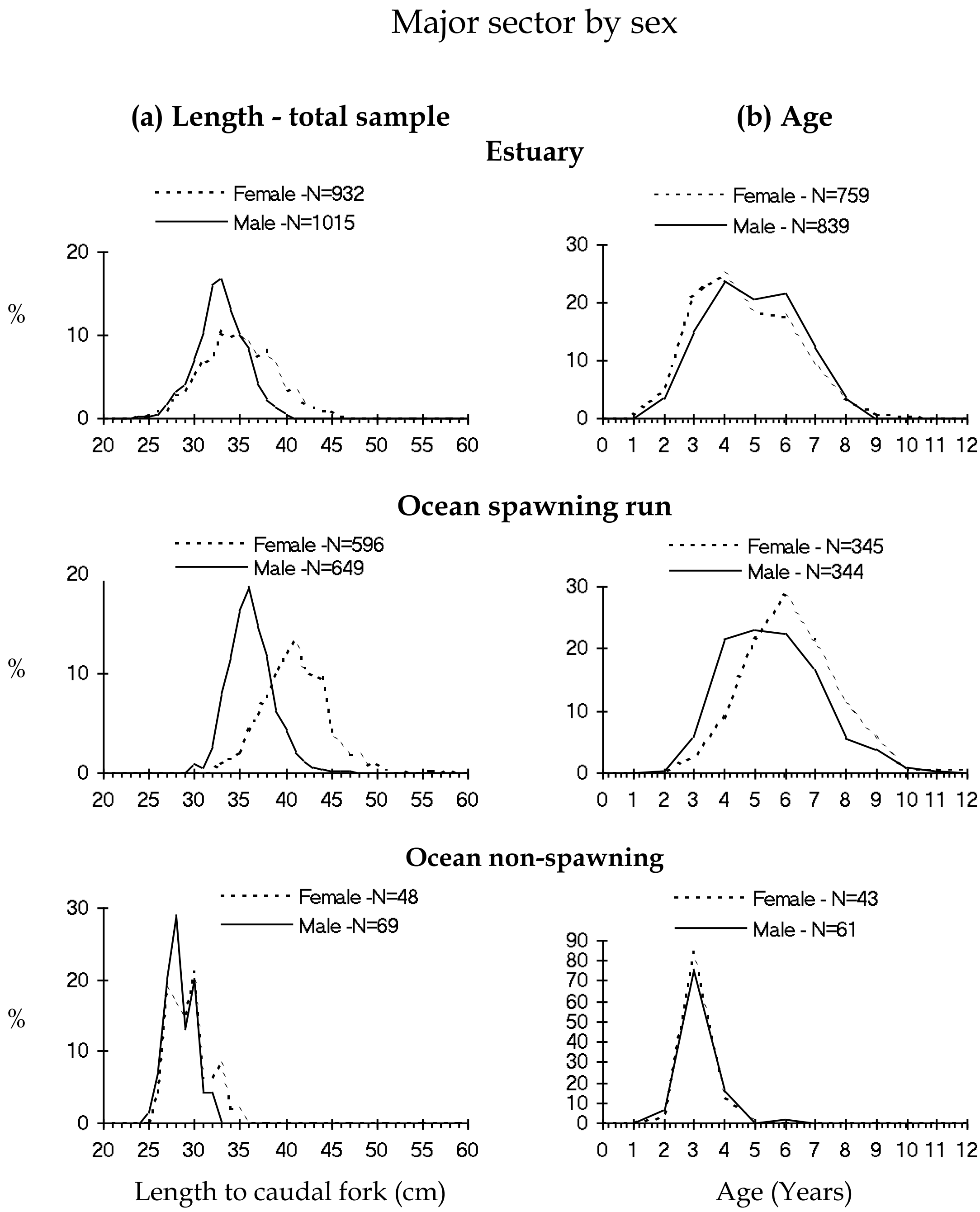

Figure 24 Length (a) and age (b) frequency distributions of commercial catches of sea mullet for the major sectors for each sex for the period from January 1995 to June 1996.

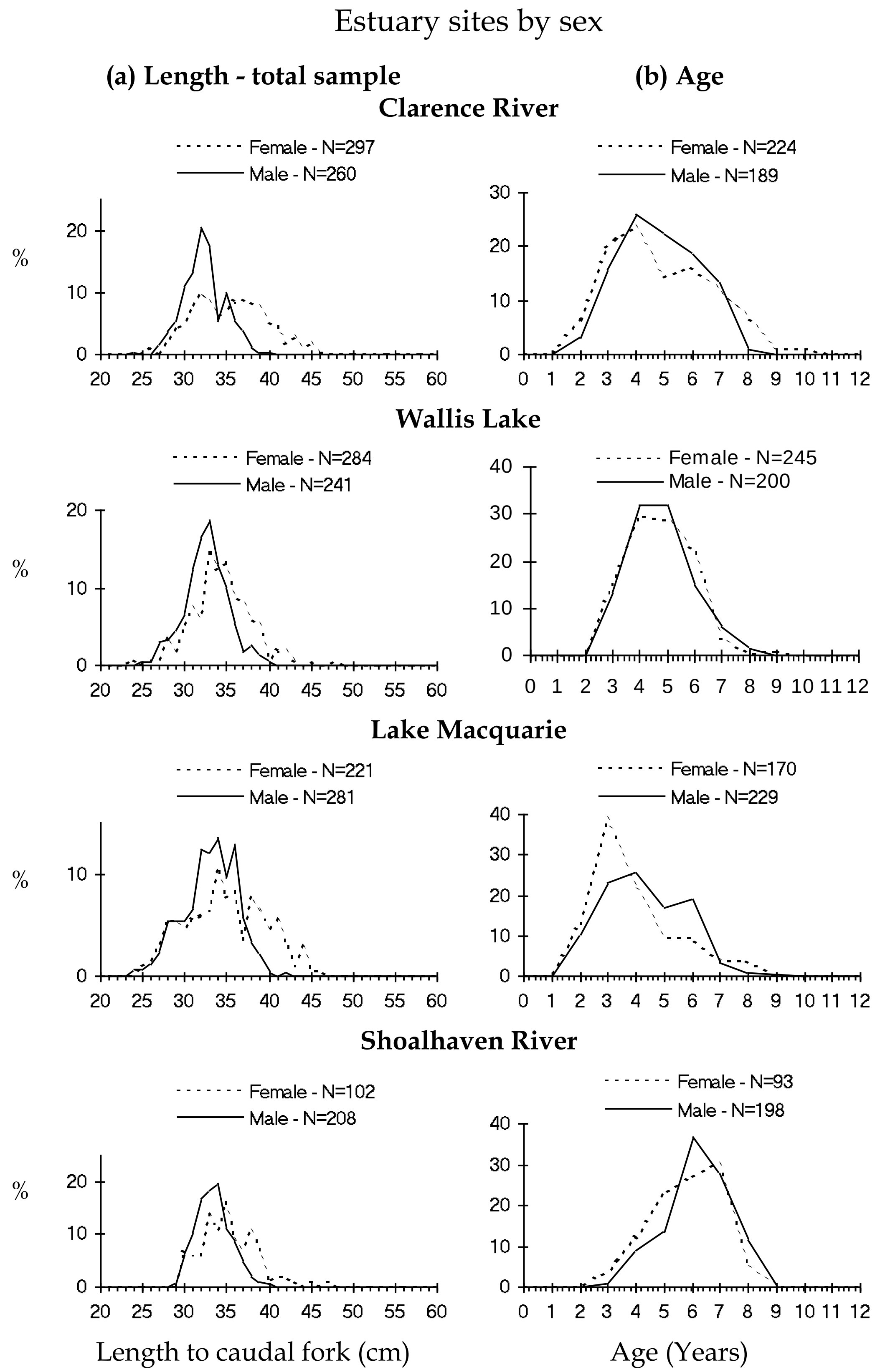

Figure 25 Length (a) and age (b) frequency distributions of commercial catches of sea mullet from the estuary sites for each sex for the period from January 1995 to June 1996.

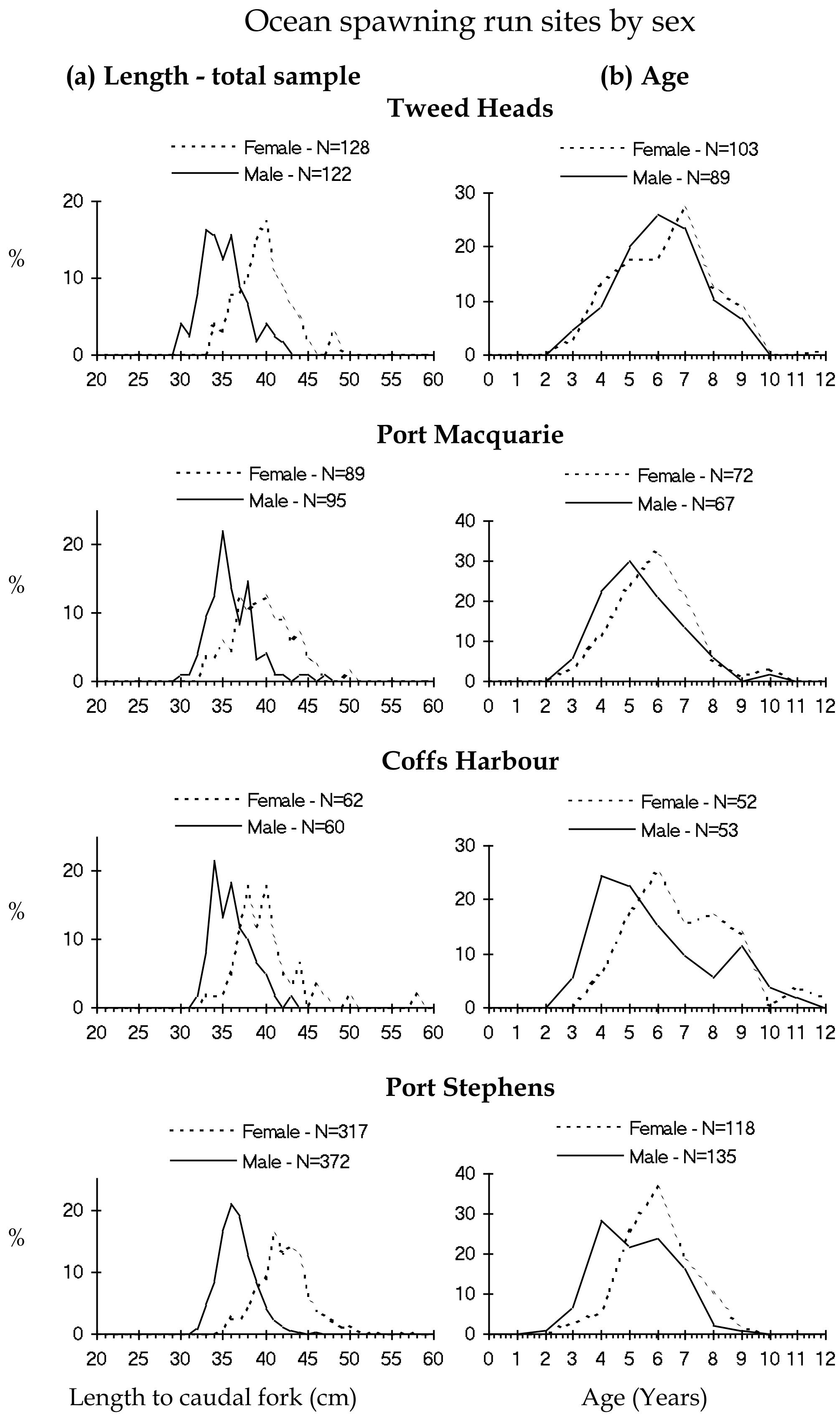

Figure 26 Length (a) and age (b) frequency distributions of commercial catches of sea mullet from the ocean spawning run sites for each sex.

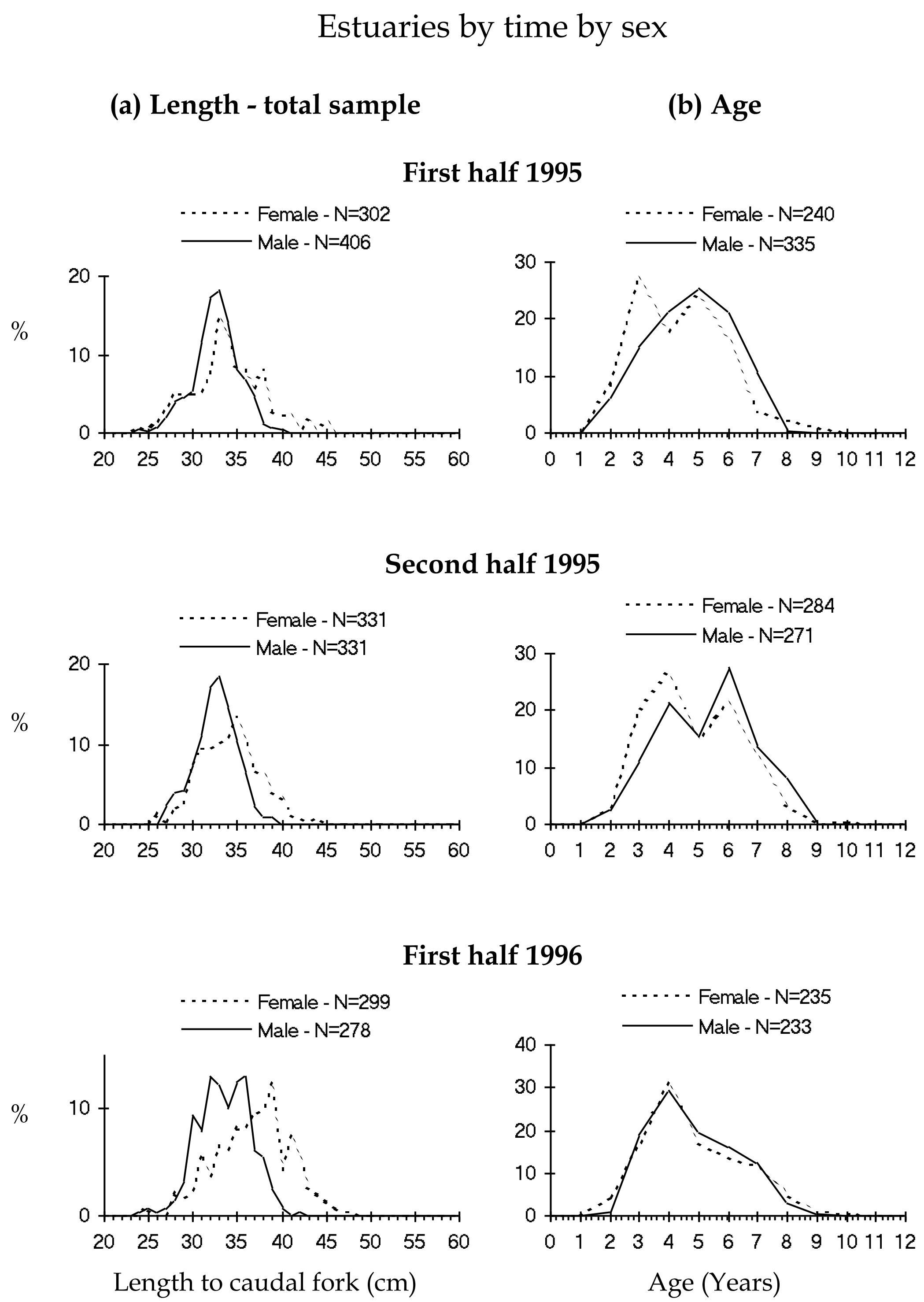

Figure 27 Length (a) and age (b) frequency distributions of commercial catches of sea mullet from the estuaries for the 1st half of 1995, 2nd half of 1995 and 1st half of 1996 for each sex.

