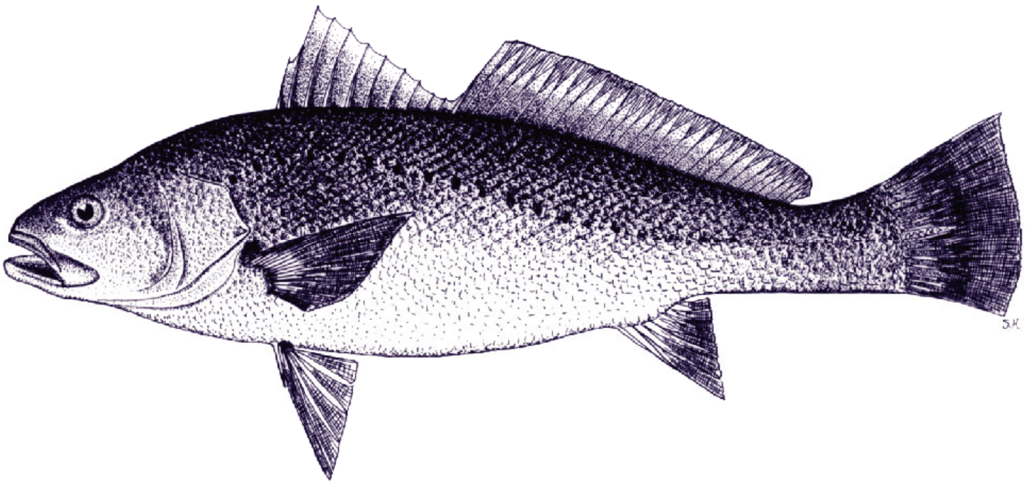
Arresting the decline of the commercial and recreational fisheries for mulloway (*Argyrosomus japonicus*)

Veronica Silberschneider & Charles A. Gray

NSW Department of Primary Industries
Cronulla Fisheries Research Centre of Excellence
P.O. Box 21, Cronulla, NSW, 2230
Australia



FRDC Project No. 2002/05
December 2005

NSW Department of Primary Industries -
Fisheries Final Report Series
No. 82
ISSN 1449-9967

NSW DEPARTMENT OF
PRIMARY INDUSTRIES

Australian Government

Fisheries Research and Development Corporation

Arresting the decline of the commercial and recreational fisheries for mulloway (*Argyrosomus japonicus*)

December 2005

Authors: Silberschneider, V. and Gray, C.A.

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

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

Internet: www.dpi.nsw.gov.au

ISSN 1449-9967

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

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACKNOWLEDGEMENTS

This was a jointly funded study between the NSW Department of Primary Industries and the Fisheries Research and Development Corporation.

We thank the many commercial fishers who assisted in the collection of samples and allowed us access to their fish catches. In particular, Terry Haack provided insight into the fishery and collected undersize individuals.

Numerous staff at the Cronulla Fisheries Research Centre provided assistance and advice during the project. In particular, Paul Lokys helped process otolith and gonad samples, Kerrie Deguara, Jo Fearman, James McLeod, Damian Young, Lachlan Barnes, James Mansfield and Victoria Andrews provided technical assistance in the Sydney Fish Market and/or field, and John Stewart did the yield-per-recruit analyses and advised on ageing procedures. The centre's librarians, Carolyn Bland and Kathy Bown, helped source many reference material for the review. Kevin Rowling provided historical data from the Sydney Fish Markets.

Ian Potter and Bryn Farmer at Murdoch University in Western Australia provided discussions and exchange of material.

Dr's Kevin Rowling, John Stewart and Steve Kennelly provided constructive comments on the report. We also thank the numerous researchers in the Wild Fisheries Program for discussions over many aspects of the study and acknowledge the fruitful discussions and contributions of staff in the Fisheries Management Branch and individual commercial and recreational fishers for their thoughts concerning the biology and fisheries of mulloway.

NON-TECHNICAL SUMMARY

2002/005	Arresting the decline of the commercial and recreational fisheries for mulloway (*Argyrosomus japonicus*)

PRINCIPAL INVESTIGATOR: Charles A. Gray
TECHNICAL OFFICER: Veronica Silberschneider

ADDRESS: NSW Department of Primary Industries
Cronulla Fisheries Research Centre
PO Box 21
Cronulla, NSW, 2230
Telephone: 02 9527 8411 Fax: 02 9527 8576

OBJECTIVES:

(1) Synthesize, write and publish a review of the biology and fisheries of mulloway (and other relevant sciaenid species) in an international scientific journal and provide a layman's summary that can be given to stakeholders.

(2) Reanalyse all existing tagging information on mulloway.

(3) Describe the growth and age and reproductive biology of mulloway in NSW and do yield-per-recruit analyses.

(4) Determine the length, sex and age compositions of commercial catches of mulloway and assess how these vary between different gear types, industry sectors (e.g. estuary v ocean) and regionally.

(5) Advise the commercial and recreational fishing communities and other interest groups on the biology of mulloway and provide recommendations on ways to stop the apparent decline in populations and future management and assessment strategies for the species.

NON TECHNICAL SUMMARY:

Outcomes Achieved

This study provides the first description and analysis of the age, growth and aspects of the reproductive biology and fisheries of mulloway in NSW. Collation of statistics on the commercial fishery and sampling of catches for length and age composition were used to assess the current status of mulloway. The data show that mulloway are growth overfished and changes in the management of the species including greater protection to spawners and juvenile fish are required for arresting the decline in populations in NSW. Proposed changes in the minimum legal length of mulloway are currently being discussed with the commercial and recreational fishing industries.

For some time there has been concern over the status of the population of mulloway (*Argyrosomus japonicus*) in NSW. This concern has primarily been driven by the continuing declines over the past two decades in reported commercial catches, recreational fishers reporting reduced catches and fewer large fish, and the identification that large numbers of juveniles are discarded as bycatch from estuarine and coastal prawn trawlers.

Mulloway are distributed in estuarine and nearshore Pacific and Indian Ocean waters surrounding Australia, Africa, India, Pakistan, China, Korea and Japan. Mulloway are commercially and recreationally fished throughout their distribution and the species is also the basis of a growing aquaculture industry in Australia. A review of the published scientific literature on mulloway

indicated a dearth of information concerning their biology and fisheries, except for southern Africa where the biology of mulloway is relatively well studied. In South Africa, mulloway is a fast growing fish that can live to a relatively old age (42+ years) and large size (> 175 cm TL). In South Africa mulloway is considered recruitment overfished.

This current study in NSW identified that, like in South Africa, mulloway grow fast reaching, on average, nearly 40 cm TL in 1 year and 95 cm TL in 5 years. Mulloway in NSW reach sexual maturity at a size of approximately 68 and 51 cm TL for females and males respectively and at an age of 2+ to 3+ years. These lengths and ages are significantly smaller and younger than corresponding attributes for mulloway in South Africa, highlighting the need for local data to fully understand the biological characteristics of a species for management considerations. Mulloway appear to predominantly spawn in ocean waters between November and March in NSW.

In NSW, mulloway are primarily caught using mesh (gill) nets in estuaries and by line in ocean waters. Analyses of the statistics of commercial fisheries of mulloway in NSW showed that reported catches have been declining in both the ocean and estuary sectors. However reported fishing effort has also declined and this may be the reason for the observed declines in total landings. The sampling of catches for length and age composition showed that most (approximately 80%) mulloway were within 15 cm of the minimum legal length (MLL = 45 cm TL) and that very few large (> 70 cm TL) fish contributed to commercial catches. Furthermore, commercial catches were dominated (> 70%) by fish aged 2 years. These data are disturbing given that these fish can potentially grow to > 175 cm TL and reach ages of 40+ years. Estimates of total mortality based on catch-curve-analyses were relatively high (0.45 – 0.7) and yield-per-recruit analyses identified that the MLL of mulloway needs to be increased greatly (to at least 70 cm TL) for optimal harvesting of the species. The data presented are indicative of a species that is growth overfished.

Changes in the management arrangements of mulloway are required for their effective conservation and sustainable harvesting. Greater protection to the spawning population and to juveniles in estuaries from capture in the prawn trawl fisheries is required. Implementation of bycatch reduction devices (BRD's) in the estuarine prawn trawl fleet should help with the latter, but a significant increase in MLL and possible seasonal and spatial closures to fishing may be required to protect the spawning population.

KEYWORDS: *Argyrosomus japonicus*, Mulloway, Sciaenidae, Fishery analysis

1. INTRODUCTION

1.1. Background

For some time there has been considerable controversy surrounding the status and allocation of the coastal and estuarine fisheries resources in NSW. For several of the major species, there is adequate biological and fisheries-related data available to base many important management strategies (e.g. appropriate legal lengths). Over the past 8 years NSW Fisheries has developed procedures for sampling the biology and fisheries of several important species of estuarine and coastal fishes. These procedures were primarily developed via funding from FRDC (e.g. FRDC 93/074, 94/042, 94/024, 95/151, 97/125). These initial studies have been rolled over into ongoing monitoring and assessment of stocks of these species (e.g. snapper, sea mullet, bream, dusky flathead, yellowtail scad). Whilst stock assessments are now being undertaken for some of our important fish species, there is only rudimentary fishery and biological information available for many other major species, including mulloway (*Argyrosomus japonicus*). The objective of this proposed study is to redress this situation for mulloway, so to provide information essential to the sustainable management of the species in NSW.

Mulloway are a relatively long-lived (> 40 years) species that can attain a large size (> 2 m) and weight (> 40 kg) (Kailola *et al*. 1993, Griffiths & Hecht 1995). They are caught by commercial and recreational fishers in all Australian states except Tasmania, and are also important to fisheries in southern Africa, Japan and Taiwan. In NSW, mulloway are an important component of the Estuary General and Ocean Trap and Line fisheries and are commonly caught as bycatch in estuarine and coastal prawn fisheries. Mulloway are also highly sought after by recreational fishers throughout Australia. An aquaculture industry is developing for mulloway in NSW and the species has been the subject of stock enhancement trials (FRDC 95/148; Fielder *et al*. 1999).

Reported commercial catches of mulloway in NSW have declined dramatically over the past 15 years (1983/84 to 2003/04) from approx. 117 to 21 tonnes in ocean waters and from approx. 45 to 41 tonnes in estuarine waters. Hence, there is considerable concern over the status of the stock and, whilst there has been much discussion whether this reported commercial catch data is indicative of stock abundance (highlighted in the NSW Fisheries Catch and Effort Working Group report), there is virtually no other biological or fisheries-related data available on which to base current and future management strategies for the species. In NSW, mulloway are currently managed through a combination of gear restrictions, minimum legal length and bag limits and spatial and temporal closures. Information on the age, growth and demographic characteristics of commercial and recreational catches is required to make more informed management decisions concerning the species. The proposed study aims to collect this very important information for this species and to synthesise this and all other available information to advise fisheries managers and other relevant groups of the status of the fishery and future management strategies for stopping the apparent decline in the populations of this species.

At present, there is only limited published information concerning the biology and ecology of mulloway in the wild in Australia (e.g. Hall 1984, Gray & McDonall 1993, West 1993), and not all of the data collected on mulloway have been analysed. For example, mulloway have been tagged in NSW but only very preliminary analyses have been made of the data (West 1993). Further, the only detailed description of a fishery for mulloway is that by Hall (1986) in South Australia. Elsewhere, there are generally fragmented pieces of information concerning commercial and recreational catches. For example, several discrete surveys of recreational fishing have been done in NSW that include data on mulloway. All available data on mulloway needs to be collated and synthesised to provide a concise critique of the biology, ecology and fisheries of the species. This will provide the foundation for discussions and decisions on future research and management options for the species.

1.2. Need

There is a need to synthesize all existing information and to obtain new basic biological and fisheries-related information on mulloway to be able to make informed management decisions concerning the continued sustainable harvesting of the species in NSW waters and elsewhere and to arrest the apparent decline in populations. Most importantly, the growth and age of mulloway needs to be accurately described and data on the length, sex and age compositions of catches and how these vary between different fishing sectors and gear types needs to be collected and analysed to provide us with even the most basic understanding of the potential effects of fishing on this very important species. Yield-per-recruit analyses need to be done to aid discussions on appropriate legal lengths.

1.3. Objectives

1 Synthesize, write and publish a review of the biology and fisheries of mulloway (and other relevant sciaenid species) in an international scientific journal and provide a layman's summary that can be given to stakeholders (Chapter 2).

2 Reanalyse all existing tagging information on mulloway (Chapters 2 and 3).

3 Describe the growth and age and reproductive biology of mulloway in NSW and do yield-per-recruit analyses (Chapter 3).

4 Determine the length, sex and age compositions of commercial catches of mulloway and assess how these vary between different gear types, industry sectors (e.g. estuary v ocean) and regionally (Chapter 4).

5 Advise the commercial and recreational fishing communities and other interest groups on the biology of mulloway and provide recommendations on ways to stop the apparent decline in populations and future management and assessment strategies for the species (ongoing).

2. A SYNOPSIS OF BIOLOGICAL, FISHERIES AND AQUACULTURE-RELATED INFORMATION ON MULLOWAY *ARGYROSOMUS JAPONICUS* (PISCES: SCIAENIDAE), WITH PARTICULAR REFERENCE TO AUSTRALIA

Abstract
Argyrosomus japonicus (mulloway) is a member of the family Sciaenidae, which are commonly known as drums and croakers. Mulloway occur in estuarine and nearshore Pacific and Indian Ocean waters surrounding Australia, Africa, India, Pakistan, China, Korea and Japan. The biology of mulloway is relatively well studied in South Africa but little elsewhere. Juveniles and adults are prevalent in estuaries and nearshore coastal waters, but there may be differences in the early life history distribution of the species between different regions, with their distribution in estuaries linked to salinity, turbidity, freshwater flows and depth of water. Studies in South Africa found that juvenile fish grow rapidly, attaining 35 cm TL in 1 year and 90 cm TL in 5 years, but sexual maturity is not attained until at least 5 - 6 years of age and > 80 cm TL. The maximum reported length and age of mulloway is 175 cm and 42 years, respectively. Spawning most likely occurs in nearshore coastal waters, but the time of spawning varies between different geographic localities and is probably linked to water temperature and oceanography. Juvenile fish (< 2 years) appear to be relatively sedentary, but sub-adults and adults can move relatively large distances (> 200 km) and such movements may be linked to pre-spawning migrations.

Mulloway is important in many recreational and commercial fisheries, but like other sciaenids, it is prone to overfishing. In South Africa the species is classified as recruitment overfished, and Australian commercial fisheries are generally characterised by declining catches. The levels of discarding of juveniles in prawn-trawl fisheries are a concern and much research has been done to minimize their capture. An aquaculture industry is developing for mulloway in Australia and preliminary research on the impacts and success of replenishing wild populations has begun. Greater information on rates of growth, size and age at attainment of sexual maturity, length and age compositions of commercial and recreational harvests and exploitation rates in Australia is required to provide better advice concerning management of Australian fisheries. Greater protection of spawners and improved fishing practices to enhance survival of discarded juveniles may be required to arrest the apparent decline in Australian populations.

2.1. Introduction

Argyrosomus japonicus (mulloway) is a member of the family Sciaenidae, commonly referred to as croakers and drums. Sciaenids are mostly demersal fishes found in fresh, estuarine and coastal marine waters in subtropical to temperate regions of the Atlantic, Indian and Pacific Oceans. The family contains approximately 70 genera and up to 270 species worldwide, with 28 species restricted to freshwater (Paxton & Eschmeyer 1994, Froese & Pauly 2003). Twenty species from nine genera have been recorded from Australia, with only two species occurring in temperate waters - *Argyrosomus japonicus* (Temminck & Schlegel 1843) and *Attractoscion aequidens* (Cuvier, 1830) (Steffe & Neira 1998).

Sciaenids, including mulloway, are important in many commercial and recreational fisheries and form the basis of aquaculture industries in many regions of the world. Thus there has been significant biological, fisheries and aquaculture-related research done on many species. This review encompasses biological, fisheries and aquaculture related studies done on mulloway.

2.2. Taxonomy

The taxonomic relationships among sciaenids have undergone much revision in recent years. Griffiths & Heemstra (1995) report that mulloway has been known by at least 13 other synonyms and, until 1995, was previously misidentified as *A. hololepidotus* in some areas, notably Australia and South Africa (Lin 1940, Trewavas 1977, Griffiths & Heemstra 1995). A full description of the morphological characteristics of mulloway is given in Griffiths & Heemstra (1995). In this review, we therefore include relevant information on *A. hololepidotus* from Australia that was published prior to the most recent change in species name (i.e. to *A. japonicus*). In contrast, we do not include several earlier studies done on *A. hololepidotus* in South Africa because they most likely represent another previously misidentified species, *A. inodorus* (see Griffiths 1996).

2.3. Distribution and stock structure

Mulloway is a nearshore coastal (< 100 m depth) species that also occurs in estuaries and is found in Pacific and Indian Ocean waters surrounding Australia, Africa, India, Pakistan, China, Korea and Japan (Fig. 2.1). In Australia, it is distributed along the eastern, southern and western seaboards from the Burnett River in Queensland to North West Cape in Western Australia (Kailola *et al*. 1993). It is found along the African south-east coast from the Cape of Good Hope to southern Mozambique, and, in the northern Indian Ocean, it occurs off Pakistan and the northwest coast of India. In the Northern Pacific it has been reported from Hong Kong, northwards along the Chinese coast, to southern Korea and Japan (Griffiths & Heemstra 1995).

There is limited information available on the stock structure of mulloway. Genetic-based studies have been done only in Australia and the conclusions from these studies are limited as they were based on samples comprising very few individual fish from only a few locations. Black & Dixon (1992) provided some electrophoresis-based evidence that a separate sub-population of mulloway occurs in Western Australia compared to the southern (South Australia and Victoria) and eastern (NSW and Queensland) seaboards. They further hypothesised that there may be additional population sub-structuring between fish in South Australia and New South Wales, but preliminary data based on mitochondrial DNA (mtDNA) did not appear to support this. There are no other reported genetic studies done elsewhere on the species and therefore the degree of genetic division among populations along different seaboards and oceans is not known.

Figure 2.1. Map of the world showing the known geographical distribution of mulloway.

We suggest that future studies to assess the genetic structuring of the species be approached using mtDNA analyses of fish collected via a stratified sampling program that incorporates several replicate samples taken in predetermined regions along and between coastlines so that within and between population variation in genetic structure can be assessed. A good example of the utility and strength of such an experimental design in a genetic study is that provided by Gold *et al.* (2002) on *Cynoscion nebulosus.*

Tag-recapture studies shed no further light on the stock structure of the species. Most tagging studies have been limited in scope (see below) and were not designed to answer questions regarding stock structure. Nevertheless, the data presented from these studies (Griffiths 1996, West 1993, and see Fig. 2.2) show relatively small-scale (< 400 km) movements of mulloway along a coastline and between estuaries. Whilst limited movements could be used to support stock separation along a coastline, no definitive conclusions can be made regarding the population structure of the species. Despite this, Griffiths & Hecht (1995) suggest that the population of mulloway in South Africa (called dusky kob) is a single genetic stock.

2.4. Early life history

Steffe & Neira (1998) give a full description of the larval development of mulloway based on reared and wild caught larvae. The previous description by Beckley (1990) of the larval development of *A. hololepidotus* is most likely that of *A. inodorus*. The eggs of mulloway are pelagic, approximately 938 ± 24 µm in diameter and under laboratory conditions, hatch in 28 – 30 hours (at 23°C) after spawning, with the larvae being 2.2 – 2.3 mm TL upon hatching (Battaglene & Talbot 1994).

Eggs have been collected near the surface in coastal waters off south-eastern Africa (Griffiths 1996) and larvae (up to 10 mm TL) have been caught in estuarine and coastal waters (out to 100 m depth contour) off south-eastern Australia between February and April (Miskiewicz 1987, Steffe 1991, Gray & Miskiewicz 2000). During daytime sampling in coastal waters of NSW, mulloway larvae (predominantly early pre-flexion stage) were caught in subsurface waters, with greatest concentrations below 30 m depth (Gray 1995). Similarly, most larvae captured in towed plankton nets in a coastal embayment (Botany Bay) in NSW, were close to the substratum (Steffe 1991), suggesting that larval mulloway may prefer deeper parts of the water column.