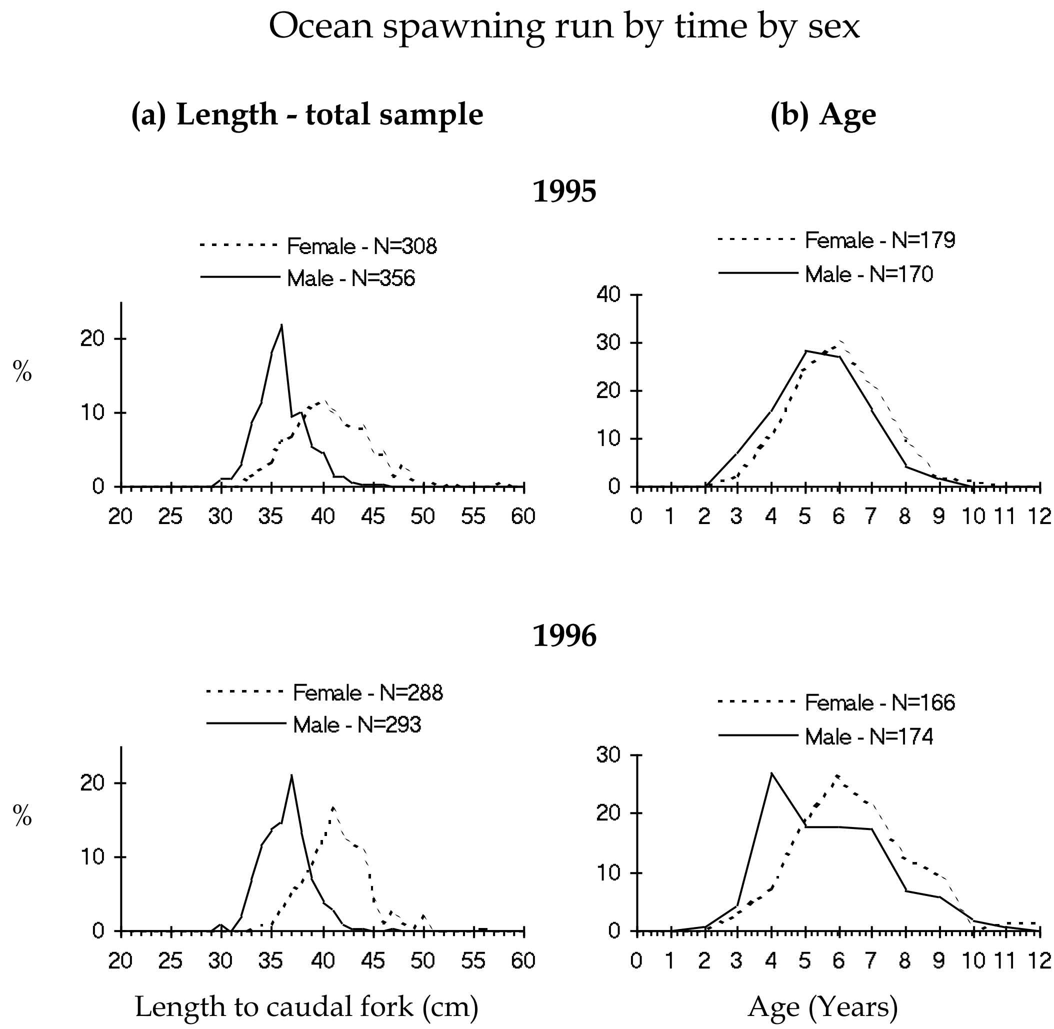

Figure 28 Length (a) and age (b) frequency distributions of commercial catches of sea mullet from the ocean spawning run sector of the fishery for the years 1995 and 1996 for each sex.

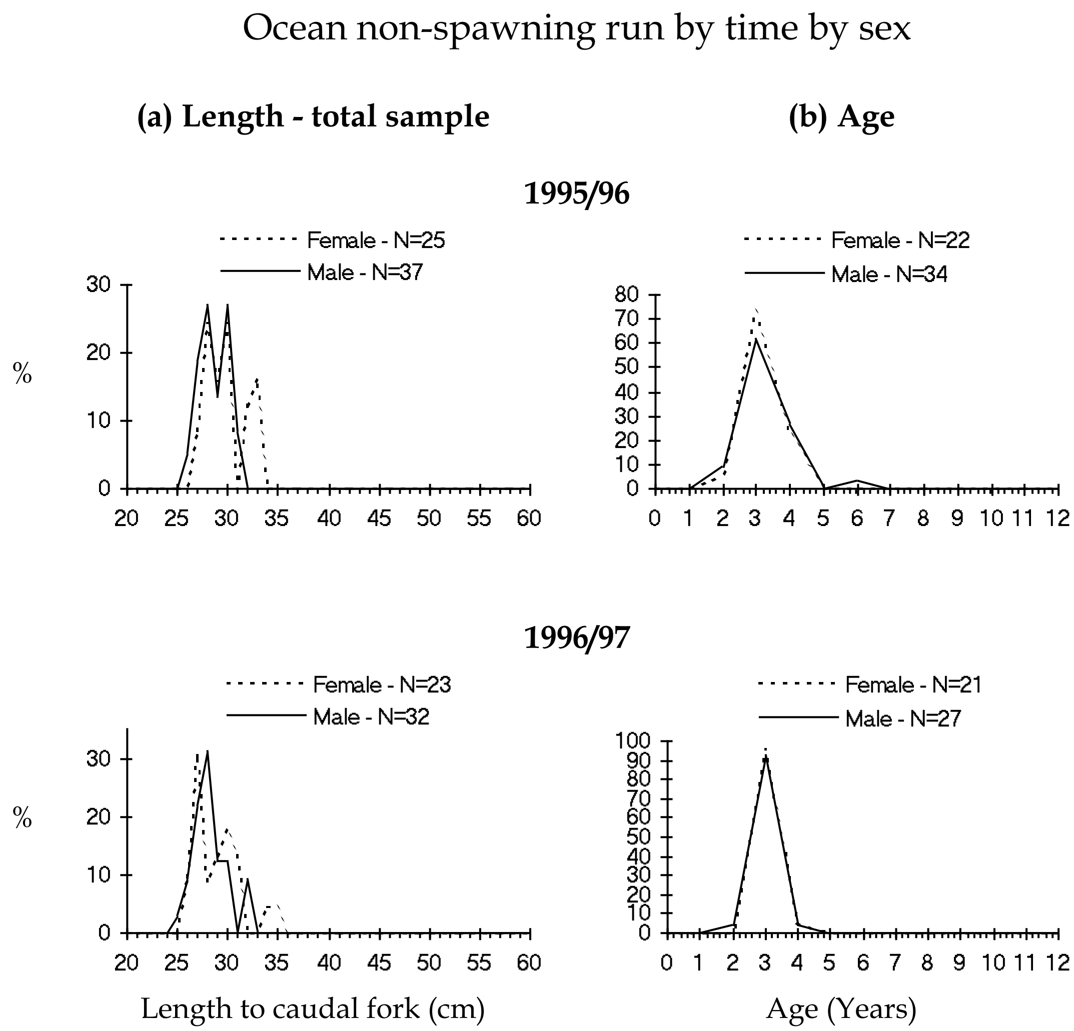

Figure 29 Length (a) and age (b) frequency distributions of commercial catches of sea mullet from the ocean non-spawning sector of the fishery for the years 1995/96 and 1996/97.

7.2.2.3 Age validation

From the reported recaptures (168) where fish have been returned to NSW Fisheries (124), 41 of these fish show clear OTC marks in otolith sections. In these sections the frequency of opaque rings between the OTC mark and the outer edge of the otolith is consistent with an annual pattern in the formation of rings (Figure 30). Fish at liberty for zero to one year duration show either zero or one opaque ring in this region of the otolith section. Those at liberty for one to two years duration show one ring. The presence of two rings in these longer duration fish would also be consistent with annual formation of rings and their absence might be explained by the fact that most were at liberty for just over one year. Any future recaptures of fish that have been at liberty for closer to two years and beyond may provide further information for age validation.

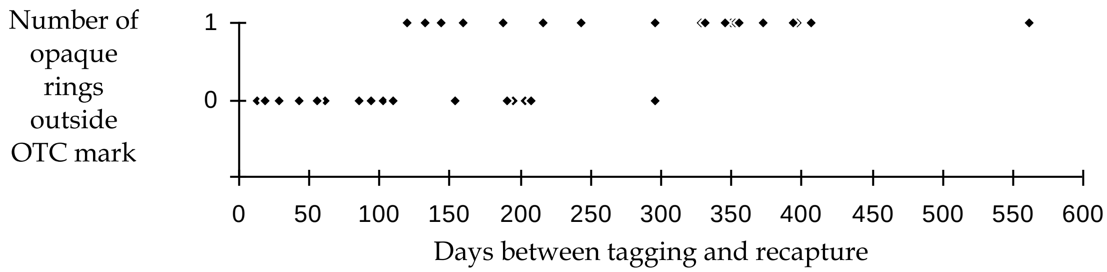

Figure 30 The frequency of opaque rings in otolith sections between the oxytetracycline mark and the edge.

The proportions of opaque and translucent edges show an annual cycle (Figure 31). The highest proportions of opaque edges are found in the cooler months of the year followed successively by high proportions of the first, second and third phases of the translucent zone in the warmer months.

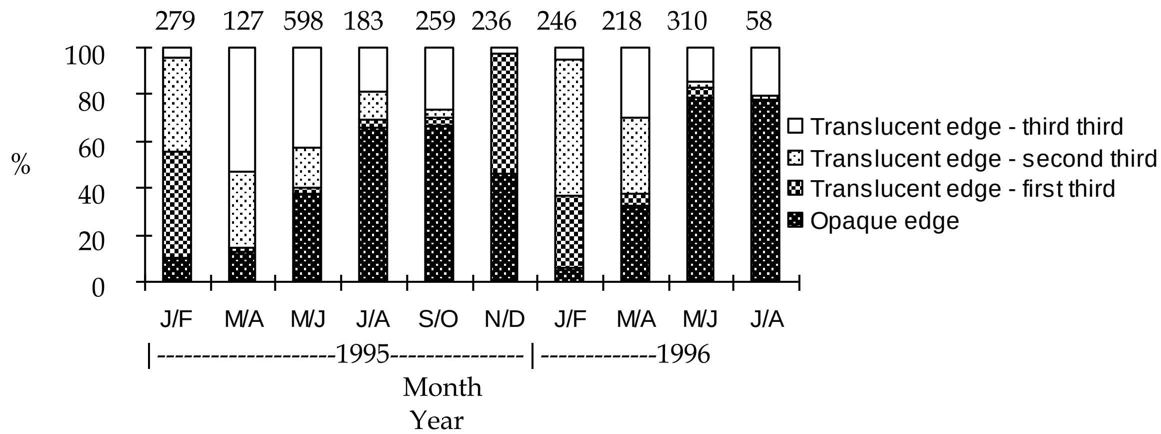

Figure 31 The proportions of otolith sections from New South Wales with opaque edges and three different levels of translucent growth on the edge for different times of the year

7.2.3 Queensland

7.2.3.1 Size and age structure

In total 10 432 sea mullet were measured from the 6 sites. Of these, 2286 were returned to the laboratory for biological sampling (Appendix 2). Of the 2286 fish returned for biological sampling 2264 were successfully aged (at least 2 out of three readings agreeing).

Sea mullet taken in estuarine catches were generally smaller than those taken in ocean beach catches (Figure 32a). The average size for estuarine caught mullet was 315 mm FL and for ocean beach mullet 353 mm FL. The proportion of the catch over 370 mm FL in the estuarine catch was 9% whereas in the ocean beach catches it was 37%. Estuarine caught sea mullet ranged in size from 190 to 490 mm FL. Ocean beach caught sea mullet ranged in size from 210 mm FL to 560 mm FL. The fish kept for biological sampling were representative of the fish measured for both estuarine and ocean beach catches with the proportion over 360 mm FL being 10% and 36% respectively (Figure 32b). Associated with the differences in size structure of the catch was a noticeable difference in the age structure. Fifty three percent of the estuarine catch was less than 4 years old while 25% of the ocean beach catch was less than 4 years old (Figure 32c).

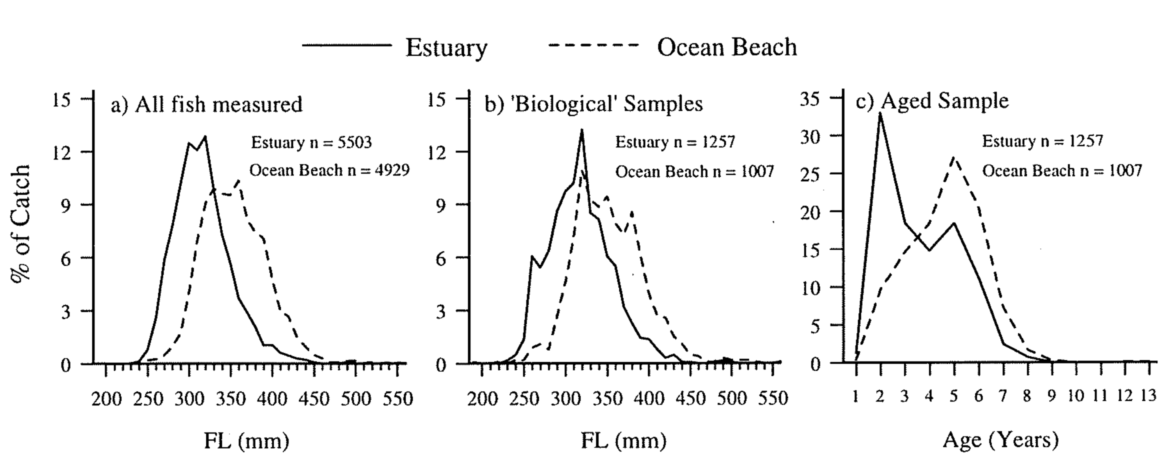

Figure 32 Size and age distribution of sea mullet from Queensland estuary and ocean beach catches. Data was derived from a) all length measurements, b) lengths of biological samples and c) ages of biological samples.

There was very little difference in the average size of mullet taken in estuaries between the two years. The average size of fish caught was 313 mm FL in 1995 and 316 in 1996 (Figure 33a). Biological samples taken from the catches of estuarine fish were a good representation of the actual catch with the average length of fish sampled 314 mm FL in 1995 and 317 mm FL in 1996 (Figure 33b). The age structure estimated from the biological data for estuarine catches showed large differences between years. The 1995 catch was dominated by 5 year old fish with almost equal representation of 2, 3 and 4 year old fish. The 1996 catch was dominated by 2 year old fish, newly recruited to the fishery in that year. Three and 4 year old fish were again represented in about equal numbers of the total catch (Figure 33c). An interesting feature to note about this difference in age structure between years is that it is not reflected by the size distribution of the catch.

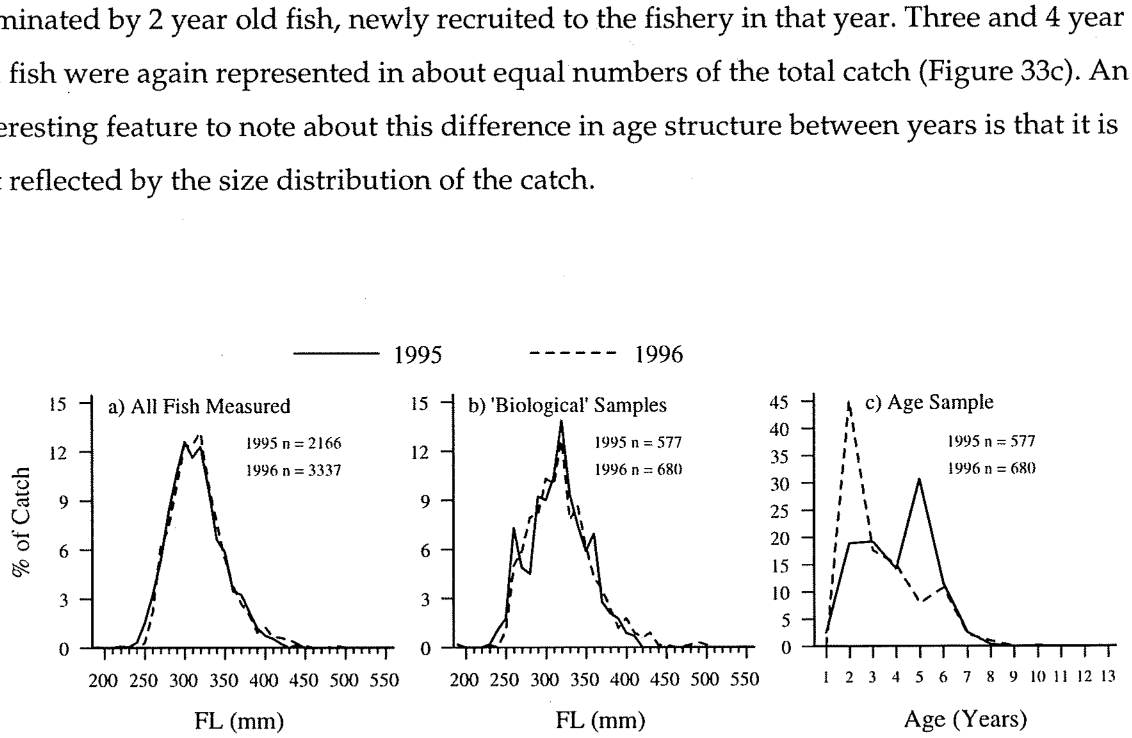

Figure 33 Annual size and age distribution of sea mullet caught in the Queensland estuary fishery. Data was derived from a) all length measurements b) lengths of biological samples and c) ages of biological samples.

Size structure of sea mullet caught on the ocean beaches were similar with average size being 357 mm FL in 1995 and 349 mm FL in 1996 (Figure 34a). Biological samples were representative of the overall size structure with average sizes of 350 mm FL in 1995 and 351 mm FL in 1996 (Figure 34b). The age structure of sea mullet caught in the 1995 ocean beach season was dominated by 5 year old fish similar to the estuarine catches for that year. The 1996 season was not dominated by any particular age class however it is interesting to note that about 17% of the catch in this year was of 2 year old fish, again similar to the pattern observed in the estuarine fishery (Figure 34c). The 2 year olds caught in the ocean beach fishery would have been newly recruited fish that had matured early resulting in their participation in the spawning run.

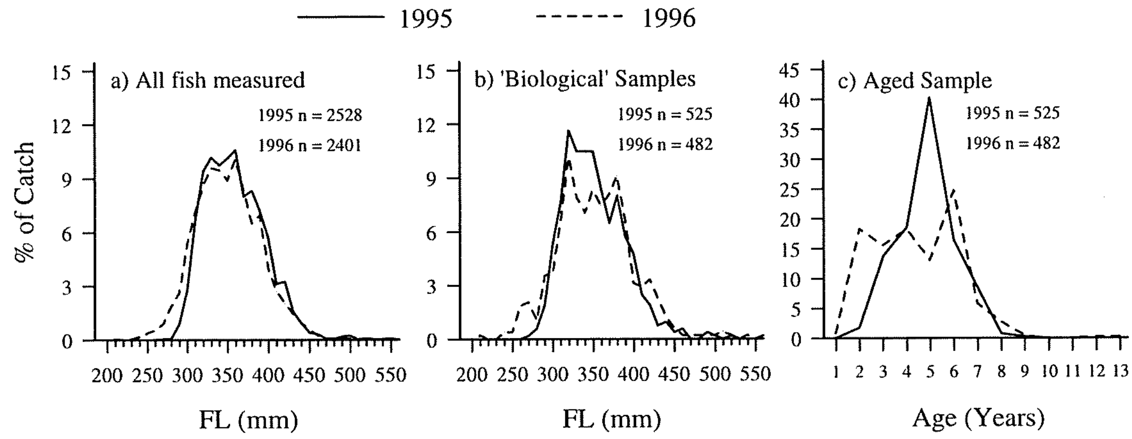

Figure 34 Annual size and age distribution of sea mullet caught in the Queensland ocean beach fishery. Data was derived from a) all length measurements b) lengths of biological samples and c) ages of biological samples.

Estuarine caught sea mullet were often hard to sex even with the use of histological sections of their gonads. Figure 35a shows the high proportion of juvenile mullet represented in the estuarine catch. Many of the juvenile mullet had reached the legal size and had entered the fishery however many were still sexually immature. Juveniles ranged in size from 230 to 340 mm FL with an average size of 279 mm FL. Females were larger than males with average sizes of 325 and 313 mm FL respectively. The age structure of the estuarine fish shows that fish from 2-7 years old were caught with females dominating the older age classes (Figure 35b). Juveniles were restricted to the younger age classes.

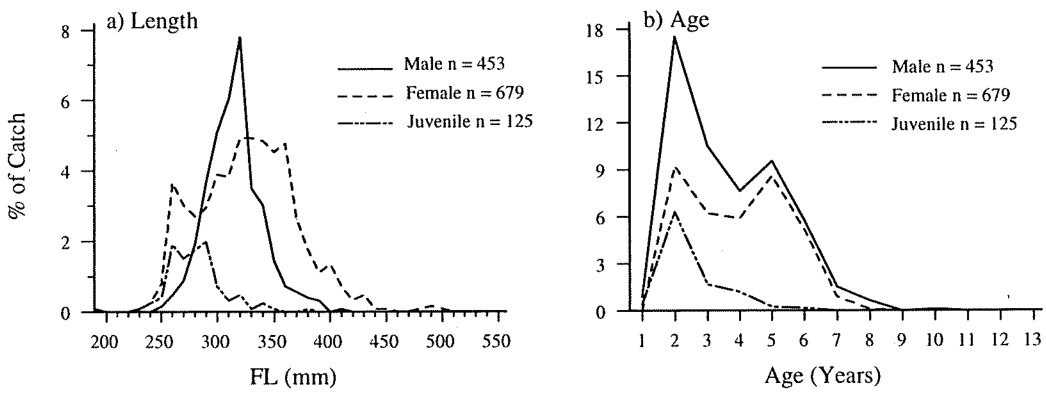

Figure 35 Sexed size and age distribution for male, female and juvenile sea mullet caught in the Queensland estuary fishery. Data derived from biological samples for a) length and b) age.

Female sea mullet caught in the ocean beach fishery were significantly larger than males. Females averaged 375 mm FL while males averaged 327 mm FL (Figure 36a). Juvenile fish were rarely caught in the ocean beach fishery presumably as a result of only mature spawning fish moving onto surf beaches in the winter. The age structure of the ocean beach catch shows that fish from 2 to 8 years old are commonly caught in the fishery. Females dominated the older age classes (6-8 years old) with males having a higher representation in the younger age classes (Figure 36b). Both male and female sea mullet caught in the ocean beach were represented in older age classes than those caught in the estuarine fishery.

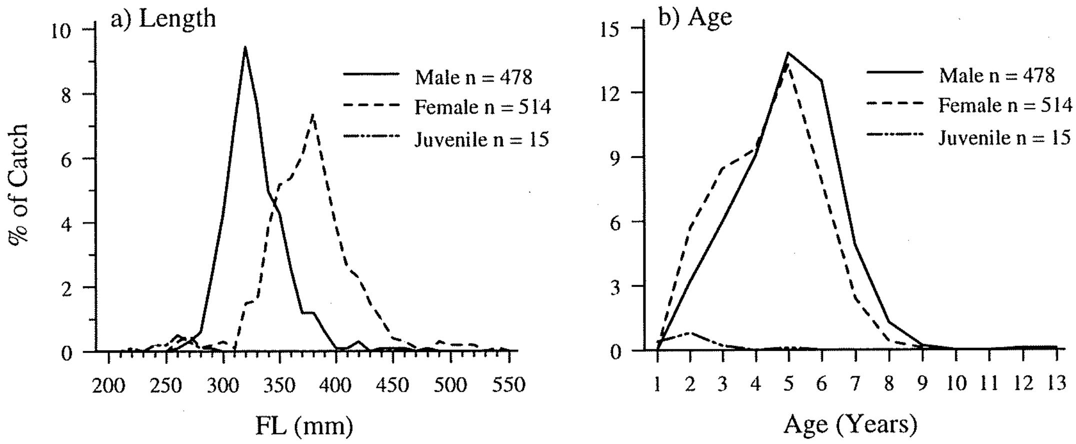

Figure 36 Sexed size and age distribution for male, female and juvenile sea mullet caught in the Queensland ocean beach fishery. Data derived from biological samples for a) length and b) age.

Size structure of sea mullet caught in the Qld estuary fishery shows that female fish were generally larger than males. Juvenile fish contributed about 10% of the catch for both years and were smaller than males and females (Figure 37a & c). In 1995 catches were mainly comprised of fish between 2 and 6 years old with five year olds dominating the male catch and 2 and 5 year olds dominating the female catch (Figure 37b & d). This trend changed significantly in 1996 with 2 year olds dominating the total catch for males, females and juvenile fish.

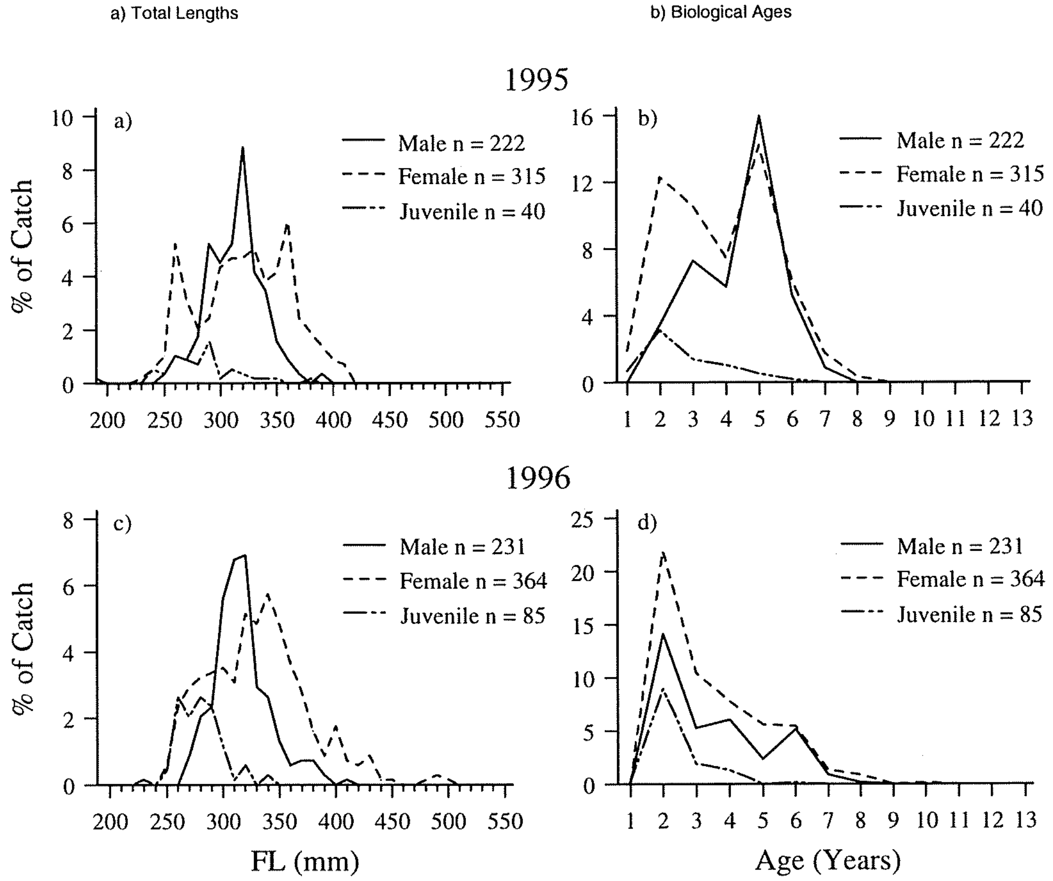

Figure 37 Yearly size and age distribution of male, female and juvenile sea mullet from biological samples caught in the Queensland estuary fishery.

Size distributions of sea mullet caught in the ocean beach fishery showed that females were larger than males for both years (Figure 38a & c). The differences in size do not appear to be due to differences in age as both males and females are represented by similar age structures (Figure 38b & d). An interesting point to note about these data is the total lack of juveniles in the 1995 catch and the small number of juveniles caught in 1996. Just prior to the 1996 spawning run a cyclonic rain depression produced a large rainfall event along the southern Qld and northern NSW coastline. This washed many immature sea mullet out of the rivers and estuaries onto ocean beaches. Even though these smaller fish were not ready to spawn they were associated with spawning run fish and were therefore caught in the fishery.

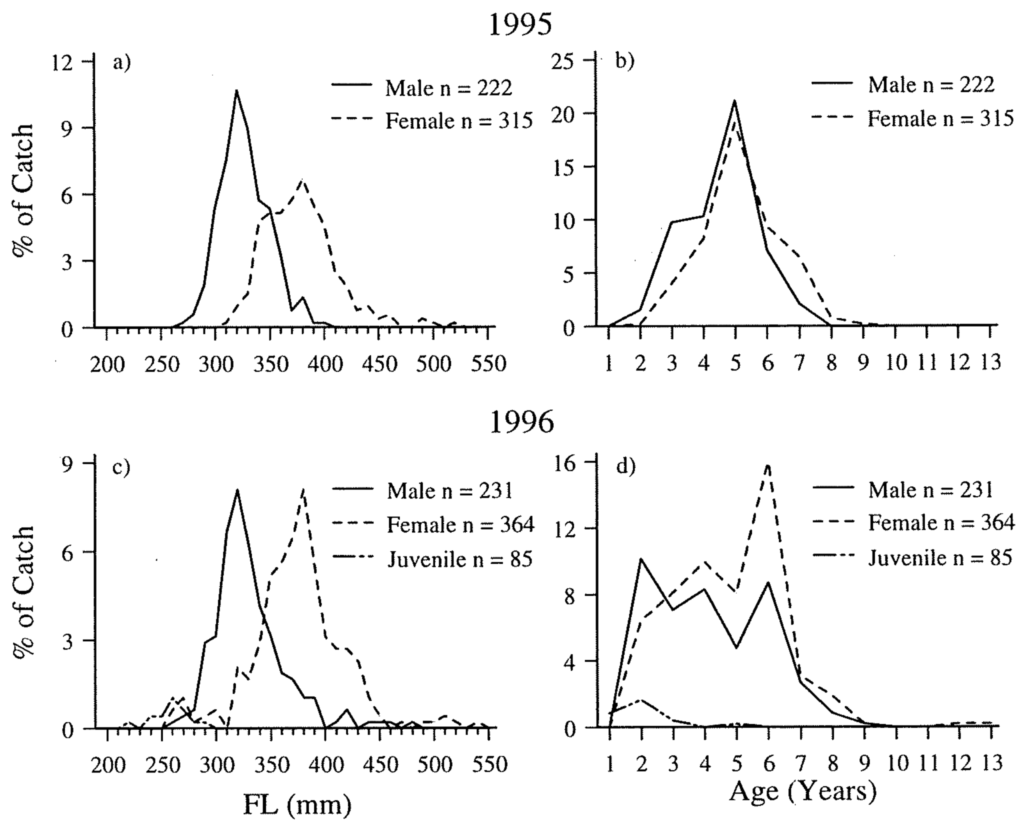

Figure 38 Yearly size and age distribution of male, female and juvenile sea mullet from biological samples caught in the Queensland ocean beach fishery.

All length data recorded at the estuarine sites shows the Moreton Bay and Maroochy River fisheries catch similar sized fish while the fish at the Tin Can Bay site were smaller (Figure 39a). This is unlikely to be a result of the sampling as the nets used by commercial fishers in these areas were of the same mesh size. Average sizes for fish from each of the sites was 323 mm FL in Moreton Bay, 326 mm FL in the Maroochy River and 301 mm FL in Tin Can Bay.

From the biological samples it is apparent that females at the Moreton Bay site were larger than males. At the Maroochy River and Tin Can Bay sites the male and female size distributions were generally of the same structure with females being present in a greater size range than males (Figure 39b). The smaller size of the sea mullet caught at Tin Can Bay is reflected in the age distribution with the majority of the catch being less than 4 years old (Figure 39c). At the Moreton Bay site male and female fish were common between the ages of 2 and 6 years with juveniles less than 5 years old making up about 7% of the total catch. A similar pattern can be seen in the catches from the Maroochy River site.

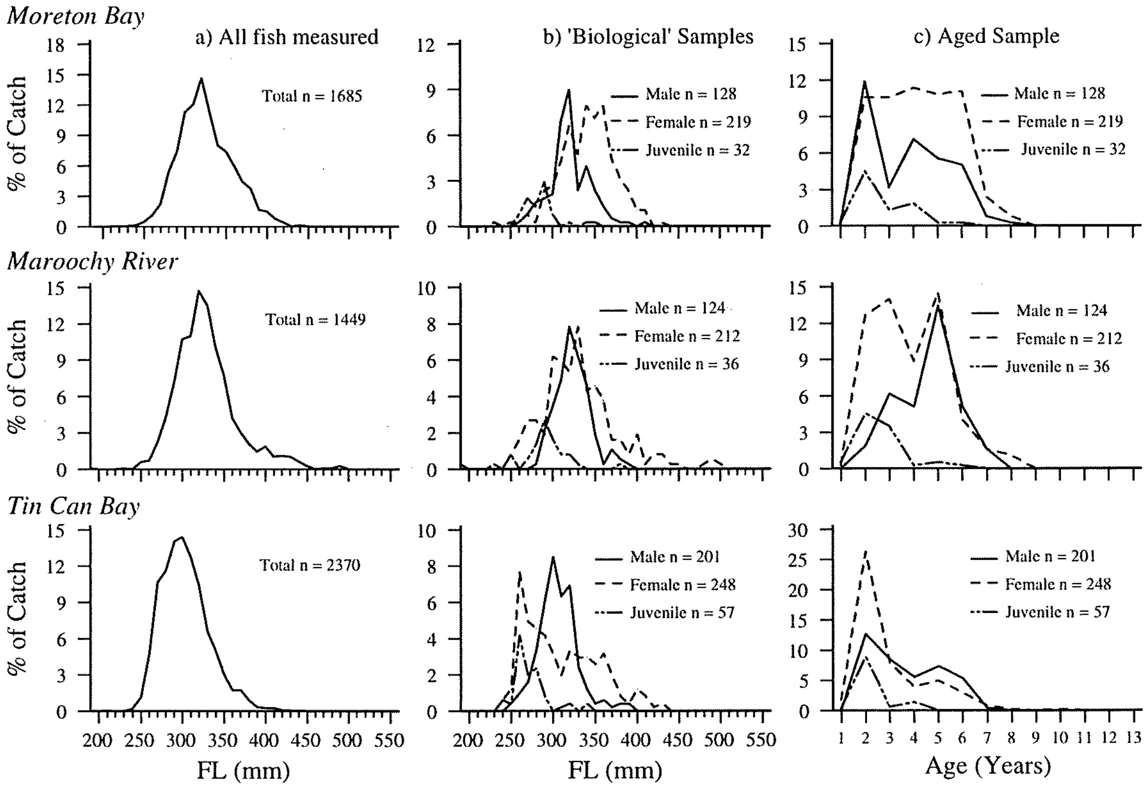

Figure 39 Size and age distribution of male, female and juvenile sea mullet caught at sites within the Queensland estuary fishery. Data was derived from a) all length measurements b) lengths of biological samples and c) age of biological samples.

All length data for ocean beach sites shows that the average size of fish caught decreases towards the north. The most southerly ocean beach site of Stradbroke Island had an average fish size of 358 mm FL, the Sunshine Coast averaged 350 mm FL and Fraser Island averaged 340 mm FL (Figure 40a).

From the biological samples it is evident that at all sites female fish were on average larger than males. The average size of female fish was between 45 and 50 mm larger than the males at all sites (Figure 40b). Age structures of these catches show that male and female fish have the same general groupings with the fishery primarily catching fish between 2 and 7 years old. Within this range fish caught at Fraser Island showed a greater proportion to be in the 2 and 3 year old range while 4, 5 and 6 year olds were dominant at the other two sites. Fish over 7 years old that occur in these catches are usually large females (Figure 40c).