2.5. Juvenile and adult distribution

Small (< 30 cm TL) juveniles are found in estuaries and nearshore coastal environments, including surf zones (Hall 1986, Lenanton & Potter 1987, Gray & McDonall 1993, Griffiths 1996, West & Walford 2000). Some ambiguity exists however, concerning the timing, age and length that individuals recruit to estuaries. Several authors suggest that early development of mulloway primarily takes place at sea and juveniles enter estuaries at a length between 10 - 20 cm TL and up to 1 year after birth (Hall 1986, Potter *et al*. 1990, Anon 1993). In contrast, Griffiths (1996) reported that mulloway recruit to estuaries in South Africa at 2 - 3 cm TL approximately 4 weeks after hatching. Given this latter study in South Africa, and the fact that larvae and small juveniles (2 - 10 cm TL) have been caught in estuaries in NSW (Anon 1981a, Gray & McDonall 1993, Steffe 1991, West & Walford 2000), we suggest that small mulloway are present in estuaries from a very early age, but are probably not susceptible to capture in most common research sampling methods (i.e. larger meshed trawls, gillnets and seines) until they reach a larger length (see also Griffiths 1996). We thus propose that previous conclusions that young mulloway do not occur in estuaries until a later age may be a result of inappropriate sampling regimes for catching small fish. We acknowledge however, that some individuals probably develop at sea and recruit to estuaries at a latter age and larger length and that reported differences in the early life history distribution of mulloway between estuaries in Western and South Australia (Hall 1986, Potter *et al*. 1990, Anon 1993) compared to eastern Australia (Anon 1981a, Gray & McDonall 1993, Steffe 1991, West & Walford 2000) and eastern Africa (Griffiths 1996) may be related to differing environmental and oceanographic conditions in these regions (see Potter *et al*. 1990). Standardised sampling of small juveniles using nets with small mesh across several estuaries and coastal areas in different regions of Australia is required to test whether the distribution of young juveniles during their first year varies between seaboards.

In estuaries, juveniles (including early post-settlement stages) may favour deeper waters and not the shallow littoral fringes where most sampling for juvenile fishes has traditionally taken place (see below). For example, in a study in two estuaries in northern NSW (West & Walford 2000) most small mulloway (2 – 40 cm TL) were captured by trawling in the deeper waters of the main river channels, particularly where prawn abundances were high. None were caught in shallow waters or small tributaries (using small seine nets). Further, relatively few small juveniles have been caught along the shallow (< 2 m depth) vegetated (e.g. seagrass and mangrove) and non-vegetated fringes of estuaries, despite the extensive sampling of these habitats in south-eastern

Australia and southern Africa (Anon 1981a, Potter *et al*. 1990, Ferrell *et al*. 1993, Connolly 1994, Paterson & Whitfield 2000). We conclude therefore, that unlike many other species, mulloway is not dependent on shallow vegetated habitats as a juvenile nursery habitat, which is in direct contrast to several other scianenids, including *Cynoscion nebulosus* (see Rutherford *et al*. 1982).

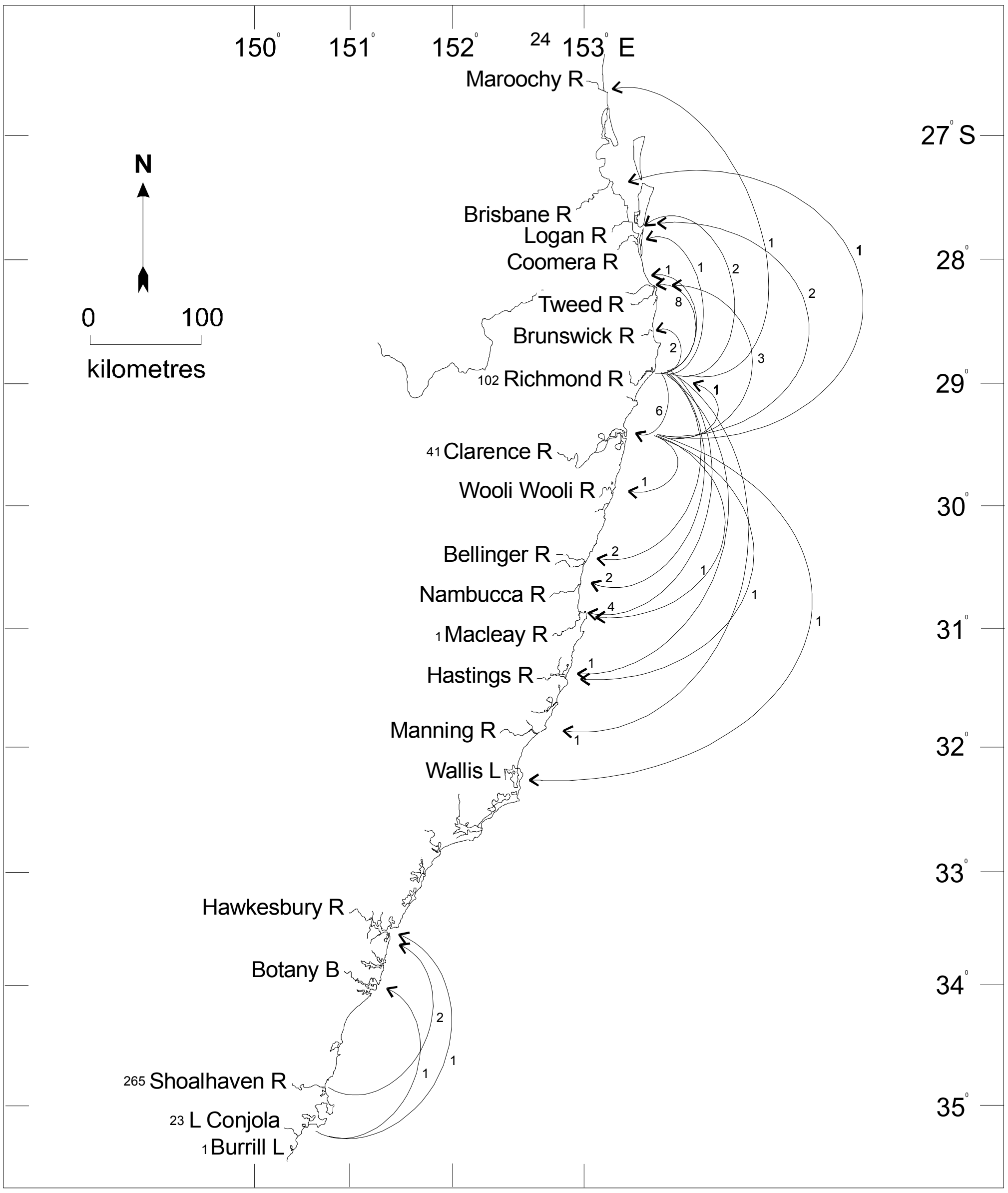
The horizontal distribution of mulloway in estuaries can vary substantially and is probably linked to environmental factors including salinity, freshwater flows, turbidity and life history stage. Griffiths (1996) reported that fish < 15 cm predominantly recruit to the upper regions of estuaries where salinities are < 5 ppt. Gray & McDonall (1993) found that most juvenile fish (10 – 20 cm TL) occurred at locations in an estuary where the salinity was 15 to 20 ppt. However, some juvenile fish were caught in upstream locations where salinity was < 5 ppt and also near the estuary mouth where salinity was > 25 ppt. Griffiths (1996) also found that juveniles were more prevalent in turbid versus non-turbid estuaries and hypothesised that juveniles may be more abundant in estuaries with significant freshwater flows. This may also be true in NSW where juveniles appear to be more prevalent in the deeper riverine type estuaries compared to the shallower barrier (coastal lagoon) estuaries. Both Hall (1984) and Griffiths (1996) further suggested that freshwater flow promoted recruitment of larval and juvenile mulloway to estuaries.

Sub-adult and adult mulloway occur in estuarine and ocean waters (Griffiths 1996). In estuaries, larger juveniles and sub-adult fish (> 40 cm TL) appear to be more abundant in the lower reaches where salinities are nearer to seawater (Anon 1993, Griffiths 1996). The distribution of these larger individuals may be related to particular hydrographic conditions. For example, Anon (1993) reported that larger fish moved from estuaries to the ocean in Western Australia in winter when estuarine salinity levels dropped. Large individuals are caught around the mouths of estuaries, in surf zones and around rocky reefs and ridges in offshore waters.

2.6. Movement

Several tag-recapture studies have been done on mulloway, although the objectives and scales of the studies, and the data published, have been variable and in some cases, unclear. In Australia, separate tag-recapture studies have been done on mulloway in NSW (Thomson 1959, West 1993, NSW Fisheries unpublished data), South Australia (Hall 1984) and Western Australia (Anon 1993), while in southern Africa there has been one published study (Griffiths 1996).

The data concerning movements of tagged mulloway show that some fish appear to be relatively sedentary (predominantly juveniles), whereas others move significant distances along a coastline and from one estuary to another (Table 2.1). For example, in South Africa, Griffiths (1996) found that 83% of the 263 recaptures (primarily juvenile and sub adult fish < 120 cm) were found < 10 km from where they were tagged even though these fish recorded long periods of liberty (> 1400 days). Only 15 fish were recaptured > 30 km from the initial tag location. Similarly, in NSW, most tagged mulloway were recaptured in the estuary where they were originally tagged (83 %, n = 519), but 70 fish (13.5 % of recaptured fish) moved between estuaries both north and south from the estuary where they were tagged (Fig. 2.2). The greatest distance migrated was approximately 400 km southward from the Clarence River to Wallis Lake with the fish at liberty for 176 days (Table 2.1 and Fig. 2.2). The greatest northward migration was approximately 300 km from the Clarence River to the Brisbane River with the fish at liberty for 851 days. To date, the longest period at liberty for a recaptured mulloway in NSW has been 1954 days, with the fish recaptured approximately 375 km south of where it was tagged. Some tagged mulloway have moved relatively large distances in opposing directions elsewhere. In South Australia, Hall (1984, 1986) reported 7 fish were recaptured about 200 km from the tagging site and that these occurred in both north and south directions. Northward and southward movements of mulloway have been observed in South Africa, with fish being recaptured up to approximately 260 km north and 190 km south from the place of tagging (see Fig 12 in Griffiths 1996). We note that caution needs to be exercised in the interpretation of the release-recapture data provided. Much more information (e.g. distribution of sampling or fishing effort) than presently available is required to assess rates of movements in different directions, between different estuaries and regions of a coastline.



ESTUARY MULLOWAY

Figure 2.2. Map showing locations of release and recapture of tagged mulloway in New South Wales, Australia. Each line & number represents the fish that travelled between locations and the number at each estuary represents how many were recaptured in the same estuary where they were released.

Table 2.1. Summaries of tag-recapture studies of mulloway showing numbers tagged and recaptured, proportion showing no movement (< 10 km from tag location), greatest distances travelled and maximum times at liberty.