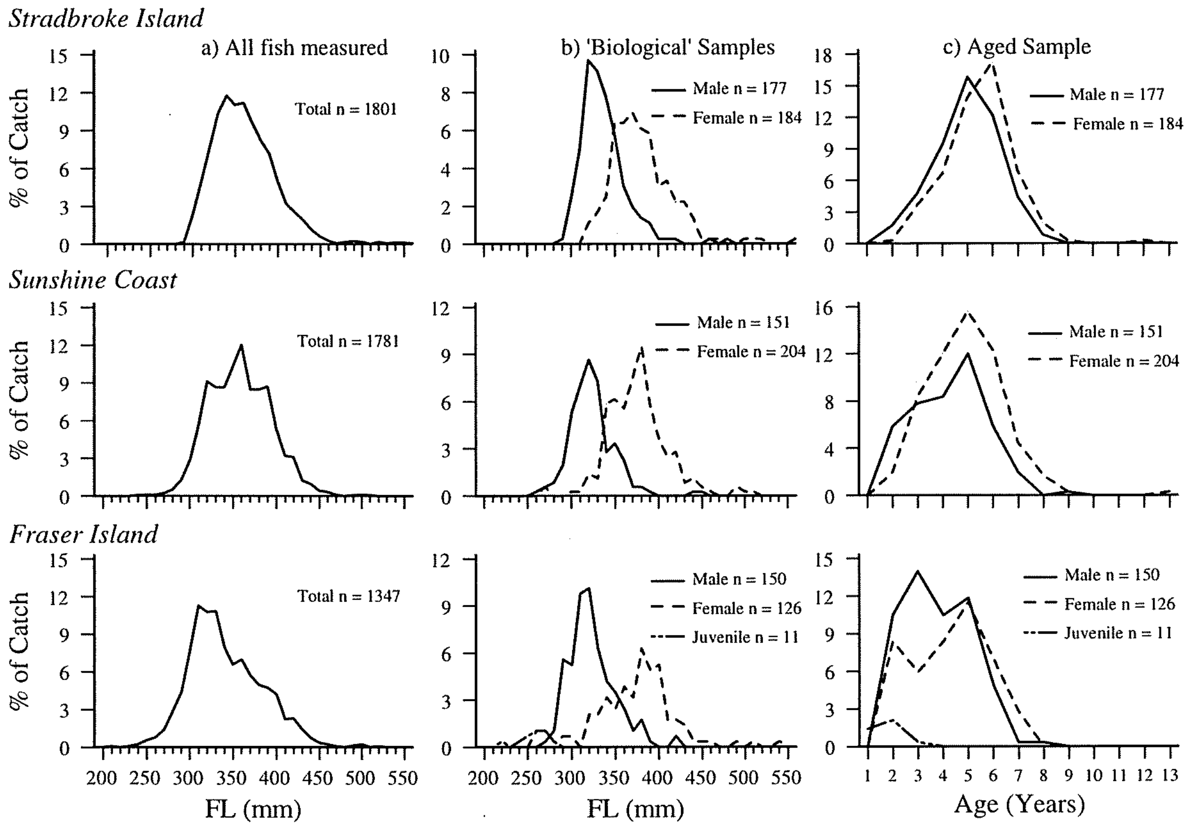

Figure 40 Length and age distribution of male, female and juvenile sea mullet caught at sites within the Queensland ocean beach fishery. Data was derived from a) all length measurements, b) lengths of biological samples and c) ages of biological samples.

7.2.3.2 *Age validation*

Edge classification was used to determine the time of year that annuli were formed before results of the tagging studies were available. By coding the outer edge of each otolith section a clear picture of the timing of opaque ring deposition obtained. This occurred in the period from November to February. There is a rapid increase in the percentage of otoliths showing annuli on the extreme outer edge from October (13%) to November (74%). After the peak in November the percentage decreased until April (2%) (Figure 41).

It should be noted that this is a subjective measure and that when making this evaluation with older fish (> 5+) it became increasingly difficult to determine the positioning of translucent and opaque growth on the outer edge of the otolith. This representation gives a fairly clear indication that the annuli are laid down in the period from November to January (late spring to summer). This pattern of opaque edge formation is similar with respect to season to that described for northern hemisphere *Mugil cephalus* (Thompson 1991). Southern United States sea mullet were shown to form the opaque margins from April to July (summer in the northern hemisphere) which is similar to the pattern found in mullet from the Qld catches.

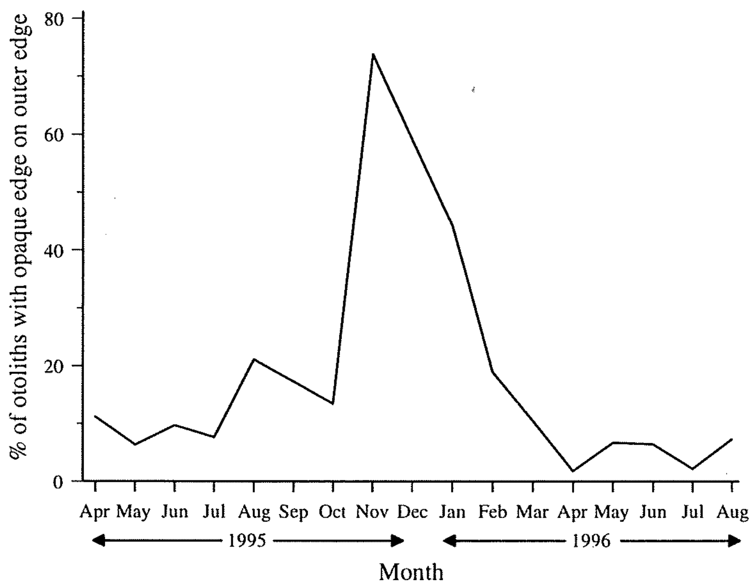

Figure 41 Seasonal changes in the proportion of otoliths showing various degrees of growth.

Of the 278 sea mullet tagged 71 were recovered dead from the edges of the dam within one week of release. This left a maximum number of 207 tagged sea mullet in the dam. A total of 84 sea mullet were recaptured from the dam, 16 of these had tags. Examination under the fluorescent light source revealed 20 sea mullet with fluorescent markings in their otolith structure. Of the OTC marked fish 19 had the fluorescent OTC ring between the outer most opaque ring and the second outer most opaque ring. The other fish had the OTC mark marginally inside the second most outer ring indicating the two rings had been laid down since application of the OTC. Growth rates over the 14 to 16 months at liberty ranged from 100 mm to 240 mm for those fish able to be identified from tags.

Photographs of otoliths showing fluorescent rings were computer scanned and overlayed onto scanned images of the entire otoliths. This was successful for fish 2, 3, 4 and 6 years old. Fluorescent rings within the otolith were positioned between the last and second last annuli that had been laid down in the otolith (Figure 42).

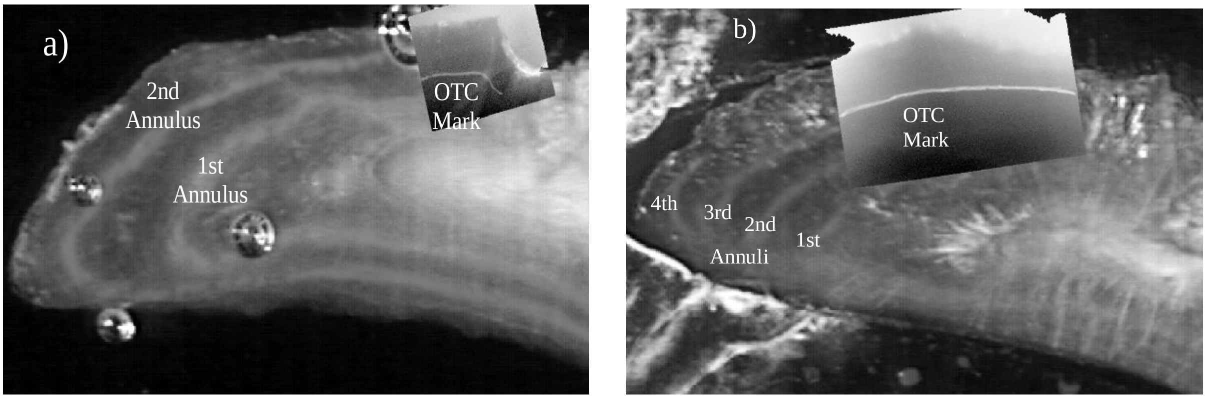

Figure 42 Otolith sections with flourescent mark overlays for a a) two year old and b) four year old fish.

The positioning of the OTC mark in both these sections indicates that the fish were OTC marked during the growth period after the laying down of the second outer most ring. This is evident as there is some translucent growth between the second opaque ring and the OTC mark. Growth continued for some time after the OTC mark was applied before the outer most ring was laid down. With the period of liberty being over 12 months it would be expected that there would be a region of translucent growth on the outer edge of the otolith as recaptures where made during or just after the growth period. This was also evident in the OTC marked fish.

The initial evidence of opaque ring formation in the period from November to January from subjective edge analysis (Figure 41) along with this infomation provides conclusive proof that annuli are formed once per year allowing age estimations from sectioned otoliths to be done with a greater degree of certainty than was previously possible. There is still some confusion about the timing of the formation of the first annuli within the otolith. Thompson *et al.* (1991) suggested that the formation of the first annuli occurs when the fish reaches about 18 months old. Investigation into the timing of formation of this first annuli is needed to complete the validation of the ageing of sea mullet.

7.3 Reproduction studies

7.3.1 Ovary tissue exchange program

Initially, NSW and Qld officers examined sea mullet ovary sections from Qld and there was only 61% agreement in identifying the leading stage of oocytes (Table 4). Samples from NSW were then examined by both states and there was a higher level of agreement of 88%. These exchanges prompted discussion of the staging of oocytes and eventually there was almost full agreement in the identification of leading stage oocytes in the 200 sections that were exchanged between the states. Stages in oocyte development are shown in Figure 43.

Table 4 The initial degree of agreement betwen New South Wales and Queensland.in identifying the leading staging oocytes in sea mullet ovaries.

	Leading Stage Oocyte Type			
	Primary	Cortical Alveoli	Vittelogenic	Total
New South Wales samples				
Agreement between NSW & Qld	8	27	53	88
Others New South Wales		10	2	12
Others Queensland	8	1	2	11
Queensland samples				
Agreement between NSW & Qld	20	9	32	61
Others New South Wales		21	18	39
Others Queensland	21	18		39

7.3.2 New South Wales

7.3.2.1 Gonadosomatic Index

The mean monthly GSI values for females and males in the catch samples are shown in Figure 44. In the estuaries, GSI values were close to zero for most of the sampling period except for some high values during the autumn months for the northern estuaries. In the ocean spawning run catches, GSI values were approximately 15% for females and 7% for males with similar values from north to south. It is evident that reproductive development occurs during autumn but a full examination of this pattern would require more frequent sampling than was possible in this study.

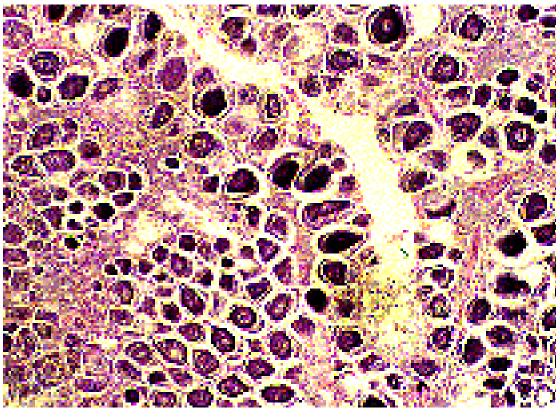

Plate (a)

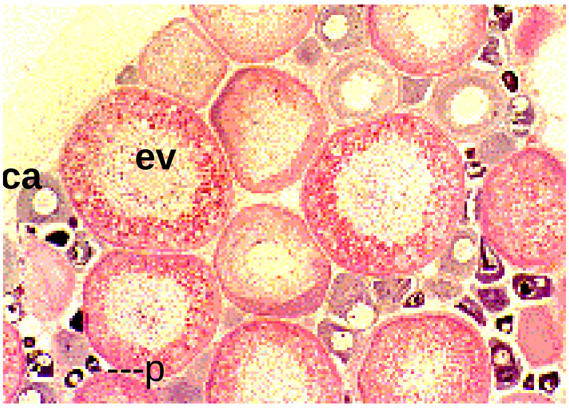

Plate (b)

Plate (c)

Figure 43 Ovary sections from New South Wales showing (plate a) immature, (plate b) early developing, and (plate c) late developing ovaries. Primary (p), cortical alveoli (ca) and early vittelogenic (ev) oocytes are marked in plate (b) and a late vittelogenic (lv) oocyte is marked in plate (c).

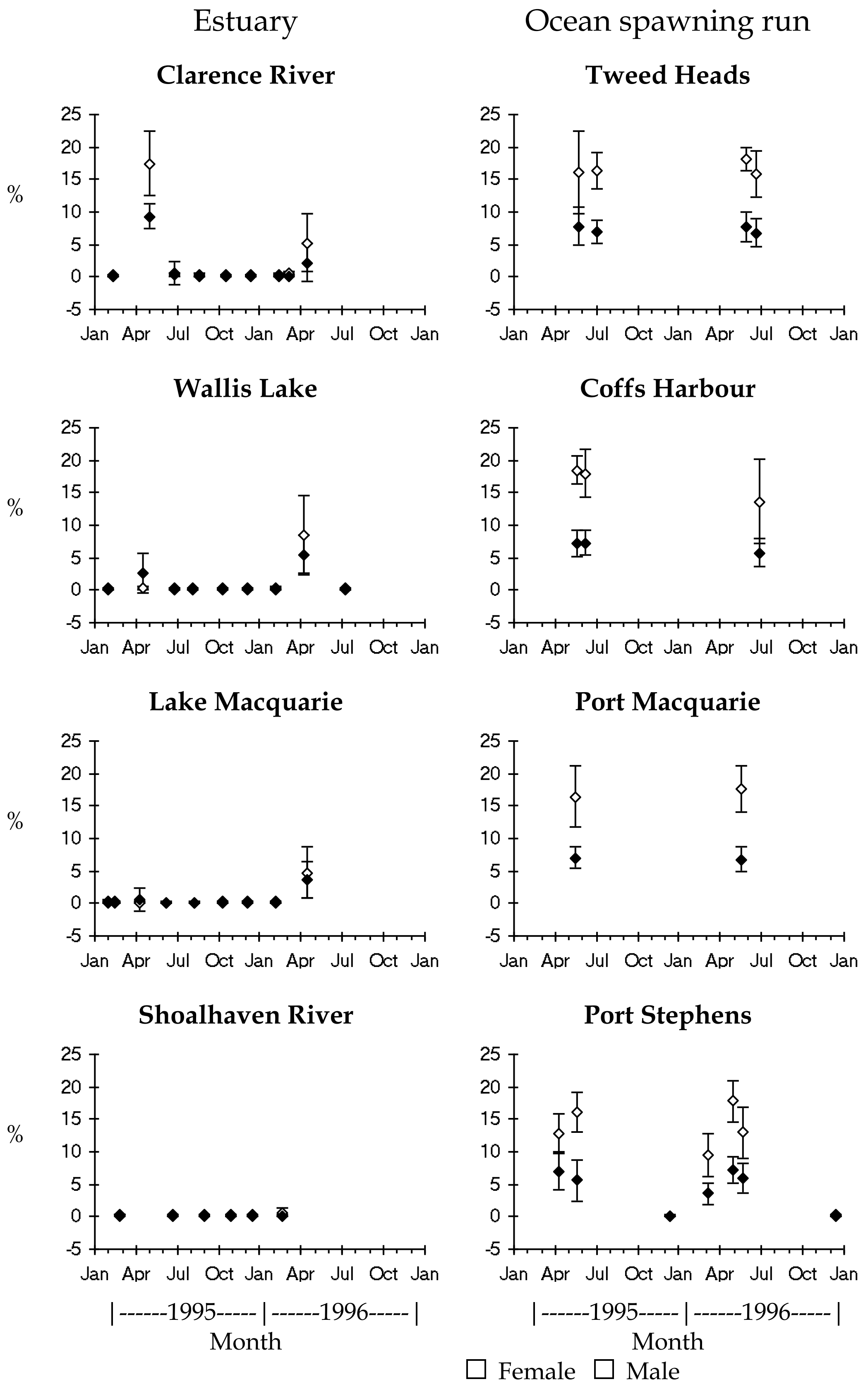

Figure 44 Mean monthly GSI values for female and male sea mullet for the estuary and ocean beach sampling locations in New South Wales for the study period.

7.3.3 Queensland

7.3.3.1 *Gonadosomatic Index*

Gonad development of Qld sea mullet begins in autumn with increases evident in both male and female GSI by April (Figure 45). Maximum GSI (~17% for females and 7% for males) is attained in both sexes between June and August with a return to low values by October. Average female GSI values are much higher than those reported for batch spawners (Hunter *et al.* 1985) with many of these commonly being below 10. Male GSI during the peak spawning period averaged 6.7% with a maximum of 13.9% and females in the same period averaged 17.0% with a maximum value of 24.6%.