Study	Number of fish tagged	Number of fish recaptured	Proportion of fish with no movement	Days at liberty of fish with no movement	Greatest movement	Days at liberty of fish with greatest movement
Thomson (1959)	12	0	N/A	N/A	N/A	N/A
Hall (1984)	628	21 (3.3%)	Not reported	Not reported	1 fish ~ 200 km	~ 150 days
Hall (1986)	6000	180 (3%)	172 (95.4%) remained within the Coorong	Not reported	7 fish up to ~ 200 km. Other fish moved >10 km within the Coorong	Not reported
Griffiths (1996)	Not reported	263	Approx. 218 (83%) recaptured < 10 km from tag site	> 1400	Approx 250 km. 5.7% moved >30 km	Approx 900 days
NSW Fisheries (unpub)	2510	519 (20.7%)	452 (87%) recaptured within the tag estuary	1060	406 km	176 days. Greatest days at liberty = 1954 (fish moved 375 km)

2.7. Age, growth and mortality

Age and growth of mulloway has been little studied except in South Africa where they grow to a large size and are relatively long lived, with the maximum reported length being 181 cm TL, weight of 75 kg (Griffiths & Heemstra 1995) and age of 42 years (Griffiths & Hecht 1995). A length of > 200 cm has also been reported for this species (Kailola *et al.* 1993) but no evidence is provided to supports this. Rates of natural mortality have only been estimated for fish in South Africa, where it was estimated that M = 0.15 (Griffiths 1997c).

Griffiths & Hecht (1995) provide the most detailed and reliable estimate (validated otolith-based study; fish 3 – 175 cm TL) of the growth of wild mulloway. Growth of both sexes is initially rapid and similar for the first 2 years, after which the rate of growth declines (see Table 2.2), with females growing faster to attain an overall greater length (165 – 170 cm) and age (42 years) than males (140 – 145 cm and age 30 years). Griffiths & Hecht (1995) estimated growth curves (using the generalised Von Bertalanffy model) for females as $L_t = 147.3[1\text{-}e^{-0.228(t + 2.620)}]^{2.468}$ and for males as $L_t = 137.2[1\text{-}e^{-0.260(t + 4.282)}]^{4.619}$. Although the rates of growth differed between sexes, the length/weight relationships for males and females did not differ significantly.

Much less has been published concerning the growth of mulloway in Australian waters and none for elsewhere. Despite this, comparative estimates of published mean length at age of mulloway are presented in Table 4.2, although we acknowledge there can be large variation in length at age (see Fig. 6 in Griffith & Hecht 1995). Gray & McDonall (1993), by following juvenile cohorts caught in prawn trawls, estimated that juveniles grew from a mean length of 7 to 15 cm TL and 16 to 25 cm TL in 6 months between April and October and that fish 15 cm in length were 6 months old. Based on tag-recapture data and scale readings, Hall (1984) estimated that mulloway grew to 46 cm (1.5 kg) in 2 to 3 years and a length of 80 cm (8 kg) in 5 to 6 years. West (1993) analysed tag-recapture data and estimated that mulloway grew to 49 cm TL in 2 years and 56 cm TL in 3 years. The available data suggests that growth of mulloway is variable and may vary greatly between different geographic regions. Much greater and validated data is required on the growth of mulloway outside southern Africa, however, to test this. Ages estimated from the current study are given here and are discussed in detail in Chapter 3.

Table 2.2. Comparisons of estimated length (TL; cm) at age for mulloway.

Age in years	Wallace & Schleyer (1979) [a*]	Hall (1986) [b]	Griffiths & Hecht (1995) [a+]		West (1993) [c]	Current study
			Male	Female		
1	23	8	35.6	35.5	41	34.7
2	44	24	50.3	51.1	49	52.0
3	62	41	64.6	66	56	66.3
4	77	53	77.6	79.5	65	78.0
5	90	65	89	91.3		87.6
6	102	81	98.6	101.5		95.5
7	112	96	106.6	110		102.0
8	120	107	113.1	117.1		107.3
9	128	114	118.3	122.9		111.6
10	134		122.4	127.7		115.2
11	139					
12	144					
15			133.1	140.8		125.5
20			136.1	145.2		129.4
25			136.9	146.6		130.8

Age estimated by: [a] otolith interpretation, [b] scale interpretation, [c] release-recapture data.
[*] Presumed to be *A. japonicus*
[+] Lengths derived using the growth equation and parameters given in the manuscript

2.8. Reproduction

The reproductive biology of mulloway has been little studied. Griffiths (1996) reported that 50% of male and female mulloway in South Africa were mature at 92 and 107 cm TL respectively, and that all males and females > 110 and 120 cm TL respectively, displayed mature gonads. The 50% and 100% maturity levels correspond to 5 and 7 years of age for males, and 6 and 8 years for females, respectively. It is reported that mulloway in South and Western Australia do not become sexually mature until they attain about 75 cm TL and are approximately 70 - 80 cm (approx. 4 kg) and 5 to 6 years old (Hall 1986, Anon 1993). A study in Botany Bay in eastern Australia collected mulloway up to 64 cm and all had immature gonads (Anon 1981a). No estimates of the fecundity of wild mulloway have been reported, but Battaglene & Talbot (1994) estimated that hatchery kept fish around 10 kg could spawn approximately 1 million eggs. Batteglene (1996) further reported that the spawning mode of mulloway is group synchronous.

The time of spawning appears to vary between geographic regions and with latitude and is probably related to water temperature and oceanography. For example, in southern Africa, Griffiths (1996) found that spawning varied along the coast from August to November (winter to spring) in the northern KwaZulu region (30 - 31°S), and from October to January (summer) in the southern and south-east Cape regions (33 - 35°S). Similarly, along the West Australian coast, Penn (1977) reported fish with mature gonads in September and October in Shark Bay (26°S), whereas Anon (1993) reported that mature fish occurred between December and January in the Swan River (32°S). In South Australia, mulloway appear to spawn throughout summer (November to February) (Hall 1986). Based on the occurrence of larvae between February and April (Gray & Miskiewicz 2000) and small juveniles 2 - 8 cm TL between April and June (Anon 1981a), spawning in central NSW (around 35°S) appears to take place in late summer and autumn (January to April). However, West & Walford (2000) reported that juvenile mulloway (< 10 cm TL) were present year round in two estuaries in northern NSW (between 28°50’ and 29°30’S). Further, both Broadhurst (1993) and Gray & McDonall (1993) reported two distinct juvenile cohorts in an estuarine population within the same region which suggests that not all spawning is synchronous within a region.

Several authors have hypothesised that mulloway spawn in nearshore coastal waters around the mouths of estuaries and in surf zones. This is based on observations in South Africa (Griffiths 1996) and South and Western Australia (Hall 1984, 1986, Anon 1993) that fish with mature or spent gonads have been caught only in ocean waters, whilst fish in estuaries did not show development of mature gonads. Further, off the east coast of South Africa, eggs have only been collected in nearshore waters and not in the offshore Agulhas Current (see Griffiths 1996) and larvae (but not eggs) have only been collected in low numbers in estuaries. Hall (1984) suggested spawning may take place near the mouths of estuaries as large fish (80 - 150 cm TL) in spawning condition have been caught in the mouth of the Murray River in South Australia. Hall (1984) further postulated that freshwater outflow during summer may promote aggregations of spawning fish near the mouths of estuaries as peak freshwater discharge generally coincided with, or just preceded, the spawning season. The spring/summer-spawning season in South Africa also coincides with the highest periods of rainfall and river discharge in that region. Griffiths (1996) hypothesised that mulloway may have adapted a river discharge-spawning relationship as an evolutionary tactic to enhance recruitment of juveniles to estuaries.

2.9. Diet

Mulloway has a relatively large mouth with caniniform teeth, sharp gill rakers and a short intestine with a large distensible stomach (Anon 1981a). It is regarded as a benthic carnivore but can apparently feed throughout the water column (Kialola *et al.* 1993). The importance of different dietary components has varied between studies and for different life history stages. Overall, crustaceans, notably penaeid, mysid and alpheid shrimp, and small teleost fish have been the primary dietary items observed in the stomachs of juvenile mulloway (Anon 1981a, Marais 1984, Hall 1986, Fielder *et al.* 1999). Crustaceans accounted for between 14% (Fielder *et al.* 1999) and 81% (Anon 1981a) of the reported diet of juveniles. The importance of crustaceans in the diet of mulloway appears to decrease with increasing fish size, resulting in fish and squid being the prey of greater relative importance in larger mulloway (see Marais 1984, Griffiths 1997a,b).

2.10. Commercial and recreational fisheries

Estimates of total worldwide commercial and recreational harvests of mulloway are not possible to ascertain, as the quantities landed in many countries are either unknown or not reported. Moreover, regional estimates of catches are incomplete for many countries. Hence, data concerning commercial and recreational catches for Australia only are presented (Table 2.3). The data show that harvests vary spatially and between fishing sectors and that estimated recreational catches in several states (NSW, Victoria and Western Australia) are of an equivalent or greater magnitude than reported commercial catches. Although there are no estimates of total commercial or recreational catches available for South Africa or elsewhere, nearshore commercial line boat fishers in South Africa caught an average of 197 tonnes/year of mulloway between 1988 and 1992 (Griffiths & Heemstra 1995).

Most Australian fisheries for mulloway are managed by spatial and temporal fishing restrictions, gear regulations, minimum legal lengths (MLL) and recreational bag limits. The MLL regulations and recreational bag limits for mulloway vary between state jurisdictions, with most MLL's set between 40 and 50 cm TL. This is comparable to South Africa where the current MLL is 40 cm TL. These MLL's are not set on any biological basis.

Table 2.3. Estimated commercial and recreational catches of mulloway in Australia in 2001. Data on recreational catches are from the National Recreational and Indigenous Fishing Survey (Henry & Lyle 2003).

State	**Commercial catch**	**Recreational catch**			
	Total Reported Weight (kg) #	Total Estimated No.	Standard error	Total Estimated weight (kg)	Mean weight of fish (kg)*
NSW	73 800	136 852	21 678	273 703	2
Victoria	98	5 421	2 997	10 841	2
Queensland	na	73 243**	13 392	84 229**	1.2
SA	113 000#	27 004	5 156	39 885	1.5
WA**	61 700	62 928**	14 921	359 699**	5.7
Total		323 460		925 057	

Commercial catch data are for the 2001/2002 financial year.
* The mean weight of mulloway used to calculate the estimated weight
** Other species of sciaenids most likely included in these data.

In Australia, reported commercial catches of mulloway are available from 1940 for NSW and between 1950 and 1984 for South Australia. Catch per unit effort (CPUE) information is also available from 1984/85 for NSW although, from 1997/98, new reporting regulations meant that CPUE could be calculated as kg per fisher month (from 1984/85 onwards) or as kg per day (from 1997/98 onwards). Reported commercial catches in South Australia fluctuated between 30 and 215 tonnes per annum between 1950 and 1984 (Hall 1986). In NSW, reported commercial catches fluctuated between 50 and 100 tonnes between 1940 and 1970, after which commercial landings increased sharply to peak at 380 tonnes in 1973/74. This increase in catch corresponded with the rise of otter trawling in coastal waters and the removal of the MLL in 1971 (Fig. 2.3). Reported commercial estuarine and ocean catches have steadily declined since the peak in 1973/74 to a low of 60 tonnes in 2003/04 which was valued at around $AUD 435000. The general decline in catch since the mid 1970's in NSW is reflected in catch statistics across all estuaries and ocean ports throughout NSW (see also West & Gordon 1994). In NSW, CPUE has consistently fluctuated between 40 and 55 kg/fisher month from 1984/85 onwards and has fluctuated between 3.5 and 4.3 kg/day from 1997/98 onwards. Thus, despite a decrease in commercial landings (kgs) CPUE has remained fairly stable. This suggests that the decrease in catch may be due to a reduction in the number of commercial fishers targeting mulloway. However, reported CPUE for mulloway in South Australia declined from approximately 15 kg/day in 1976/77 to about 5 kg/day in 1982/83 (Hall 1986). No current CPUE data for South Australia is available.

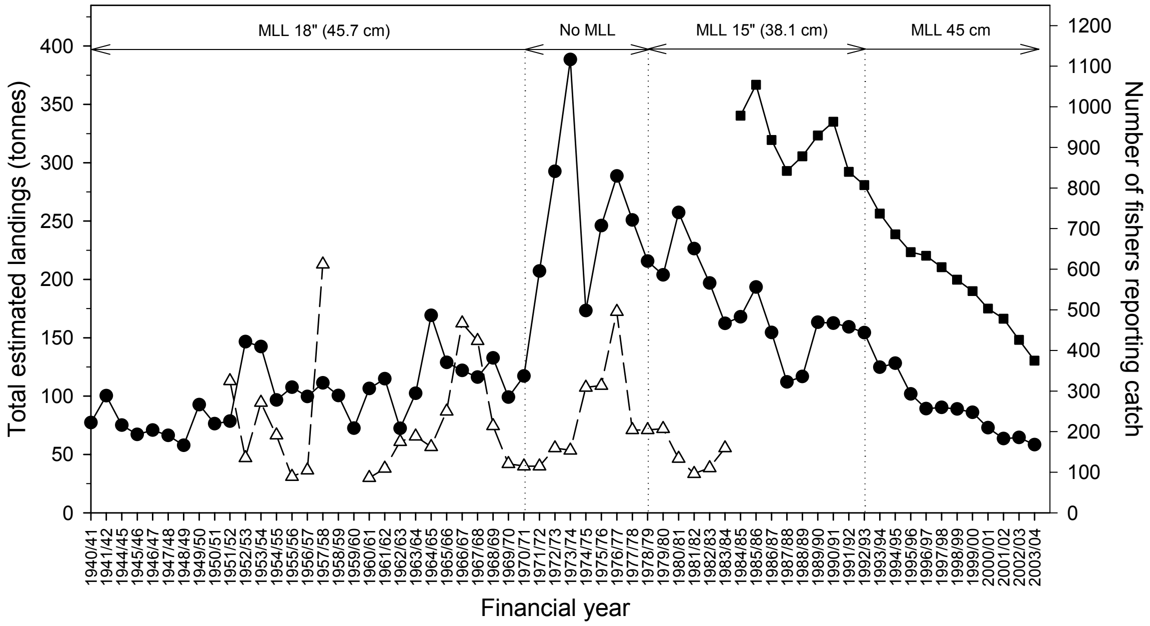


Figure 2.3. Reported commercial catches of mulloway in NSW since 1940/41 and associated changes in MLL, number of NSW fishers reporting catch of this species, and commercial catches from South Australia. Filled circles – NSW estimated landed catch; open triangles – SA landed catch (reproduced from Hall 1986); filled squares – number of NSW fishers reporting mulloway.

Reported commercial catches of mulloway throughout the past decade in NSW have generally been greatest in estuaries (52 – 65% of reported annual production) compared to ocean waters (26 - 40%) (Table 4.4). Fish are mostly caught using gillnets in estuaries and by hook and line in ocean waters. Reported estuarine commercial catches are generally greatest in the deeper coastal rivers that experience high freshwater flows (Hawkesbury, Clarence and Shoalhaven rivers). In South Australia, approximately 80% of the mulloway commercial fishery centres on one large estuary (the Coorong) and 20% from waters immediately adjacent to the Coorong (Hall 1986). Within the Coorong, the main fishing methods are gillnets and beach-seine nets, but in contrast to NSW, gillnets and seine nets as well as hook and line are the main capture methods in ocean waters (Hall 1986). Commercial catches are generally greatest between December and June in NSW and between December and March in South Australia.

Table 2.4. The proportion of total reported commercial catch of mulloway taken in each fishery in NSW for the years 1997/98 and 2002/03.

Fishery	Main gear type used to catch mulloway	Proportion of mulloway caught in each fishery (%)	
		1997/98 (total est. landed weight = 93380 kg)	2003/04 (total est. landed weight = 60129 kg)
Estuary General	Mesh net	51.63	65.23
Ocean trap & Line	Handline	39.66	26.51
Fish Trawl	Fish trawl net	4.04	2.80
Ocean Haul	Beach haul net	3.94	4.85
Ocean Prawn Trawl	Prawn trawl net	0.70	0.51
Estuary Prawn Trawl	Prawn trawl net	0.03	0.10

The length composition of commercial catches in NSW has changed considerably over the past 3 decades (Fig. 2.4), corresponding to changes in MLL, with the modal length of fish harvested increasing as MLL increased. The majority of fish landed were < 10cm TL above the MLL (when in existence).

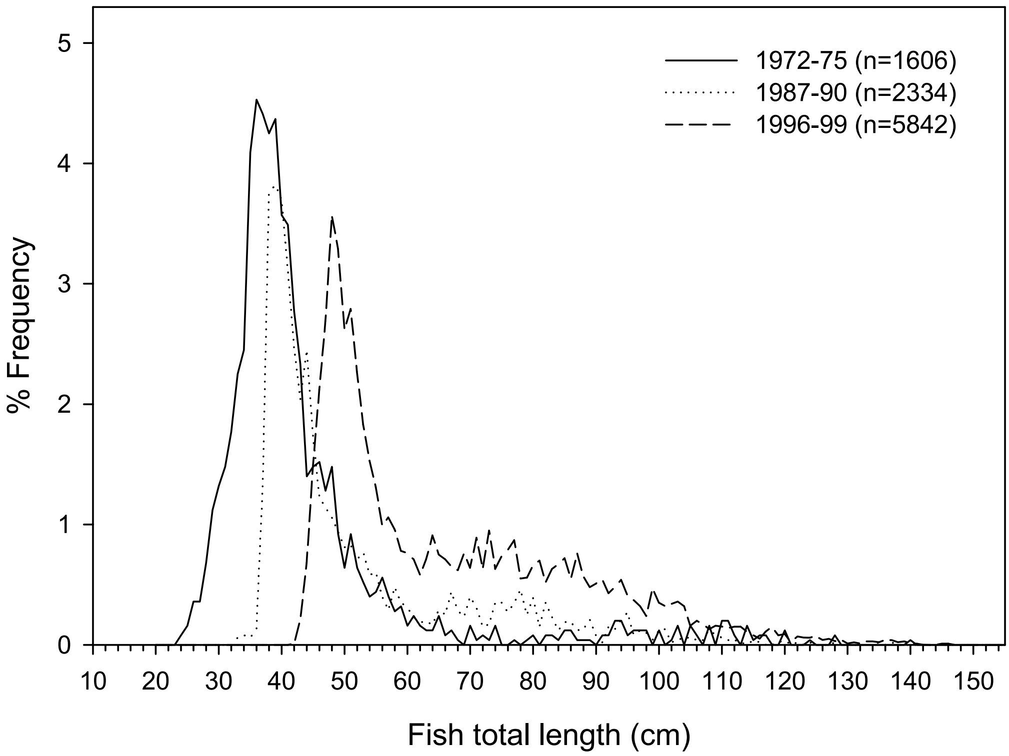


Figure 2.4. Estimated length compositions of retained fish from commercial catches of mulloway in NSW for three periods between 1972 and 1999.

Estimates of total recreational catches of mulloway are available only for 2001 (Henry & Lyle 2003). This study estimated that recreational anglers retained approximately 323000 and released approximately 276000 mulloway nationwide during 2001. Table 2.3 provides a breakdown of catches on a regional basis. In NSW, fishers retained approximately 137000 and discarded a further 36000 individuals, whereas between 30000 and 40000 individuals were retained by recreational anglers in South Australia and Western Australia. No time series of estimated recreational catches of mulloway are available for any region.

Most other surveys of recreational harvests in Australia have been done at smaller spatial scales, which have generally covered one catchment or a restricted area of coastline. Nevertheless, these studies further document the importance of this species to recreational fishers. Steffe *et al*. (1996) estimated that recreational offshore trailer boat anglers in NSW retained between 2800 and 5100 mulloway per annum, with the species ranking between 15th and 20th by weight and 40th and 44th by number in total catches throughout the survey. By weight, mulloway ranked in the top ten fish species caught by recreational fishers in northern NSW estuaries (West & Gordon 1994, Gartside *et al*. 1999) and ranked 11th by weight and 20th by number in an earlier survey of recreational fishers in Botany Bay (Anon 1981b). In South Africa, recreational boat fishers are estimated to catch a similar quantity to commercial fishers (Griffiths & Heemstra 1995) and, amongst shore anglers, *Argyrosomus* spp ranked in the top four of the preferred recreational target species and ranked in the top five (by weight) for recreational catches in the Eastern Cape and KwaZulu-Natal coast (Brouwer *et al*. 1997). Although relatively high numbers of mulloway are caught by recreational fishers, estimated recreational catch rates for the species in Australia are generally low: < 0.12 fish per angler per trip and 0.01 fish per angler per hour (West & Gordon 1994, Gartside *et al*. 1999).