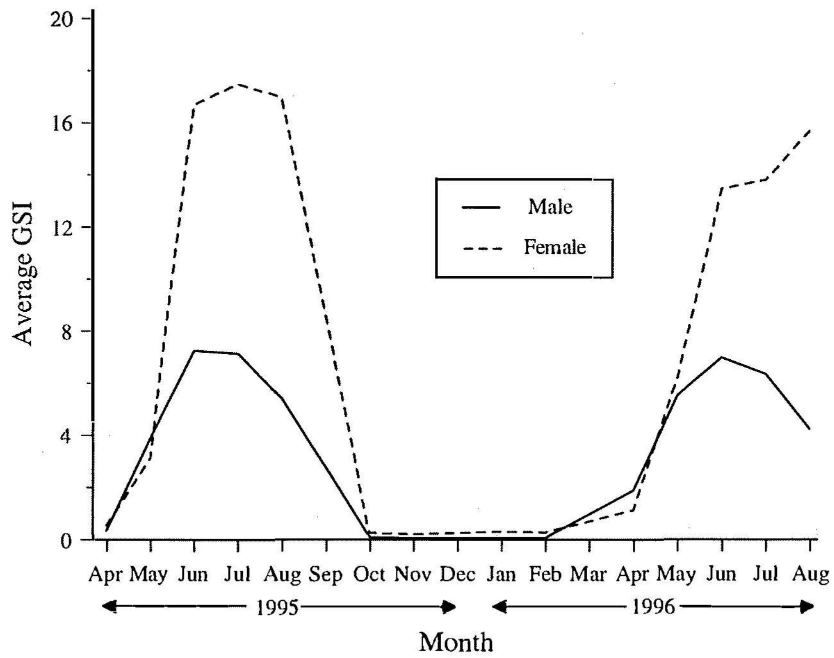

Figure 45 Gonadosomatic index for male and female sea mullet caught in Queensland.

7.3.3.2 *Histology.*

Histological sections taken of 136 fully developed ovaries collected from spawning run fish in June and July 1995 revealed that all oocytes in the ovary were class 4, stage 4 (vitellogenic). Subsequently, only small numbers of fully developed ovaries were sectioned to verify macroscopic class and staging. Sectioning effort was directed at gonads that showed differences in macroscopic appearance during the remainder of the 1995 spawning and the 1996 spawning. The observable differences may have been due to immaturity, slow development or the fish having already spawned. Class 5 development (running ripe) and stage 5 oocytes (hydrated eggs) were never found in any of the fish collected during the sampling period. This indicates that there is a high probability that spawning occurs away from the surf zone despite the fact that fully developed ovaries are common.

An interesting feature recognised during sampling was that the sex ratio of mature fish caught on the ocean beach changed over the season (June to August). During May the sex ratio of males/females was 60:40 and changed over the course of the season to 40:60 in August.

7.4 Movements

A total of 2425 sea mullet were tagged and released in NSW waters during 1995 and 1996 (Table 5). To the end of August 1997, 108 (5.8%) recaptures had been reported out of 1877 tagged and released in 1995 and 59 (10.8%) out of 548 tagged and released in 1996.

Table 5 Numbers of sea mullet tagged at various locations on the east coast of Australia between 1st January and 31st June 1995 and the numbers of reported recaptures up to August 1997.

Location	Number tagged in 1995	Number recaptures reported by August 1997	Number tagged in 1996	Number recaptures reported by August 1997
Tweed Heads (Hardgut)	355	17	-	-
Tweed Heads (Spawning run)	653	22	277	25
Port Stephens (Spawning run)	287	23	162	8
Clarence River	495	39	72	25
Shoalhaven River	87	7	37	1
Total	1877	108	548	59

Sea mullet tagged during spawning runs have been caught north and south of the release site indicating that there are northward and southward movements during or after spawning migrations (Figure 46). There were many examples of sea mullet tagged during spawning runs and recaptured in the same or following spawning seasons. Several sea mullet tagged on Stockton Bight in the 1995 and 1996 spawning run season were recaptured at the same stretch of beach in subsequent seasons.

To date, all sea mullet tagged in the estuaries have been recaptured in the estuary of release or further north. This is a similar result to that in a previous sea mullet tagging study (Kesteven 1953) on the coast of NSW. In this previous study, the recorded coastal movements of sea mullet which were tagged mostly in estuaries, were predominantly northward (Figure 46).

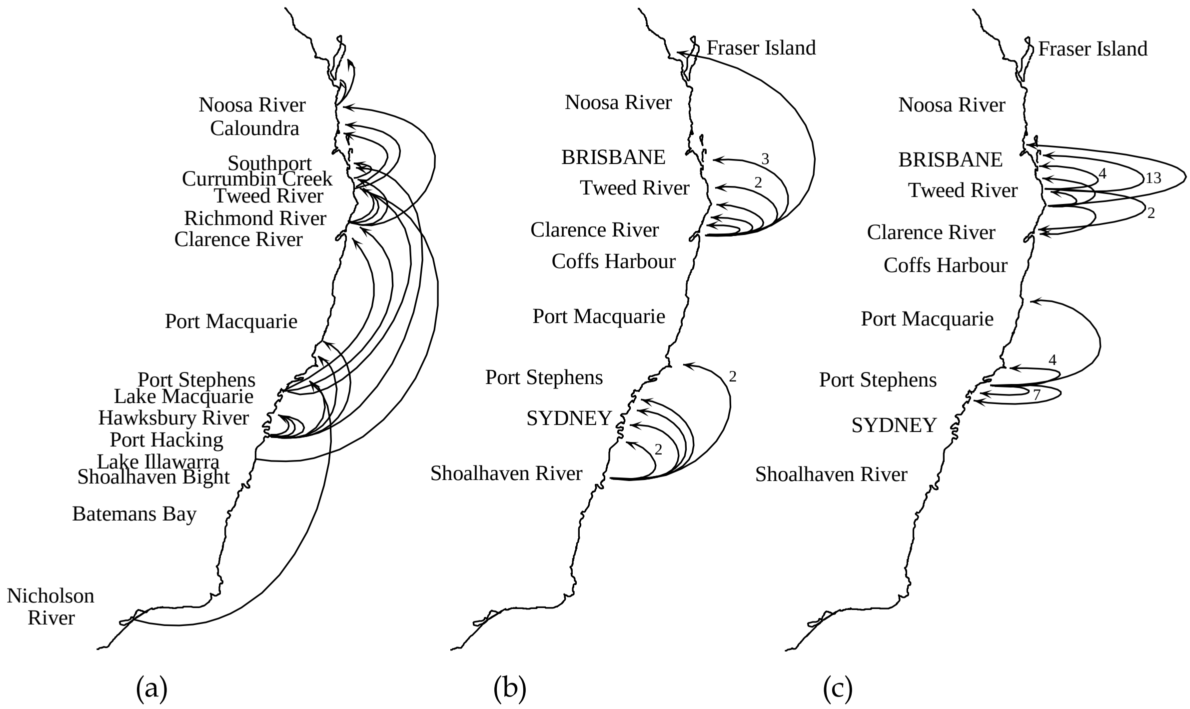

Figure 46 Map showing the movements of recaptured sea mullet in (a) a previous study (Kesteven 1953) and from (b) estuary releases and (c) ocean beach releases in this study.

8. Discussion

8.1 New South Wales

8.1.1 Value of components of the fishery

The sea mullet fishery is currently the most valuable amongst finfish fisheries in NSW with an estimated value of $11.4 million in 1996. Much of this value results from the relatively large amount caught and the high price paid for spawning run sea mullet for the export roe market. Catches in this sector of the fishery alone were valued at approximately $7.3 million. These catches were mostly made in autumn and were greatest within the central and mid northern areas on the coast which accounted for approximately $5.2 million.

Catches of sea mullet from estuaries were valued at approximately $4.1 million. The value was spread more evenly throughout the year than for the ocean beach catches. (Figure 13). Most of the estuary catches of sea mullet were in the central and far north areas of NSW.

Within the ocean beach component of the fishery the value of the non-spawning run component ($100 thousand), which includes the hardgut run fish, is only a small proportion (0.9%) of the total value of the ocean beach sector of the fishery.

8.1.2 Social and biological impact of redirecting effort between the estuary and ocean

Subsequent to the submission and commencement of this project, the management of many fisheries in NSW has altered to such an extent that it impacts upon the relevance of this objective. Commercial fisheries in NSW are now currently divided into 6 restricted and 2 share managed fisheries. The commercial catch of sea mullet is almost equally split between the Estuary General and the Ocean Haul Restricted Fisheries. These 2 fisheries have separate Management Advisory Committees, different fishers and methods and they are developing separate management plans. Consequently the logistics of determining a scheme whereby any effort/catch from one managed fishery can be equitably re-directed into another are likely to be immense.

The social implications of any policy to achieve re-direction would also be large, more than half (871 of 1800 fishers in 95/96) of NSW commercial fishers caught mullet. Of this number, 772 took mullet in estuaries with only 380 taking them on ocean beaches (281 in both). Furthermore, a significant proportion of the catch of sea mullet in estuaries is taken by non targeted mesh netting which would be difficult to remove and still maintain any level of estuarine mesh net fishing. Finally, the landings of mullet in estuaries comprise a significant component of the catch in this fishery (≈50%) and a substantial reduction in this figure could jeopardise the viability of the entire fishing operations. It should be remembered that if effort is being shifted purely for some perceived economic benefit, then individuals in both fisheries would need to be satisfied with the outcomes.

The economic rationale for suggesting such a re-direction of effort comes from the difference in the price paid per for the "roed" ocean caught mullet compared to the generally non-roed estuary caught mullet. Theoretically, if only an extra 1200 tonnes of mullet were caught on the ocean beaches during the spawning run, this would equate in value to the entire estuary catch of 2000 tonnes. Even accepting the logistics above, this assumes that extra effort would enable the capture of one half more mullet on the ocean beaches than are presently caught. The extra crews that would increase conflicts with other beach users and competition for suitable hauling sites may become intense. There is also the potential that increased fishing effort could impact on the migration of the mullet and potentially break up schools such that less may be caught, not more. Finally, even if more roed mullet was caught there is no guarantee that the price would remain at it's current high level. Thus, a simplistic assessment based solely on price differential is insufficient basis for recommending that any such policy be considered.

The biological benefits of re-directing effort from one fishery to another are even more complicated. Firstly, there should be evidence that the stock has declined to a non-optimal level before changes in effort are recommended. If in the future reductions were needed for this reason, whether they should come from only one or from both fisheries would ideally take more information and analyses than are present in this report.

8.1.3 Questions raised in the objectives.

8.1.3.1 (1) What percentage of mullet spawn each year? In what area?

It is difficult to estimate the percentage of sea mullet that spawn each year because spawning and non-spawning fish are located in different areas. They move from the estuaries to ocean waters during spawning runs. However, from the spawning run samples in this study it appears that the proportions of fish involved in spawning increases from ages 3 to 6 (Figure 21c). Information on sexual maturation of sea mullet in the estuaries may provide an indication of the percentage of mullet that spawn each year but the two monthly interval between estuary samples in this study was too large do detect patterns in maturing sea mullet. Maturation time is probably less than two months.

It is uncertain where sea mullet spawn since no running ripe fish were found in samples. However, the similar and high GSI values found at all the sampled ocean beach sites, from north to south, indicate that spawning occurs over a wide range of latitude. Also running ripe females were not found in any of the estuary or ocean beach samples which indicates that they spawn away from these areas in areas such as headlands or deep water areas. The overseas literature and anecdotal information in Australia suggest the latter.

8.1.3.2 (2) For how many years do individual mullet spawn (do they spawn only once)?

There are many indications that mullet may spawn for more than one year.:

- many fish which were tagged during the spawning migrations were recaptured after the spawning season showing they survive and have the potential to spawn again. More convincingly, some fish tagged during ocean spawning runs were recaptured in subsequent spawning runs.
- fishers often talk about returning spent females towards the end of the spawning season which they refer to as whips or fence posts due to their long and slender shapes.
- fish were found in a spent condition in the estuaries after the spawning season. These fish potentially could spawn again.
- there are many ages represented in the spawning run catches which suggests that they spawn more than once.

8.1.3.3 (3) Does the age and size at first spawning differ among individuals from different estuaries?

From the spawning run samples in this study it appears that the age at first spawning is 3 years and that the proportion of fish spawning increases from 3 to 6 year old fish. (Figure 24). It is difficult to determine the size at which 50% of the population are involved in spawning because pre-spawning sea mullet move out of the estuaries and travel in ocean waters.

The smallest size of spawning run fish in the samples was 33 cm (TL) for females. and 30cm

(TL) for males. While there appears to be little difference in the size and age at first spawning between sampling sites larger samples may be required to examine any differences.

8.1.3.4 (4) What is the appropriate legal size for mullet?

For most of this century the minimum legal size for sea mullet in NSW has been 12 inches (30.5 cm) total length. The current minimum legal size is 30cm (TL) total length which was introduced about the time of the change from imperial to metric units of measurement in Australia in 1973.

A notable exception to the 12 inch minimum legal size was in the early 1950's when increases to 13 and 14 inches were introduced due to a perceived decline in the abundance of sea mullet, which was thought to be due to overfishing. It was considered that too many fish were being taken before they had a chance to spawn which, based on earlier studies by the CSIRO, usually first occurs when sea mullet are approximately 13 inches (33 cm) in total length.

Adjustment of the minimum legal size of fish is one of the tactics that can be used to manage fish stocks. Potentially it can be used to increase the probability of individual fish undergoing successful spawning. Also, changes in size at first capture in conjunction with changes in fishing mortality can be used to increase yield per recruit. Ideally the minimum legal size should be set at a level that does not allow growth or recruitment overfishing. A common objective is to allow the fish to spawn at least once before entering the fishery.

The current minimum legal size (26.5cm LCF, 30cm TL) is well below the size at first spawning and therefor theoretically does not allow fish to spawn if they are caught at that size. Increases in the minimum legal size above 30cm (TL) for males and 33cm (TL) for females would allow increasing proportions of fish to spawn at least once.

8.2 Queensland

8.2.1 Value of components of the fishery

8.2.1.1 The hardgut fishery

The hardgut sea mullet run usually occurs in the summer months between December and

March. This is usually very dependent on the seasonal conditions, particularly the occurrence of a period of high rainfall which flushes the non-reproductive fish out of rivers and bays onto the open surf beaches. This is a spasmodic and unpredictable event that may or may not occur from year to year. The hardgut run was historically a good supply of fresh fish to the local market when there was a scarcity of other fish during that time of the year. This has decreased in importance over the last 15-20 years with imported frozen fish filling much of that market. The hardgut run is not targeted by ocean beach fishermen to the extent that it was historically. During this project the hardgut run was in January and early February in 1995 and failed to occur in Qld during the 1996 season. This meant that no samples were available during the study. Many ocean beach fishermen now view the value of the hardgut run by weighing the cost of allowing the fish to swim for an extra 3-4 months (when they would receive about $1.5/kg) and the benefit they would receive if they are able to catch a proportion of these fish as roed females during the winter spawning run.

8.2.1.2 Food fish only

The creation of a fishery for sea mullet as a food fish only would have a dramatic effect on the economy of the whole fishery, impacting directly on the 70 ocean beach licence holders and the ~300 fishers who catch mullet throughout the year outside the ocean beach fishery. The lost production of the roe alone decreases the value of the fishery to the fishers by about $5 m annually. It would also affect the large number of seasonal workers currently employed to process the roed females. As almost all the mullet roe taken in this fishery is exported, Qld would lose a large amount of export earnings.

8.2.1.3 A roe fishery alone

By developing a roe only fishery there is the possibility that a number of social problems may occur. The initial impacts of this type of management regime would be felt by the 300 fishers that currently catch sea mullet as one of their main target species. Fishing techniques currently used in the ocean beach fishery would have to be modified to reduce the catch of the male fish as these would be of little value to the fishers.

Mullet meat holds about 15% of the fresh fish market in Qld. Without a fresh fish trade in mullet consumers would not have access to this cheaply priced fish with the short fall in supply having to be filled by imported products. This could cost a great deal more than the $3 m in extra production roe production. The local market consumes about 78 t of mullet per month resulting in the need to reduce the catch of male fish, as trunks from roed female fish would fill this market.

A roe only fishery exists in Louisiana, USA where there is a 90 day mullet open season. Fishers can only use 4" gill nets and processors buy only catches with ≥ 90 % of the catch is female, fishers are paid on the % of roe cut from the fish they catch and trunks are sold for ~$0.45/kg for bait. It should also be noted that the Louisiana fishery is estuarine based with no catching of fish from shore based operations (Thompson pers. comm.). This fishery appears to be sustainable because the mesh size used in this fishery allows most fish less than 340 mm FL to escape capture (Thompson et al. 1989). Fish under this size are usually male or female that are spawning for the first time. By allowing these fish to escape almost all female fish reaching maturity can contribute to the spawning stock before entering the fishery.

8.2.2 Social and biological impact of redirecting effort between ocean beach locations

8.2.2.1 The effect of ocean beach zoning

Zoning has been introduced into the ocean beach fishery (for the 1997 season) with the view of restricting the movement of licences between local areas in south-east Qld. Most of the 70 licences in the ocean beach fishery are held by fishers that are involved in the fishery and use the licences in their local areas. The remaining 3 or 4 are held by processing companies who lease the licences to the highest bidder. Currently all fishermen can access any of the beaches from the Qld/NSW border to the northern end of Fraser Island. Restrictions on licences will be in the form of allocation of each licence into one of the 8 zones depending on their history in the fishery (Figure 18).

Catches may vary greatly between years and presumably from zone to zone. Zoning will mean that fishers can not move outside their licensed zone without leasing or working on a licence allocated to a different zone. The effect of changes in annual catch within different zones cannot be estimated because of an inability to reduce CFISH logbook data to zone based components.