Several studies have shown that the proportion of the total catch of mulloway taken by recreational and commercial sectors can vary greatly across relatively small spatial scales. For example, the recreational daytime catch of mulloway in Port Jackson was estimated at 8924 kg (6716 fish) in 1981, which was approximately ten times greater than the reported commercial catch in that estuary (~726 kg) (Henry 1984). In contrast, the estimated recreational harvest of mulloway in Botany Bay was about one third of the reported commercial catch (930 kg compared to 2960 kg) (Anon 1981b).

Griffiths (1997c) states that the stock of mulloway in South Africa is depleted and recruitment overfished. This is based on sound knowledge of the species biology and estimates of growth, and natural, fishing and total mortality. This may also be true for stocks in Australia, particularly for NSW given that commercial catches have declined over the past decade.

2.11. Bycatch and discarding

Juvenile mulloway are a significant component of the discarded bycatch in several fisheries, particularly estuarine and oceanic prawn trawl fisheries (Gray *et al*. 1990, Broadhurst & Kennelly 1994, 1995, Liggins & Kennelly 1996, Liggins *et al*. 1996, Kennelly *et al*. 1998). Kennelly *et al*. (1998) estimated that up to 97% of mulloway caught in the NSW oceanic prawn trawl fishery were discarded and that approximately 48000 fish were discarded over two years from prawn trawlers operating out of the 4 major ports in NSW in 1990-92. Miller (2002) further reported very high discarding rates of small mulloway from the oceanic prawn-trawl fleet following floods, where small fish were flushed from estuaries. Liggins & Kennelly (1996) estimated that approximately 120000 mulloway were discarded from the prawn trawl fishery in the Clarence River for the 3 years 1989 to 1991. These fish were predominantly < 20 cm TL (see also Gray *et al*. 1990). Similar sized fish are also discarded in the estuarine prawn seine fishery in NSW, but in greatly reduced quantities than the trawl fisheries (generally < 15 individuals were caught per fisher per day fished) (Gray *et al*. 2003).

Mulloway also occur as minor bycatch in the estuarine gillnet (Gray 2002) and beach-seine fisheries (Gray & Kennelly 2003, Gray *et al*., 2003), and the coastal protective shark-meshing program (Krogh & Reid 1996) in NSW. Mulloway comprised only 0.7% of the discards from the NSW estuarine gillnet fishery (Gray 2002) and only 282 fish were caught in the coastal shark meshing nets in NSW between 1950 and 1993 (Krogh & Reid 1996).

Because of the high discarding rates of juvenile mulloway in the prawn trawl fisheries, and the fact that the species is relatively sensitive to handling and stress, culminating in high mortality upon interaction with fishing gears (Gray 2002), much research has been done on developing Bycatch Reduction Devices (BRD's) to exclude small mulloway from capture in these fisheries (see Broadhurst 2000 for a review). Alternative codend designs showed that the mean number of mulloway caught in the estuarine prawn trawl fishery could be reduced by 95%, but these designs were not acceptable to industry as they also significantly reduced catches of retained prawns (Broadhurst & Kennelly 1994). Consequently, other alternative cod ends that did not significantly reduce prawn catches, but reduced the catch of mulloway by between 34 and 54% (Broadhurst & Kennelly 1994, 1995), have been introduced in the estuarine prawn-trawl fisheries in NSW. The potential benefits of these changes in fishing gears on stocks of mulloway have not been assessed.

Henry & Lyle (2003) estimated recreational anglers discarded approximately 50000 individuals during each year. The condition of these released fish was not reported and thus the impacts of recreational and commercial hook and release on survival remains largely unknown for mulloway, particularly from deeper waters where fish may suffer barotrauma stress. Broadhurst & Barker (2000) showed that juvenile mulloway hooked in the mouth from a relatively shallow (< 2m) depth and then released, had minimal effect on their overall condition and no mortalities were recorded over the 25-day holding time in experimental pond conditions. However, studies incorporating a range of fish hooks, hooking location (i.e. mouth v gut hooked), capture times, and exposure to air need to be done to assess mortality rates and to help identify fishing and handling practices that may enhance survival of released fish.

2.12. Aquaculture

Sciaenids are generally considered good aquaculture species because they are widely distributed, euryhaline, highly fecund, fast growing with good food conversion ratios (FCRs). Several species of scianeids are widely used in aquaculture and in the year 2000 an estimated 2220 tonnes of scianeids were produced in aquaculture throughout the world (FAO 2002). Sciaenids are not only reared for human consumption, but for enhancement of wild fish stocks. For example, in Texas, red drum (*Sciaenops ocellatus*) is mainly reared to enhance wild stocks and to improve catches in recreational fisheries (McEachron *et al*. 1995).

Unlike the vast amount of research into the aquaculture potential and actual aquaculture production of sciaenids throughout the world (Arnold *et al*. 1988, Chamberlain *et al*. 1990), only over the past decade has there been a developing aquaculture industry based on mulloway in Australia (Gooley *et al*. 2000). Reported commercial aquaculture production of mulloway in Australia in 1997/98 was 6.8 tonnes and in 1998/99 0.1 tonnes (O'Sullivan & Roberts 2000, O'Sullivan & Dobson (2001). There are no reported aquaculture initiatives for mulloway elsewhere. Mulloway shows a high degree of similarity in its ontogenetic development with other cultured sciaenids, including *S. ocellatus* and *A. nobilis*, and these similarities have assisted the development of hatchery techniques for mulloway.

Initial research done in NSW developed the methodology to induce captive adults to spawn, rear the larvae and grow out fish to a marketable size in controlled experimental ponds (Battaglene & Talbot 1994, Fielder & Bardsley 1999, O'Sullivan & Ryan 2001). Mulloway broodstock can be held in aquarium facilities and induced to spawn in tanks after injection with hormones and pellet implants (Thomas & Boyd 1988, Battaglene & Talbot 1994). Like other sciaenids, mulloway generally spawn approximately 30 to 35 hours after induction, with spawning occurring in salinities between 30 and 35 ppt and at temperatures around 25^{o}C (Battaglene & Talbot 1994). Larval mulloway require a salinity between 5 to 35 ppt and temperatures of 18 to 25°C, although they can tolerate temperatures up to 30°C. Optimum salinity for growth and survival in juvenile rearing is approximately 5 to 12.5 ppt, where disease problems have been found to be least (Fielder & Bardsley 1999). Larvae that are 2 - 3 mm TL at hatching begin to feed and inflate their swim bladders 3 days after hatching, with metamorphosis complete after day 34 when larvae are 15 - 26 mm TL (Battaglene & Talbot 1994). Because mulloway can tolerate low salinities, current research is assessing the feasibility of farming fish in ponds filled with extracted saline ground water and underground aquifers (i.e. inland saline ponds).

In controlled aquaculture conditions, initial growth of mulloway is dependent upon the type of technique used, with growth varying from 0.3 – 0.5 mm/day in intensive tank systems to 1.2 – 1.7 mm/day in extensive ponds (Fielder *et al*. 1999). These authors further reported that captive fish with a mean length of 15 cm TL were 5 months old and that they could maintain a growth rate of approximately 1 mm/day and reach 45 cm TL in 500 days.

Mulloway can be stocked into grow out operations at about 40 mm (~30 to 40 days old), where they have been grown in sea cages to a legal size of 45 cm (~ 1.1 kg) within 26 months. To date, stocking rates of 15 kg/m^3 have been assessed but further research is needed to determine optimal stocking densities. The feeding schedules used for mulloway are comparable with those of other cultured sciaenids, including *S. ocellatus* (Robinson 1988, Battaglene & Talbot 1994). Enriched rotifers and brine shrimp can be fed to larvae while juveniles can be fed a variety of foods including adult brine shrimp, fishmeal and a 50% protein pellet.

The need for low culture densities to avoid cannibalism, coupled with the fast growing attributes of juvenile mulloway, suggests that production of large quantities of the species may be best achieved by larval rearing in intensive tanks, followed by extensive larval culture methods in ponds, similar to that practiced with *S. ocellatus* (see McCarty *et al*. 1986). The relative ease of larval rearing enhances the suitability of mulloway for aquaculture however the reliable supply of mature broodstock has been highlighted as a problem (Battaglene 1996). Mulloway matures at a larger size (and age) than most other cultured sciaenids and therefore the broodstock may have to be kept for longer periods than other cultured sciaenids before they spawn in captivity (Battaglene & Talbot 1994).

The technology of rearing and raising mulloway in Australia has recently been transferred to industry and they are successfully being grown out in sea cages for a small domestic market (500 kg produced in 2001/02 in NSW). In NSW, permits currently exist for 25 farms of which 7 have hatchery permits and 1 for growout. For 2001/02, NSW aquaculture produced 120600 fingerlings (NSW Fisheries 2003). Currently, there are commercial mulloway aquaculture operations using sea cages in Botany Bay (NSW), Port Stephens (NSW) and Port Lincoln (South Australia). Site availability of sea cages (due to conflicts with other waterway users) may limit the expansion of this industry.

2.13. Enhancement of wild fish stocks

Because of declining recreational and commercial catches, the potential to enhance wild stocks of mulloway is being assessed in eastern Australia. The first experimental release of small hatchery-reared mulloway was done in three intermittently opening-closing lagoons in NSW, with approximately 25000 juveniles (chemically marked with oxytetracycline) stocked in each lagoon (Fielder *et al*. 1999). Commercial fishers recaptured many (100's) of released fish in one lagoon, but none were recaptured in the two other lagoons, probably because the fish were flushed into ocean waters as the lagoons opened to the sea due to flooding soon after being stocked (Fielder *et al*. 1999). As part of a larger environmental assessment of stock enhancement, a second experiment has recently begun with more than 100000 small fish released into two estuaries in NSW. This study aims to assess the potential negative ecological impacts of stocking and determine the best strategy for enhancing wild populations and fisheries.

2.14. Conclusions and recommendations

The biology of mulloway is has been well studied in South Africa. It is a relatively fast growing and long-lived species (maximum age 42 years), but does not mature until 6-8 years old. Sciaenids are prone to overfishing (Sadovy & Cheung 2003, Piner & Jones 2004) and mulloway has been declared recruitment overfished in South Africa (Griffiths 1997c). It appears that populations of mulloway have been declining in Australia since the mid 1970's. To make more informed decisions concerning the future management of the fisheries and wild populations of mulloway throughout Australia, more detailed information on rates of growth, size and age at sexual maturity, length and age structure of populations and estimates of exploitation and mortality rates, as determined for this species in South Africa (Griffiths 1997c), are required. A greater understanding of the impacts of hook and release fisheries and of potential positive impacts of BRD's in commercial prawn trawl fisheries would assist fisheries impact studies. Greater protection of juveniles from bycatch associated mortality and spawning aggregations from fishing may be required to arrest the apparent decline in Australian populations.

3. GROWTH AND REPRODUCTION OF MULLOWAY IN NSW

3.1. Introduction

The assessment of the exploitation status of many fish stocks is often dependent on the knowledge of the age and growth characteristics of a species and how this varies spatially and temporally. This together with information on the reproductive dynamics of a species can be beneficial in determining the effects of fishing and management changes on populations. Although basic information concerning the age, growth and reproductive dynamics of several key species of fish inhabiting south-eastern Australia is known, little information is available for many important species, including mulloway.

Mulloway (*Argyrosomus japonicus*) are distributed throughout coastal and estuarine waters in Pacific and Indian Ocean waters surrounding Australia, Africa, India, Pakistan, China, Korea and Japan (Griffiths & Heemstra 1995). Despite the importance of this species in many commercial and recreational fisheries throughout its distribution (see Chapter 2), there is very little information concerning its life history in many areas. Basic biological information concerning the age, growth, reproduction and movements of mulloway exists for South Africa (Griffiths & Hecht 1995, Griffiths 1996), but comparable information does not exist in Australia. This is surprising given that mulloway are caught in commercial quantities in at least three Australian states and are regarded as a trophy fish amongst recreational anglers. There is also a paucity of information on stock structure and the demographic characteristics of harvested populations in different regions, including their length, sex and age compositions. Consequently, there is little fisheries-related biological data to assess stocks of mulloway, the effects of fishing on stocks and thus little information to aid future options concerning the management of the species.

In this chapter we redress the current lack of information concerning age determination, growth and reproduction of mulloway in south-eastern Australia. We specifically document: (1) age and growth characteristics, and (2) size and age at sexual maturity, for the species in NSW. These data are later used to assess the exploitation status of the species (Chapter 4).

3.2. Methods

3.2.1. Sampling procedure

Samples of mulloway for age and reproductive determination were primarily sought from commercial catches from estuarine and ocean waters throughout NSW. Commercial landings of mulloway caught throughout NSW were sampled on a regular basis between November 2002 and February 2005. Sampling was primarily done at the Sydney Fish Market (SFM) but also at several ports of landings (fishing co-operatives). Some fish were also sampled from catches of selected individual commercial and recreational fishers. Fish below the minimum legal length (MLL) of 45 cm were collected from catches obtained by other scientific research programs and also by a commercial fisher who was issued with a special permit.

All fish sampled were measured to the nearest millimetre and weighed to either the nearest: (1) gram (fish < 0.7 kg), (2) 10 g (fish 0.7 - 5 kg), (3) 25 g (fish 5 - 10 kg) and (4) 50 g (fish 10 - 25 kg). When possible, each fish was also sexed, gonads weighed (nearest gram) and the sagittal otoliths removed for age estimation.

3.2.2. *Estimation of age and growth*

Sectioned sagittal otoliths were used to estimate the age of mulloway. One whole sagittae from each fish was weighed to the nearest 0.001 g. This otolith was then embedded in clear resin and sectioned transversely through the otolith core using a low-speed saw fitted with two diamond blades. Both sides of the resulting thin section were polished with 9 µm lapping film after which the section was mounted on a standard glass slide with glue and a cover slip. Age was estimated by viewing the section under a binocular microscope (6 – 12x) with reflected light against a black background. Opaque bands were evident in sections of otoliths viewed in this way and were scored as annual marks. Otolith weight was compared to fish age, total length and whole weight to determine if otolith weight could be used as a predictor for these parameters. To determine the periodicity of increment formation by marginal increment analysis, measurements were taken between the otolith core and first opaque band, last opaque band to the otolith edge, and from the last to second last opaque band. If age was recorded as 0+, then the measurement was from the core to the otolith edge. If the age was recorded as 1+, then the distance from the opaque band to the otolith edge was compared, as a proportion, to the distance from the core to the band. If the age was recorded as 2+ or greater, the distance from the last band to the edge was compared to the distance between the last and second last bands. A random sample of otolith images was sent to Western Australia for verification of ageing procedure.

Growth was estimated by fitting the size-at-age data to the von Bertalanffy growth function:
$L_t = L_\infty [1-e^{-k(t-t_0)}]$, where L_t is the length at age t; L_∞ is asymptotic length; k is the rate at which the curve approaches the L_∞ and t_0 is the hypothetical age at zero length.

Growth was also attempted to be modelled using available tag-recapture data for mulloway. Previous tagging studies carried out by the NSW DPI (previously NSW Fisheries) were reanalysed using GROTAG, a maximum likelihood approach (Francis 1988), to estimate growth rate of mulloway. However, only 58 of the 477 fish (12%) were at liberty for more than one year and only 15 fish (3%) were at liberty for greater than two years. Of these fish, the recapture size was comparatively small (79% of the fish recaptured were <55 cm TL) given the large size that mulloway can attain (181 cm TL, Griffiths & Heemstra 1995). Consequently, estimates of growth provided by GROTAG using the available data were unrealistic.

The length-weight relationship for mulloway was calculated using the equation:
$y = ax^b$, where y = fish weight (kg), x = fish length (cm), and a and b are constants.

3.2.3. *Size and age at maturity and timing of spawning*

Macroscopic examination of gonads was used to determine the sex of the fish and the stage of gonad development. A reproductive stage was assigned to each gonad for male and female fish according to the developmental criteria based on size, colour and visibility of oocytes outlined in Table 3.1.

Size at sexual maturity was estimated for males and females using assigned reproductive stages. Fish staged 4, 5 and 6 were assumed to be reproductively mature and capable of spawning in the ensuing season. The proportion of female and male fish assigned being mature in each 2 cm length class was calculated and logistic curves were fitted to the data for each sex using a non-linear least squares procedure.

Table 3.1. Macroscopic ovary and teste staging schedule used for mulloway.

Stage	Classification	Macroscopic characteristics
I/II	Virgin and Immature/resting	Ovaries small and translucent, pink or orange in colour. Oocytes not visible through ovarian wall. Testes very thin and flat, light pink in colour.
III	Developing	Ovaries slightly larger. Oocytes visible through ovarian wall. Testes slightly larger, triangular in cross-section, beige in colour. Sperm present in main sperm duct.
IV	Maturing	Ovaries larger, opaque, yellow or orange in colour. Yolk granule oocytes visible through ovarian wall. Testes larger, mottled beige and cream in colour. Softer texture, sperm present in tissue. Testes rupture when pinched.
V/VI	Mature/Spawning	Ovaries larger than stage IV, orange in colour. Testes larger, cream in colour, ruptures under slight pressure.
VII	Spent	Ovaries and testes far smaller than stage V/VI. Ovaries flaccid. Some yolk granule oocytes still visible through ovarian wall. Testes mottled-beige and cream in colour. Some sperm present in main duct and tissue.
VIII	Recovering spent	Ovaries and testes were small. Similar to stage II, but ovaries red in colour.

3.3. Results

3.3.1. Age and growth

Mulloway aged in this study were estimated to be between 0 and 24^+ years old (Table 3.2). Fish aged 0 and 1 were primarily observed in samples caught in estuaries, whereas a greater proportion of older fish (> 6 years) were sampled in ocean catches (Tables 3.3 and 3.4). The mulloway estimated to be 24 years old was 120 cm TL. The largest fish sampled was 169 cm TL and it was estimated to be 14 years old. We acknowledge that our ageing procedure has not been validated. We assumed that the banding observed on sectioned otoliths were annual marks and that the first observed ring was actually 1 year old.

There was considerable variation in the length of mulloway at any given age (Table 3.2, Fig. 3.1), and similarly for the weight of mulloway at any given age (Fig. 3.2). The von Bertalanffy growth parameters were calculated to be as follows: t_0 = -0.552, k = 0.197, L_∞ = 131.7. Growth could not be modelled for each sex separately as sample sizes were small (the majority of fish sampled from commercial catches were sold whole or were cleaned prior to sampling and thus could not be sexed). Nevertheless, mulloway grew rapidly in the first 4 years, reaching approximately 80 cm TL, after which the rate of growth slowed (Fig. 3.1). Mean length at age data based on fish that could be sexed indicated that males and females grew at the same rate until about 5 years of age (Fig. 3.3). After this age, females appear to grow more rapidly although no definitive result can be obtained due to small sample sizes for older fish.

Table 3.2. Age-length key for all mulloway sampled during the present study (2002-2005).

Length class (cm, TL)	Ages (years)																									Total
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
5-9	23																									23
10-14	188																									188
15-19	75	3																								78
20-24	31	34																								65
25-29	15	50	2																							67
30-34	3	13	4																							20
35-39		23	17																							40
40-44		11	43																							54
45-49		23	737	4																						764
50-54			673	39																						712
55-59		1	237	64	4																					306
60-64			81	70	22																					173
65-69			30	44	40	1																				115
70-74			8	26	30	4	5																			73
75-79			3	14	34	6	2	3																		62
80-84				3	30	9	2	3	1	1	1	1	3													54
85-89				7	21	10	4	4			2															48
90-94				6	27	8	3	4			1	1		1	1											52
95-99				1	15	9			2				1		2											30
100-104					9	18	3	4	1	1									1							37
105-109					2	9	2	2	1	1			2		1											20
110-114						7	8	3	6		1		2		1											28
115-119						2	5	5	5	3	1			2	1	3										27
120-124							1	4		4		2	1		1							1			1	15
125-129						1			1			1			3	1						1				8
130-134										1	1	2	1													5
135-139						1					1	1		1	2				1							7
140-144									1				1													2
145-149												1			1	1										3
150-154																										
155-159																										
160-164																										
165-169															1											1
n	335	158	1835	278	234	85	35	32	18	11	8	9	11	4	14	5	0	0	2	0	0	2	0	0	1	3077

Table 3.3. Age-length-key for mulloway caught in estuaries throughout the study.