Ocean beach zoning will have a number of impacts on the fishery because of social issues and interactions involving local government, the commercial industry and the general public. Local Government began to take an indirect role in fisheries management by restricting community access to beaches. This had the effect of reducing the areas accessible to commercial ocean beach fishers. Local governments were also concerned about the potential influx of traffic onto their local beaches as fishers follow the mullet migration north. Zoning will restrict the number of fishers allowed to access beaches within each zone. This will allow the fishers in each zone to work out problems with the local councils. Itinerant fishers tend to not comply with local council rules and are often not aware of the agreements made between fishers and other local users of the beaches and this often causes areas of conflict. Zoning will alleviate local government concerns by providing a degree of certainty about the number of commercial crews that will be licensed to fish the sea mullet stocks off local beaches.

Annual catches of sea mullet have fluctuated significantly since 1943. Factors such as kerosene-taint (a kerosene taste in the flesh that makes it inedible) and low market prices have resulted in notable reductions in fishing effort. Although the annual catch trend appears to be decreasing, CPUE has remained relatively constant. This result relies on the assumption that effort information is accurate and reflects the true situation. In the last three years there has been an increase in fishing effort in areas north of the regulated ocean beach fishery brought about by the increased value of roe on the export market.

8.2.3 Questions raised in the objectives

8.2.3.1 Assessment of the legal size

During the course of the current project 10 432 mullet from the estuarine and ocean beach fisheries were measured with a subsample of 20% retained for analysis of age and reproductive status. The size at first maturity is defined as the size class when 50% of the population are mature. Maturity class was determined by macroscopic staging. Microscopic analysis was used to discriminate between Class 1 (immature) and Class 2 (resting mature) ovaries. This is necessary due to the total reduction of ovarian tissue outside of the spawning period. Data from the May (estuarine), June and July (ocean beach) samples for 1995 and 96 were used to determine the size and age at first maturity. These data were used as gonad development in males and females is most evident during this time of the year. Length measurements from all samples were used to estimate the proportion of immature mullet in commercial catches.

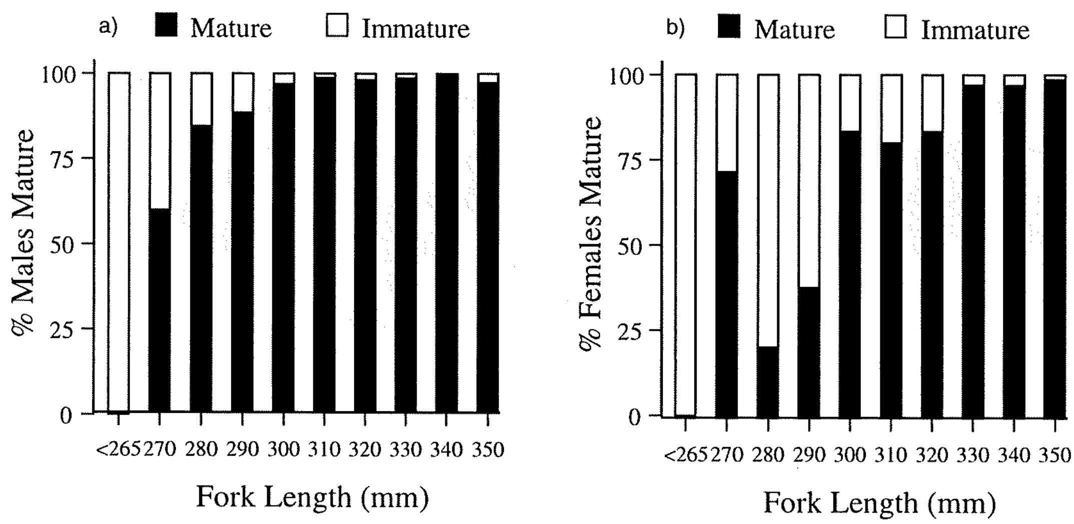

Figure 47 Proportion of mature mullet of different size-classes (males left, females right).

50% of male sea mullet mature at about 270 mm fork length (Figure 47a). This corresponds with a total length of 304 mm as calculated from the regression : $TL = 1.112 * FL + 4.1476$, $R^2 = 0.99$ (where TL = total length and FL = fork length). This indicates that the current size limit on mullet is achieving the required outcomes by allowing male mullet to mature before entering the fishery.

Female sea mullet mature at about 300 mm FL, corresponding to 338 mm TL (Figure 47b). The large percentage (70%) of mature females in the 265-274 mm size class was probably the result of a small sample (7) being caught over the period of the study. These sizes at maturity are almost identical to those reported by Kesteven (1942). The difference in size at first maturity may be due to differences in age structure of the male and female components of the stock or may be indications of differences in growth rates between male and female mullet. Of the 1103 mullet returned to the laboratory for biological sampling from the combined 1995 and 1996 May, June and July samples 7 males (0.6%) and 5 females (0.5%) were under the legal size. A total of 29 females (2.6%) were under the length at first maturity of 300 mm FL.

Of the 10 432 sea mullet caught by commercial estuarine and ocean beach fishing operations in Qld, 225 (2.2%) were below the legal size limit of 30 cm TL. Estuarine fishing operations accounted for 197 (1.9%) of these with ocean beach operations taking 28 (0.3%). In the estuarine operations 74% of the undersize mullet were taken during the summer period from November to February. This is the period when smaller hardgut fish congregate in the estuaries to participate in the sporadic summer hardgut run. During the course of this project the summer hardgut run has not occurred, probably due to environmental factors ie. the dry summers experienced for the last two years. This has meant that no indication of the appropriateness of the current size limits can be ascertained for this minor part of the fishery.

Of all sea mullet measured 1 691 (16%) were below the size at first maturity for females. Estuarine catches contained 1 508 (89%) of these while ocean beach catches contained 183 (11%). Assuming that 75% of the total catch is taken during the ocean beach season and 25% in the estuarine fishery, with a 1:1 sex ratio, 1.4% of total ocean beach catch and 3.4% of the total estuarine catches would be of immature females.

Under the current management arrangements used in the Qld commercial mullet fisheries, the legal size limit and net restrictions are allowing the vast majority of male and female mullet to mature before entering the fishery. As the ocean beach fishery is based on the sale of roe the mullet entering the fishery on reaching maturity may not have a chance to spawn.

9. Benefits

A direct benefit of this study is a description of the biology of and the fisheries for sea mullet that will lead to a better understanding of the dynamics of the sea mullet stock and its fishery on the east coast of Australia. This information will provide the basis for development of long term monitoring strategies for the fisheries, and will provide a sound basis for decisions regarding the future management of the fisheries dependent on the sea mullet resource. There will be a flow of benefits to businesses associated with the sea mullet catch and the public by better management of the stock and the chance for better harvesting strategies.

The primary beneficiaries of this study will be the NSW and Qld commercial fishers. It is anticipated that 45% of the benefit will accrue in each of NSW and Qld, and 5% in each of Victoria and Western Australia. The long-term benefits are likely to be equally felt by Qld and NSW as a result of the methods developed in this study. Both the methods and substantive results of this work will be of use in the administration and management of mullet fisheries elsewhere.

In NSW the catch of sea mullet is the largest amongst the commercial catches of finfish species and is important to a large proportion of commercial fishers. During 1995/96, 658 skippers recorded catches of sea mullet on return forms with this species accounted for 50% or more of catch (by weight) for 350 of these fishers.

In Qld sea mullet is the single most important finfish to net fisheries. The winter ocean beach fishery involves 70 licence holders and associated crews with about 300 other net fishermen relying on sea mullet as a primary or secondary target fish. Sea mullet are considered to be one of the "bread and butter" species of south-east Qld providing season employment and a cheap fish source to consumers. The monitoring of the sustainability and management changes arising from this will benefit both fishermen and consumers, particularly in the south east of Qld.

10. Intellectual property

Results will be published in journals and industry magazines such as Fisheries NSW and the and provided to management and fishers in summary reports. They will contain information that will help in the conservation and efficient harvesting of sea mullet stocks in NSW and Qld. No patents are expected from this project.

11. Further development

The plans for future work on sea mullet include 1) more detailed examination of CPUE in the NSW commercial fishery statistics, 2) using the data we have collected in the FRDC project to help plan representative size and age sampling of the commercial catch and 3) examination of the relationship between catches and environmental factors.

Additional work on the pattern of otolith ring formation in juveniles commenced at the NSW Fisheries Research Institute as a result of and during the course of this project. The work is under way and involves quarterly subsampling of captive and wild juveniles and examination of their otoliths. The results of this work should help clarify the pattern of ring formation in juveniles.

12. Staff

<u>NSW Fisheries Research Institute</u>

John Virgona (80%)	Principal Investigator	NSW Fisheries	1st Jan 1995 to 31st Mar 1997
Kerrie Deguara 100%	Fisheries Technician	FRDC	1st Jan 1995 to 31st Dec 1996
Darryl Sullings 100%	Fisheries Technician	FRDC	1st Jan 1995 to 28th Feb 1997

<u>Qld. Southern Fisheries Centre</u>

Ian Halliday 80%	Principal Investigator	DPI Qld	1st Jan 1995 to 31st Mar 1997
Kath Kelly 100%	Fisheries Technician	FRDC	1st Jan 1995 to 31st Mar 1997

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14. Appendices

14.1 **Appendix 1** Details of sea mullet samples in New South Wales showing the number of fish for which: (a) lengths were measured and (b) more detailed biological information was collected.

Estuary locations

Clarence River	(a)	(b)
Feb-95	51	51
May-95	426	60
Jun-95	301	61
Aug-95	373	61
Oct-95	420	60
Dec-95	528	60
Feb-96	678	60
Mar-96	306	58
Apr-96	531	57
Jun-96	397	34
	4011	562

Wallis Lake		
Jan-95	100	100
Feb-95	146	0
Apr-95	395	46
Jun-95	246	64
Aug-95	580	64
Oct-95	259	60
Dec-95	422	52
Feb-96	347	60
Apr-96	295	59
Jul-96	201	64
	2991	569

Lake Macquarie		
Feb-95	101	101
Apr-95	131	76
Jun-95	133	64
Aug-95	181	47
Oct-95	164	60
Dec-95	309	61
Feb-96	523	92
Mar-96	70	0
Apr-96	37	37
	1649	538

Shoalhaven River		
Feb-95	44	44
May-95	20	20
Jun-95	50	50
Aug-95	61	0
Sep-95	90	60
Oct-95	111	46
Nov-95	126	0
Dec-95	58	36
Feb-96	187	57
Jul-96	20	0
	767	313

Ocean beach locations

Tweed Heads	(a)	(b)
May-95	513	67
Jul-95	283	63
May-96	61	61
Jun-96	221	59
	1078	250

Coffs Harbour		
May-95	170	60
Jun-95	170	68
Jun-96	110	56
	450	184

Port Macquarie		
May-95	296	60
May-96	73	62
	369	122

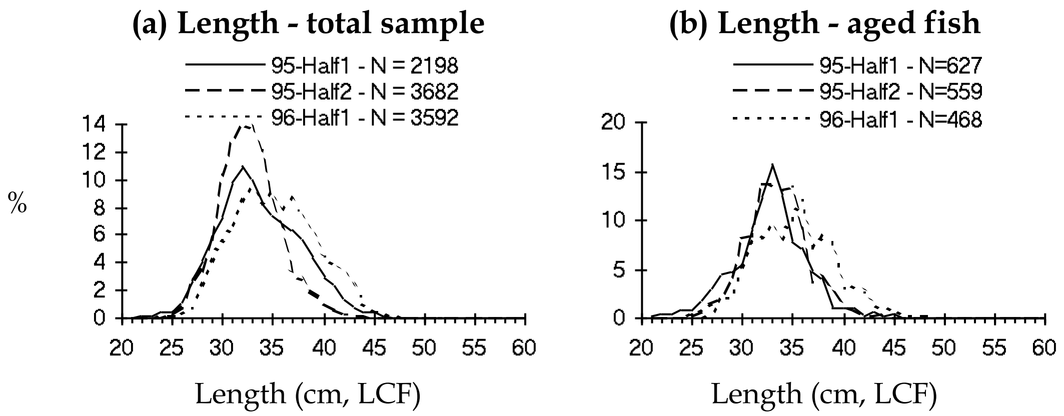
Port Stephens		
Apr-95	371	47
May-95	176	76
Dec-95	103	71
Mar-96	100	60
Apr-96	144	0
May-96	351	124
Dec-96	88	55
	1333	433

14.2 **Appendix 2** Details of biological sampling in Queensland

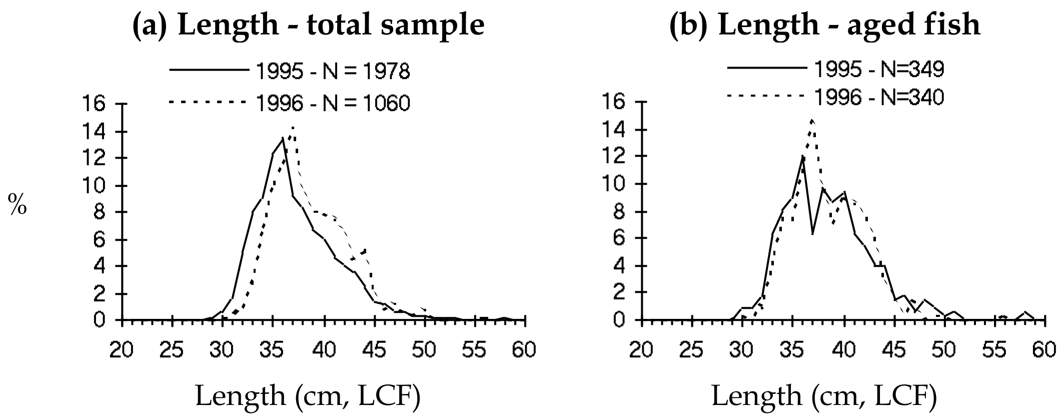
ESTUARY SITES	Trip	Measured	Biologicals	OCEAN BEACH SITES	Trip	Measured	Biologicals
MORETON BAY	April 1995	23	23	STRADBROKE ISLAND	June 1995	300	65
	May 1995	162	60		July 1995	300	60
	October 1995	0	0		August 1995	301	57
	November 1995	300	60				
					June 1996	300	59
	January 1996	300	65		July 1996	300	60
	February 1996	300	60		August 1996	300	60
	April 1996	300	58				
	May 1996	300	60	TOTAL		1801	361
TOTAL		1685	386				
MAROOCHY RIVER	April 1995	251	60	SUNSHINE COAST	June 1995	300	60
	May 1995	251	61		July 1995	281	61
	October 1995	61	59		August 1995	300	59
	November 1995	244	53				
					June 1996	300	60
	January 1996	0	0		July 1996	300	61
	February 1996	278	60		August 1996	300	60
	April 1996	272	60				
	May 1996	92	22	TOTAL		1781	361
TOTAL		1449	375				
TIN CAN BAY	April, 1995	300	72	FRASER ISLAND	June 1995	300	64
	May 1995	276	67		July 1995	305	63
	June 1995	14	14		August 1995	141	39
	November 1995	284	60				
					June 1996	301	60
	January 1996	300	60		July 1996	300	64
	February 1996	301	60				
	April 1996	294	60	TOTAL		1347	290
	May 1996	300	60				
	July 1996	301	60				
TOTAL		2370	513				

14.3 Appendix 3 Figures showing (a) the length frequency distributions of samples and (b) the length frequency distributions of aged subsamples from New South Wales.

Estuary sector by time

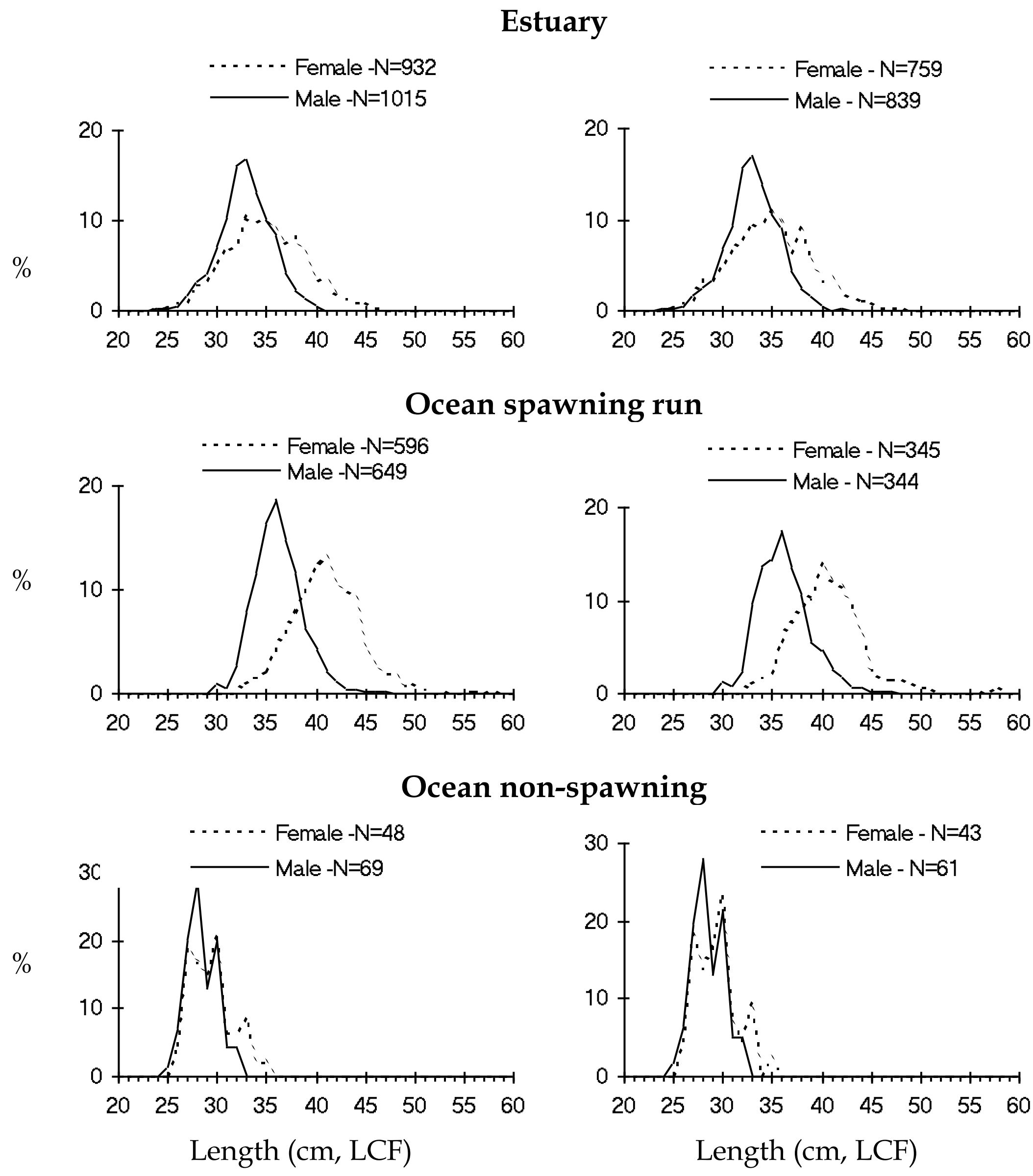


Ocean spawning run sector by time



Major sector by sex

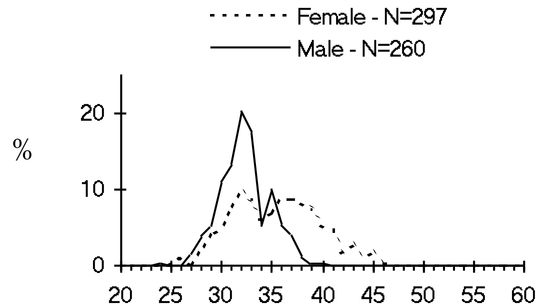
(a) Length - total sample **(b) Length - aged fish**

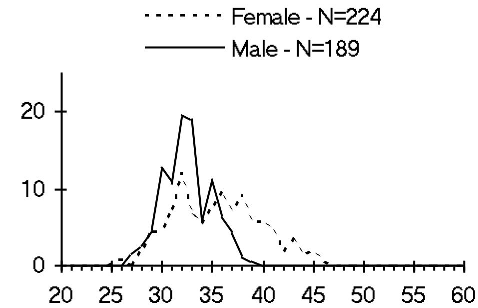


Estuary sites by sex

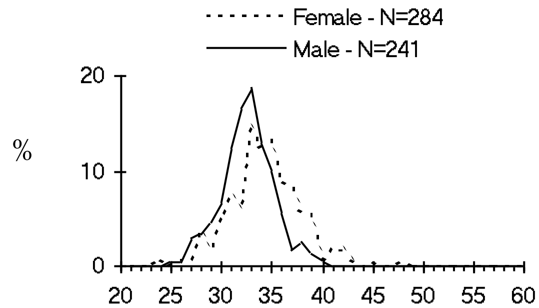
(a) Length - total sample | **(b) Length - aged fish**

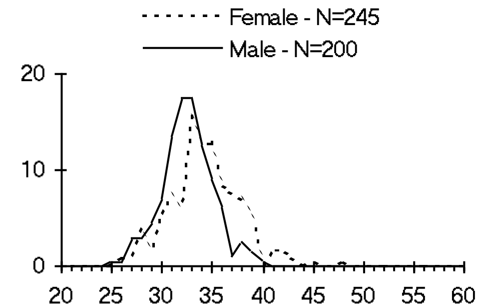
Clarence River



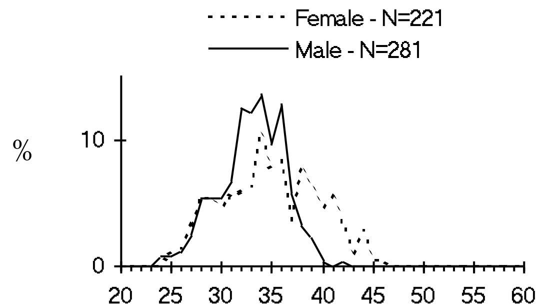


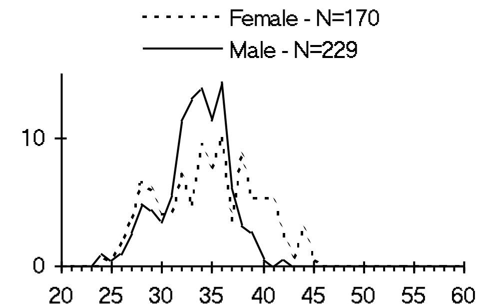
Wallis Lake



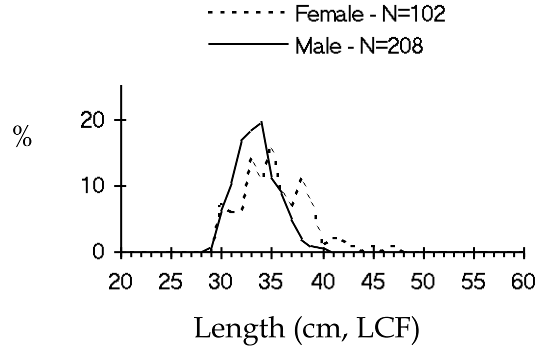


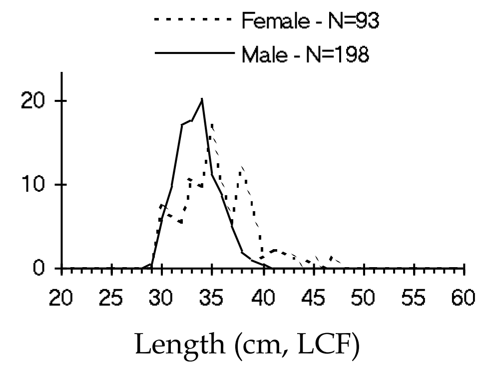
Lake Macquarie





Shoalhaven River

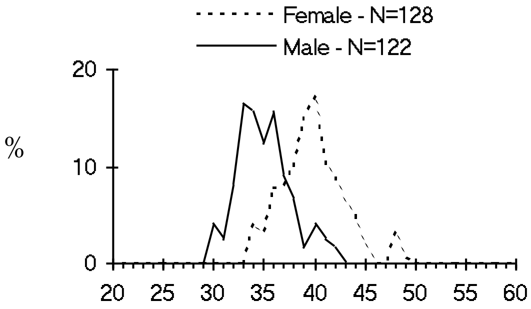


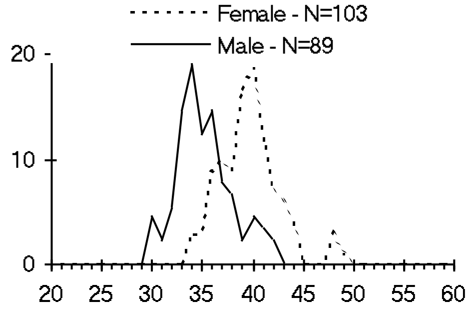


Ocean spawning run sites by sex

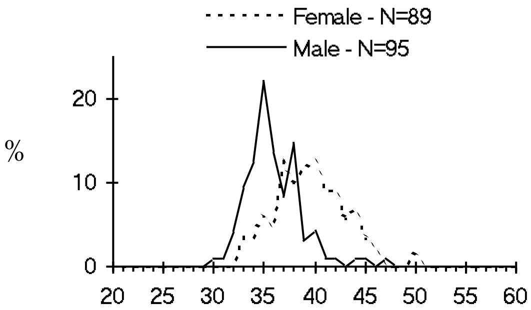
(a) Length - total sample | **(b) Length - aged fish**

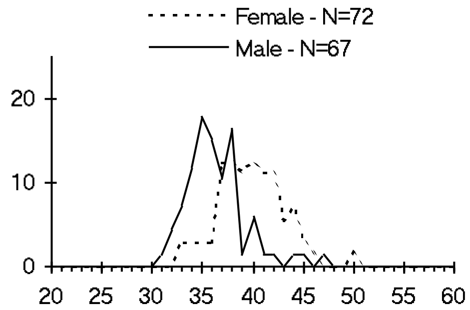
Tweed Heads



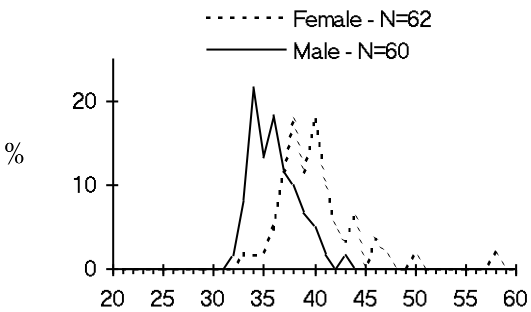


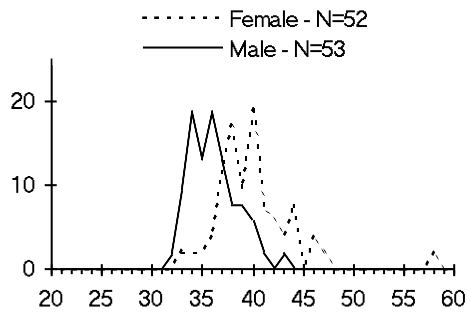
Port Macquarie



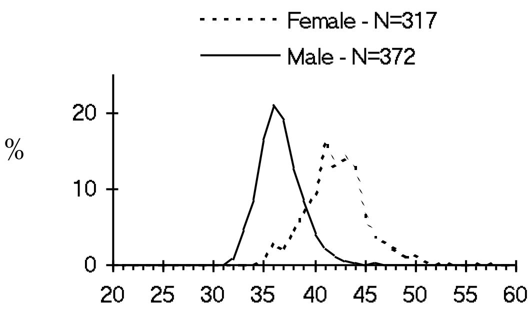


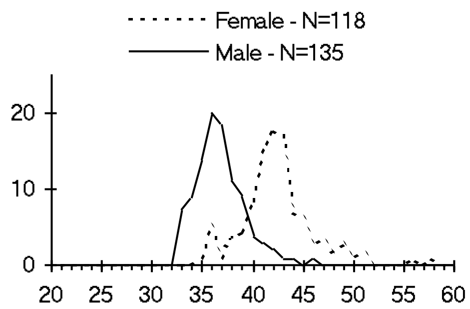
Coffs Harbour





Port Stephens



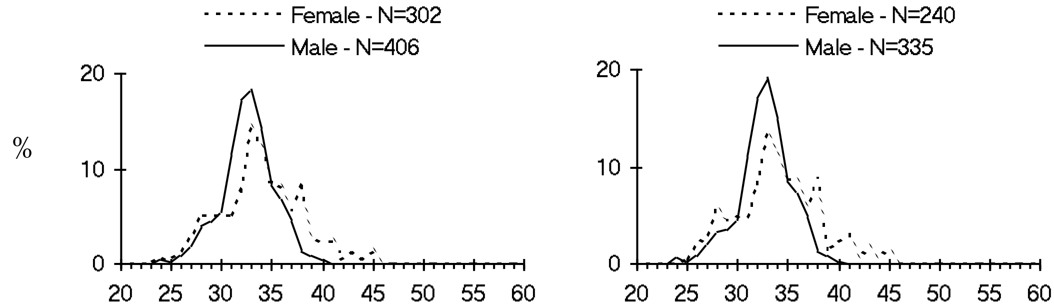


Length (cm, LCF) | Length (cm, LCF)

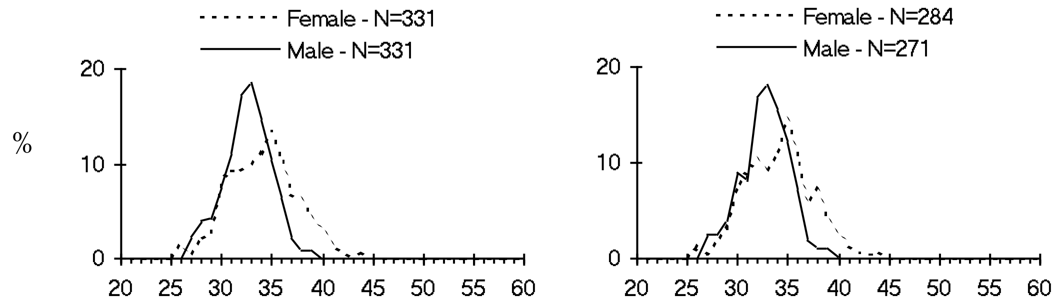
Estuaries by time by sex

(a) Length - total sample **(b) Length - aged fish**

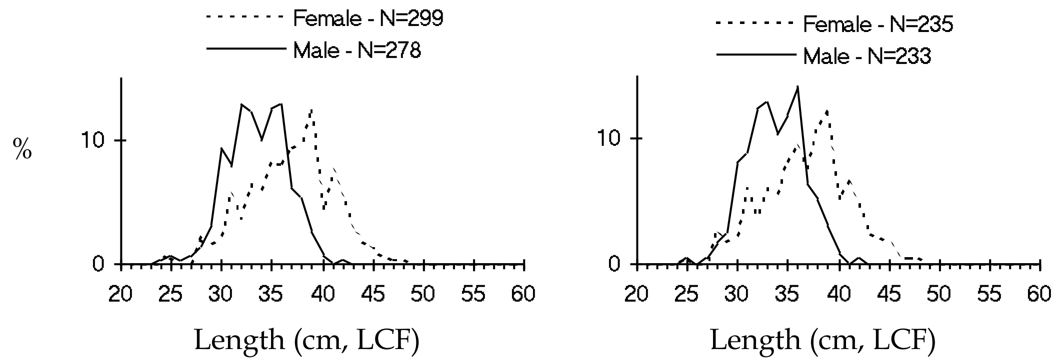
First half 1995



Second half 1995



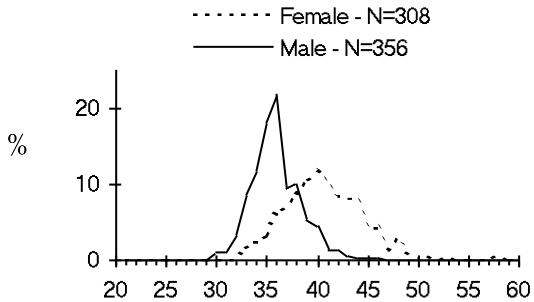
First half 1996

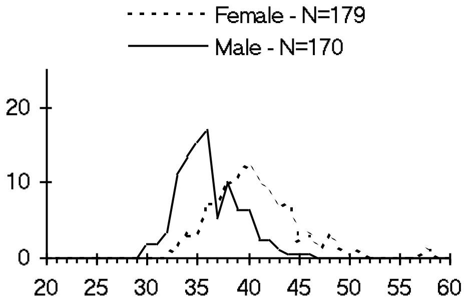


Ocean spawning run by time by sex

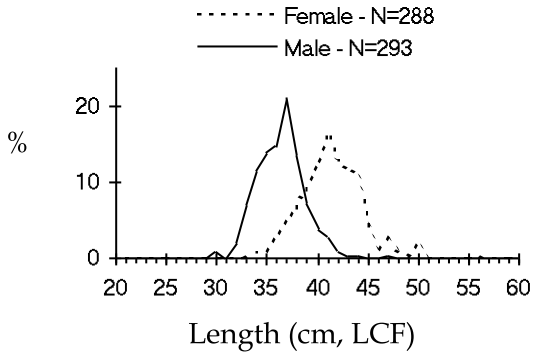
(a) Length - total sample **(b) Length - aged fish**

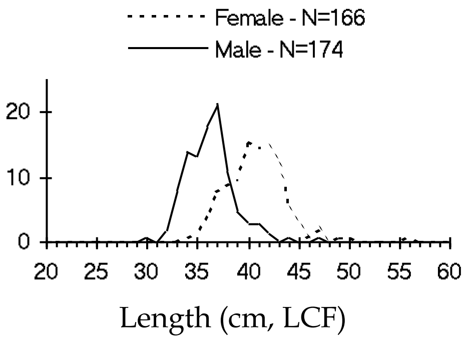
1995



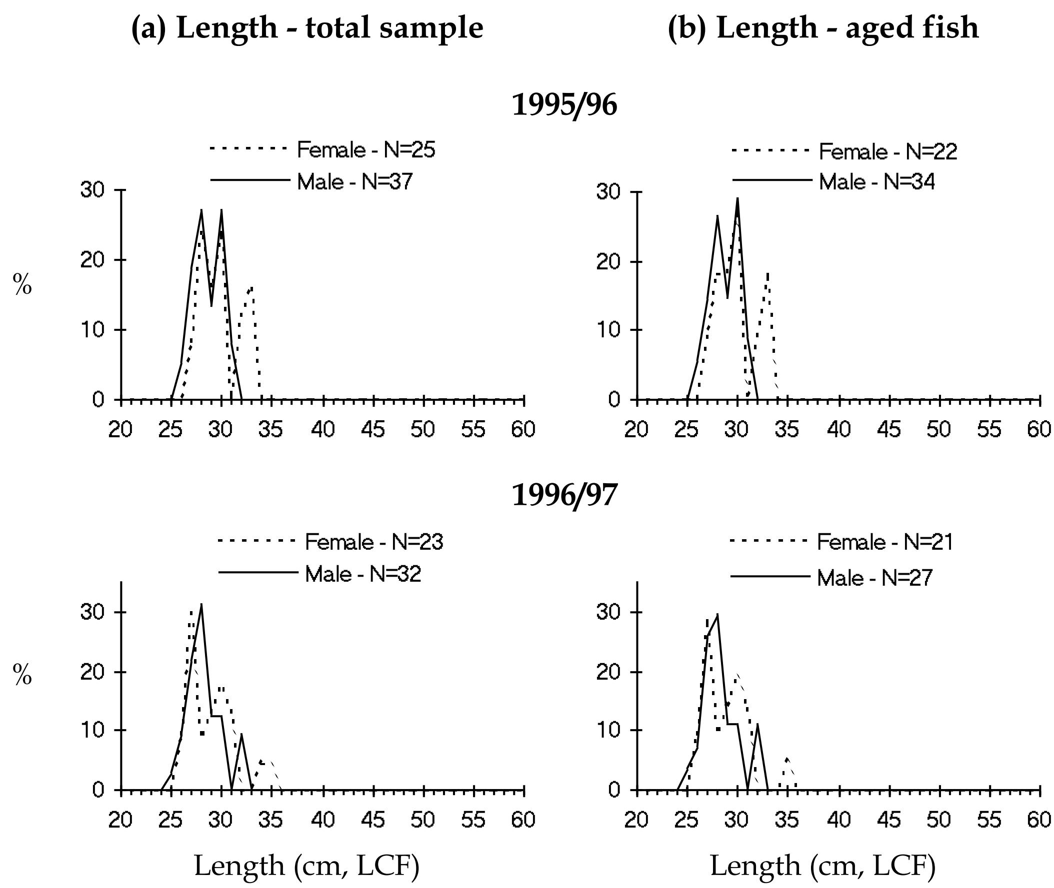


1996





Ocean non-spawning run by time by sex



14.4 **Appendix 4** Abstract for World Fisheries Congress Poster

Assessment of stocks of sea mullet (Mugil cephalus)
in New South Wales and Queensland waters

J. Virgona (1)*, I. Halliday (2)

(1) New South Wales Fisheries Research Institute, Sydney
(2) Queensland Southern Fisheries Centre, Deception Bay

The sea mullet (Mugil cephalus) is a very important fish species in Australia and worldwide. In Australia the commercial catch averaged approximately 6000 tonnes per annum during the past 10 years. Most of this catch was from the east coast with ~3000 tonnes (50%) from New South Wales and ~2500 tonnes (42%) from Queensland. In these states the sea mullet catch is the largest amongst finfish species. Another ~500 tonnes (8%) of the catch was from Western Australia and less than 1% from the rest of Australia.

A preliminary assessment of catch statistics from New South Wales indicates that while the estuary catches have remained stable at approximately 2000 tonnes, the ocean beach component of the catch has increased substantially from approximately 500 to more than 1000 tonnes in the past 10 years. The ocean beach component of the fishery targets the pre-spawning sea mullet which travel in ocean waters during autumn and winter. The increase in catch of these pre-spawning sea mullet is driven largely by the developing overseas markets for sea mullet roe.

In January 1995 a two year research project on sea mullet in New South Wales and Queensland commenced. This is a joint project involving the New South Wales Fisheries Research Institute and the Queensland Southern Fisheries Centre. Also, the project has federal funding from the Fisheries Research and Development Corporation. The main justifications for the project are that 1) the sea mullet is commercially important and 2) there is a need to examine the possible impact of the increases in ocean beach catches on the stock. The project aims to collect information for stock assessment, to compare the value of different components of the fishery and to calculate the social and biological impact of alternate management regimes. To achieve these objectives the project is estimating the value of various components of the fishery and collecting biological information on the growth and reproduction of sea mullet, the age structure and sex ratio of commercial catches and trends in the catch and fishing effort.

Important sources of catch and effort information include departmental, fishermen’s cooperative, and buyers/processors records. Departmental records in New South Wales contain data on total catches for at least the last 40 years and have the potential to provide useable effort data, particularly for the last 10 years.

Otolith sections are being used to age sea mullet. Many show clear growth rings and appear to be more reliable than scales, even though scales have been used in most previous studies on sea mullet. Also, early results indicate that otolith weight has the potential for estimation of age.

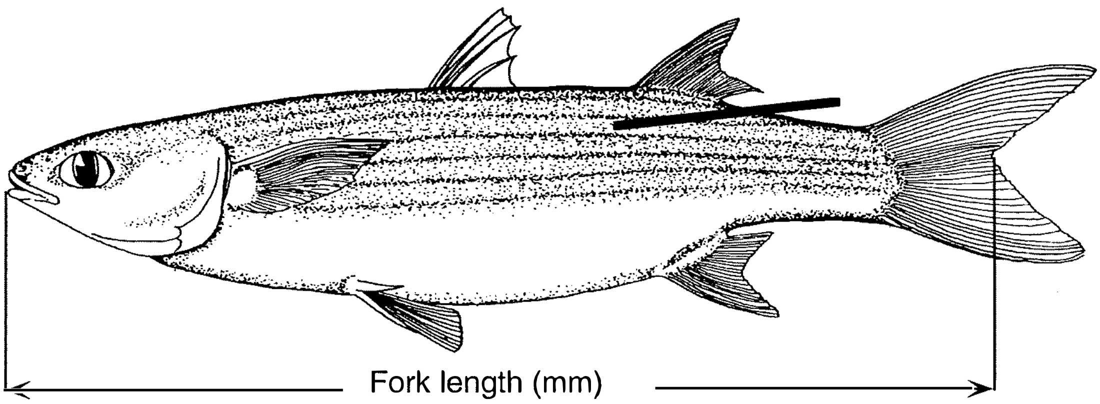
A tagging study has revealed many northern and southern movements of sea mullet on the coast of New South Wales. In a previous tagging study by the Commonwealth Scientific and Industrial Research Organisation on the coast of New South Wales, the recorded movements of sea mullet were predominantly northern. The movements recorded in this study have implications for stock identity and management of the fishery.

This project is providing information for stock assessment and comparison of alternate fishery management regimes for sea mullet in New South Wales and Queensland.

14.5 **Appendix 5** Tag poster

WANTED

TAGGED SEA MULLET



Sea mullet are being tagged to study their growth and movements. Orange plastic tags are being used.

REWARD

A reward of $10.00 is offered for the RETURN of each TAGGED SEA MULLET with the tag in place, together with the DATE and LOCATION of capture.

If the whole fish cannot be kept $5.00 will be paid for the return of each tag and details of the mullet's 1) fork length 2) date of capture and 3) place of capture.

Please notify:

1) Your local Fisheries Officer <u>or</u>
2) Fisheries Research Institute, *PO Box 21, Cronulla NSW (02-5278411)* <u>or</u>
3) Southern Fisheries Centre, *PO Box 76, Deception Bay QLD (07-2031444)*
so that arrangements can be made to collect the fish.

Note: Tagged undersized fish are exempt from minimum size regulations.

NSW FISHERIES

THANK YOU

DPI QUEENSLAND DEPARTMENT OF PRIMARY INDUSTRIES

14.6 **Appendix 6** Reproductive protocol

REPRODUCTIVE PROTOCOL - PART A

METHODS:
Collection: Fish can then be stored on ice or frozen, dissected and gonads fixed in 10% FAACC (1:10, volume to fixative). Fixation period needs to be 48 hours to a week depending on the size of the ovary/section. Samples can then be transferred to 70% alcohol for long term storage, however FAACC is designed for relatively long term storage (up to 18 months).

Large ovaries can be cut open and injected in several places to guarantee good preservation of oocytes for histological analysis. Sections of large ovaries may need to be taken in the field, particularly running, ripe ovaries where size will create a fixing/storage problem. Sections of one centimetre thickness from the middle of each lobe. Keeping both lobes is important in case one lobe is degenerate. Sections of ovary do not transport well in jars and tend to fall apart. It is therefore suggested to keep one lobe, either right or left depending on the quality.

Measurement: Fresh Whole Wet Weight to 1.0g

Sectioning: Tissue blocks sections of 6μm thickness should be taken transversely at the middle of each lobe. A wedge taken from a cross section from the centre to the periphery may need to be used due to the size of the ovary, however complete cross sections are preferable.

Staging: Staging of the ovary is based on the dominant oocyte type through assessing relative numbers of each oocyte type in the section.

FAACC FORMULA

FAACC = Formaldehyde 4%; Acetic Acid 5%; Calcium Chloride Dihydrate (CaCl $2H_20$) 1.3% (pH approx. 3.5). Originally designed as a Buoin's substitute as it is cheaper, safer and provides better long term storage.

20% Strength FAACC
37% Formaldehyde - 200ml
CaCl $2H_20$ - 13gm OR/ $CaCl_2$ (anhydrous) - 10g
Glacial Acetic Acid - 50ml
Tap water - 750 ml

10% Strength FAACC
37% Formaldehyde - 100ml
CaCl $2H_20$ - 13gm OR/ $CaCl_2$ (anhydrous) - 10g
Glacial Acetic Acid - 50ml
Tap water - 850 ml

OOCYTE STAGES:

Stage 1: chromatin nucleolar stage - large nucleus surrounded by thin cytoplasm with one single large nucleolus

Stage 2: perinuclear stage - pre-vitellogenic oocytes with numerous nucleoli at the periphery, strongly basophilic cytoplasm which stains uniformly , late Stage 2 oocytes have vacuoles appearing in the cytoplasm. Oocytes at this stage can rejuvenilise into a resting state which is visually apparent microscopically.

Stage 3: yolk vesicle (cortical alveoli) formation (vacuolated cytoplasm) - oocyte expands and becomes rotund, nucleus increases in size to 50% of the oocyte diameter with nucleoli at the periphery, cytoplasm not as strongly basophilic as yolk vesicles form and appear empty after dehydration from staining process, zona radiata appears as a thin acidophilic membrane, well formed follicular layer.

Stage 4: vitellogenic -

(early stage in development) oocyte expands and reaches maximum size before ovulation, well defined nucleus with lampbrush chromosomes, yolk vesicles prominent surrounding the nucleus and may coalesce towards the centre, thin bright acidophilic zona radiata

(middle/late stage in development) nucleus looses integrity with chromosomes becoming indistinguishable. Acidophilic yolk globules replace basophilic cytoplasm and coalesce at the oocyte periphery to present a smooth appearance (giving transparent appearance macroscopically), well developed follicular layer, zona radiata becomes a broad band.

Stage 4 oocytes cannot recover into a 'resting' state and are 'resorbed'

Stage 5: hydrated, diameter reaches maximum size with peripheral migration of the nucleus, breakdown of the nucleus membrane (germinal vesicle membrane) occurs and is often used as an indicator of final maturation, thin zona radiata, hydrated oocyte (egg) ruptures from the follicle and is ovulated into the lumen (often lost during initial tissue preparation).

FEMALE OVARY DEVELOPMENT CLASSES:

Class 1: **Immature (virgin)**

Macroscopically: firm, small in diameter

Microscopically: no evidence of prior spawning, muscular tunica tightly envelops the developing ovarian lamellae. Stage 1 & 2 oocytes are present at the centre of the lamellae with oogonia at the ovary periphery.

Class 2: Mature Resting Female

Ovary has undergone extensive vitellogenesis and has recovered into a resting state[1]. The ovary diameter is larger than Class 1 with the muscular tunica showing varying degrees of expansion depending on the extent of recovery from spawning. Stage 2 oocytes dominate with Stage 1 & 3 present. No vitellogenic activity however Stage 3 oocytes may be entering yolk vesicle stage. Atretic bodies[2] are common in the centre of the lamellae which indicates

[1] Rejuvenilization: Early Stage 3 or expanded Stage 2 oocyte regresses into a typical Stage 2 resting state. The oocyte has a strongly basophilic broad inner band surrounding the nucleus and a narrow outer band of light basophilic cytoplasm which is often separated from the inner cytoplasm. This stage is easy to confuse with the zonation of a Stage 3 oocyte.

[2] Atretic (brown) bodies: remnants of yolk globules and yolk vesicles from Stage 4 oocytes which are unshed, retained in the post spawning ovary, resorbed (cannot regress to a resting state) and eventually move to the centre of the lamellae. Old established atretic bodies are found near a veinule in the centre of the lamella or near a dorsal vein. Yolk globules persist after evidence of spawning (postovulatory follicles) or vitellogenic activity. Characterised by irregular shape, a change in the appearance of the yolk and a breakdown of the outer membranes.

evidence of previous maturation or at least vitellogenic activity.

Class 3: Mature active (early development)

Stage 3 oocytes dominate with Stage 1, 2 & early Stage 4 present. Atretic bodies usually present.

Class 4 : Mature active (imminent spawning)

Active vitellogenesis, ovary expands to maximum pre-spawning diameter and can remain in this state for several weeks or until suitable conditions for spawning occur. Late Stage 4 oocytes dominate, atretic bodies usually present but obscured by oocyte development.

Class 5: Ripe Mature (Running)

Stage 5 oocytes dominate, oocytes reach maximum diameter due to hydration.

Class 6 : Spent (post spawning)

Macroscopically: Direct evidence of recent spawning, ovary is reduced in diameter with loose, flaccid muscular tunica which eventually contracts to the resting state, may be bloodshot in appearance.

Microscopically: Gonad structure is disrupted with individual lamellae indistinguishable and extensive vascularization. All five oocyte stages are present with Stage 3, 4 & 5 degenerating. Yolk globules from Stage 4 oocytes are scattered throughout and forming atretic bodies. Empty follicles collapse and follicular cells are resorbed into the restructuring gonad. Postovulatory follicles[3] remain. The ovary becomes Class 2 Mature Resting[4].

Towards the end of the spawning season atresia is very common and it is important to distinguish between viable and atretic oocytes. The presence of 'remnant ripe eggs' in ovaries that are developing towards maturity indicates that a fish has spawned previously and is capable of Group-synchrony (de Vlaming, 1983).

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[3] Corpora lutea: readily identifiable when new but rapid degeneration occurs within 2 days from spawning and cannot be distinguished from intermediate stages of atretic oocytes.

[4] *Mugil cephalus* may be a 'serial spawner' where only part of the compliment of yolked oocytes are spawned and spawning occurs over a protracted period. We may need to include another development class between Class 5 & 6 in which females have partly spawned, where there is evidence of spawning but are not fully spent and may have a large number of vitellogenic oocytes present OR// Class 4 may need to be divided into two classes, early and late stage, depending on the nature of the reproductive status of individuals that are collected.

REPRODUCTIVE PROTOCOL - PART B

1) Gonad Somatic Indices (GSI) for males and females

2) Macroscopic sexing of individuals

3) Histological Analysis of oocyte stages and the rate of maturation for females

4) Histological determination of oocyte diameter for the leading maturation stage

5) Fecundity estimates for females (low priority)

6) Histological determination of abnormal ovary development

METHODS:

1) GSI:
Gonad Weight (GWt; wet. blotted dry) is expressed as a function of Body Weight (BWt; total weight) where:

$$GSI = 100 \times GWt / BWt$$

2) Macroscopic sexing of individuals:
Each individual collected is sexed macroscopically where possible and microscopically where necessary.

3) Histological analysis of oocyte stages and the rate of maturation for females:
Ovaries are to be collected from all females sampled. Each ovary is to be sectioned for microscopic staging except in the spawning season when ovaries can be staged macroscopically. Macroscopic staging of advanced pre-spawning ovaries needs to be verified through histological analysis of a sub-sample of ovaries.

The description of oocyte stages and ovary development classes is based on West (1990), as given in the previous Reproductive Protocol. Reproductive classes are determined through the criteria of the dominant oocyte stage which covers 50% or greater of the field of vision.. A Class 2 ovary dominated by irregular shaped Stage 2 oocytes can be easily distinguished from an early maturing Class 3 ovary which is dominated by rotund Stage 3 oocytes.

4) Histological determination of oocyte diameter for the leading maturation stage:
Ten measurements of the most advanced oocyte stage present in each ovary are taken using an OPRS or Optimas software package. A starting point is selected randomly at any given area around the tunica of either lobe. Within the field of vision the maximum diameter of oocytes sectioned through the nucleus is taken. The field of vision is then shifted toward the centre of the ovary until ten diameters have been measured.[5]

[5] Ovaries which have been frozen usually show some degree of deterioration. This usually appears in the form of phagocytes within the ovarian structure and disintegration of the lamellae walls. Oocytes may also have dehydrated in the embedding process which results in underestimation of the oocyte diameter.

5) Fecundity estimates for females (low priority)
Estimates of relative fecundity will be made through counting the number of eggs in three tissue samples randomly selected from the anterior, posterior and medial sections of either lobe from advanced ovaries collected during the spawning season. Sections are to placed in a 3:7; glycerin : water solution, making sure that oocytes are well separated. Fecundity estimates will be based on preserved or frozen samples. It was agreed that fecundity estimates will take low priority and only be achieved if time permits.

6) Histological determination of abnormal ovary development
Any abnormal ovary development will be detected through histological analysis and recorded as such.

Other titles in this series:

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. Fincal Report to Fisheries Research and Development Corporation. Project no. 96/139