Length class (cm, TL)	Ages (years)																									Total
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
5-9	3																									3
10-14	182																									182
15-19	75	2																								77
20-24	31	34																								65
25-29	15	50	2																							67
30-34	3	13	1																							17
35-39		23	3																							26
40-44		9	19																							28
45-49		15	444	3																						462
50-54			477	32																						509
55-59		1	167	63	2																					233
60-64			48	69	19																					136
65-69			19	43	33	1																				96
70-74			5	25	18	2	1																			51
75-79			3	12	16	2	1																			34
80-84				2	21	3	1	2					2													31
85-89				2	8	4	2	2																		18
90-94				5	13	5	3	2																		28
95-99					5	4																				9
100-104					2	7		1																		10
105-109					1	7							1													9
110-114						1	2	1	1																	5
115-119							2	3	2							1										8
120-124							1			2		1	1												1	6
125-129												1														1
130-134												1														1
135-139																										0
140-144													1													1
n	309	147	1188	256	138	36	13	11	3	2	0	3	5	0	0	1	0	0	0	0	0	0	0	0	1	2113

Table 3.4. Age-length key for mulloway caught in ocean waters throughout the study.

Length class (cm, TL)	Ages (years)																									Total
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
40-44			3																							3
45-49		2	51																							53
50-54			38	6																						44
55-59			25	1	1																					27
60-64			12	1	3																					16
65-69			4	1	6																					11
70-74			2		11	2	3																			18
75-79				1	16	2	1	3																		23
80-84				1	6	5	1	1	1	1	1	1	1													19
85-89				5	10	5	2	2			2															26
90-94				1	12	2		2			1	1		1	1											21
95-99				1	10	4			2				1		2											20
100-104					5	11	3	3	1										1							24
105-109					1	2	2	2	1	1			1		1											11
110-114						6	5	2	5		1		2		1											22
115-119						1	3	1	2	3	1			2	1	2										16
120-124								3		2												1				6
125-129						1			1						3	1						1				7
130-134										1	1	1	1													4
135-139						1					1			1	2				1							6
140-144									1																	1
145-149												1			1	1										3
150-154																										
155-159																										
160-164																										
165-169															1											1
n	0	2	135	18	81	42	20	19	14	8	8	4	6	4	13	4	0	0	2	0	0	2	0	0	0	382

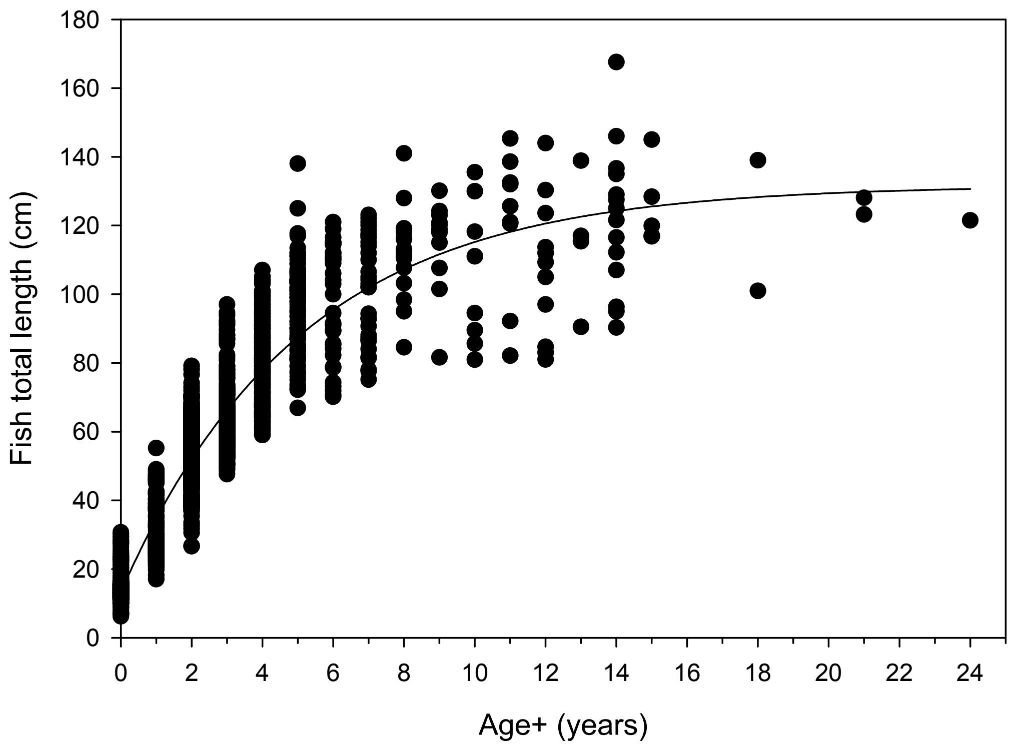


Figure 3.1. von Bertalanffy growth curve of mulloway sampled in NSW (n = 3077).

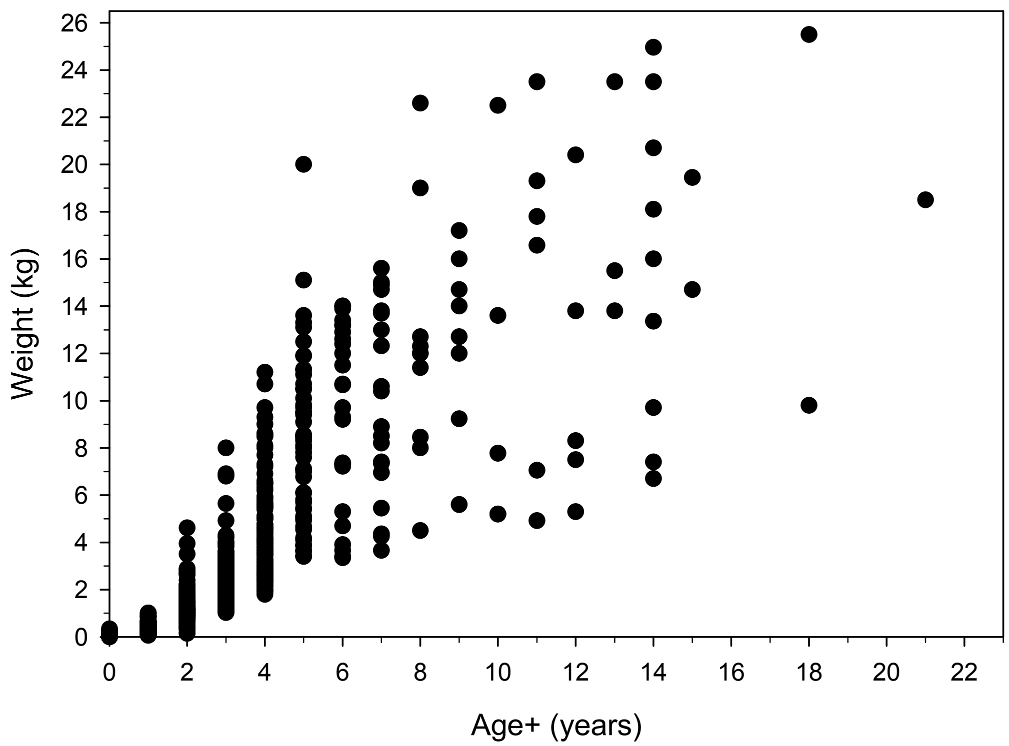


Figure 3.2. Age – fish weight relationship of mulloway sampled in NSW (n = 1386).

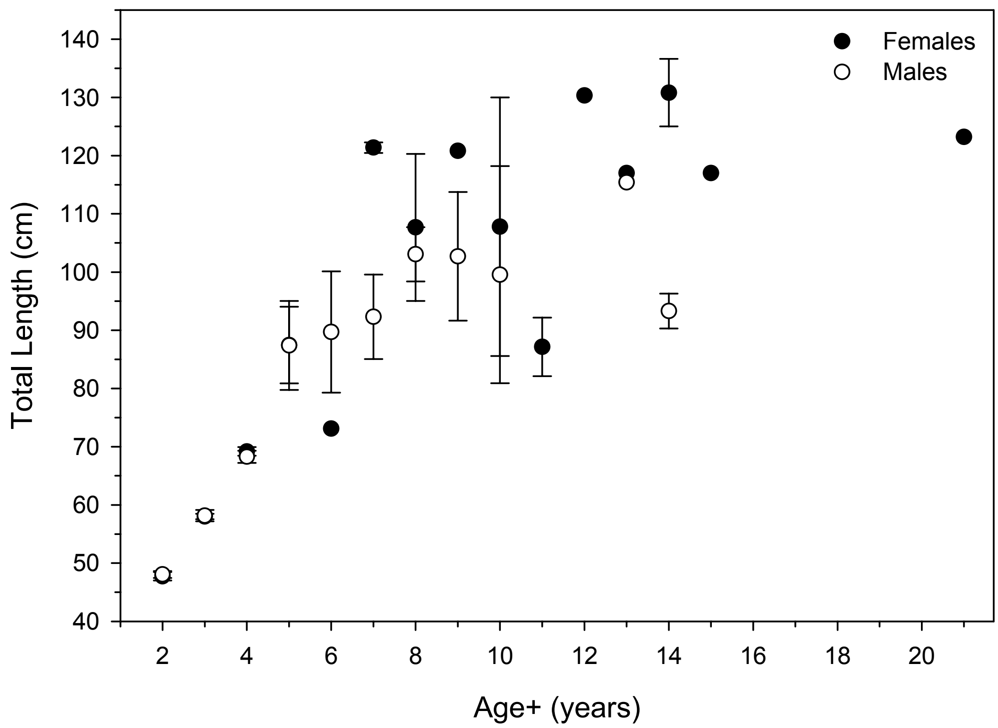


Figure 3.3. Length (mean ± se) at age of male and female mulloway sampled in NSW (n = 91 males and n = 162 females).

A good relationship was found between fish age and otolith weight (Fig. 3.4a; adj r^2 = 0.88). However, otolith weight was not considered a practical predictor of fish age, as any particular otolith weight could correspond to a range of ages. For example, a 1 g otolith could indicate that a fish was between 2 – 4 years old, while a 3 g otolith could indicate that a fish was between 7 – 14 years old. Although there was a strong relationship between fish length/weight and otolith weight (Figs 3.4b,c; adj. r^2 = 0.93 and 0.94 respectively), otolith weight was still spread across a wide range of fish lengths and weights. For example, a 1 g otolith could correspond to fish of total length around 50 – 70 cm and a fish weight of 1 – 3 kg, while a 3 g otolith could correspond to fish of about 90 – 140 cm in length and 8 – 23 kg in weight.

Results from the marginal increment analysis suggest that opaque bands on otoliths are formed between late spring and early summer for 1^+, 2^+ and 3^+/older fish in each year (Fig. 3.5). Sampling of 0^+ year old fish was not extensive enough to determine timing of first ring formation.

The length-weight relationship for mulloway fitted well to the regression equation (Fig 3.6, adj r^2 = 0.97) with the constants estimated at a = 0.00001679 and b = 2.869.

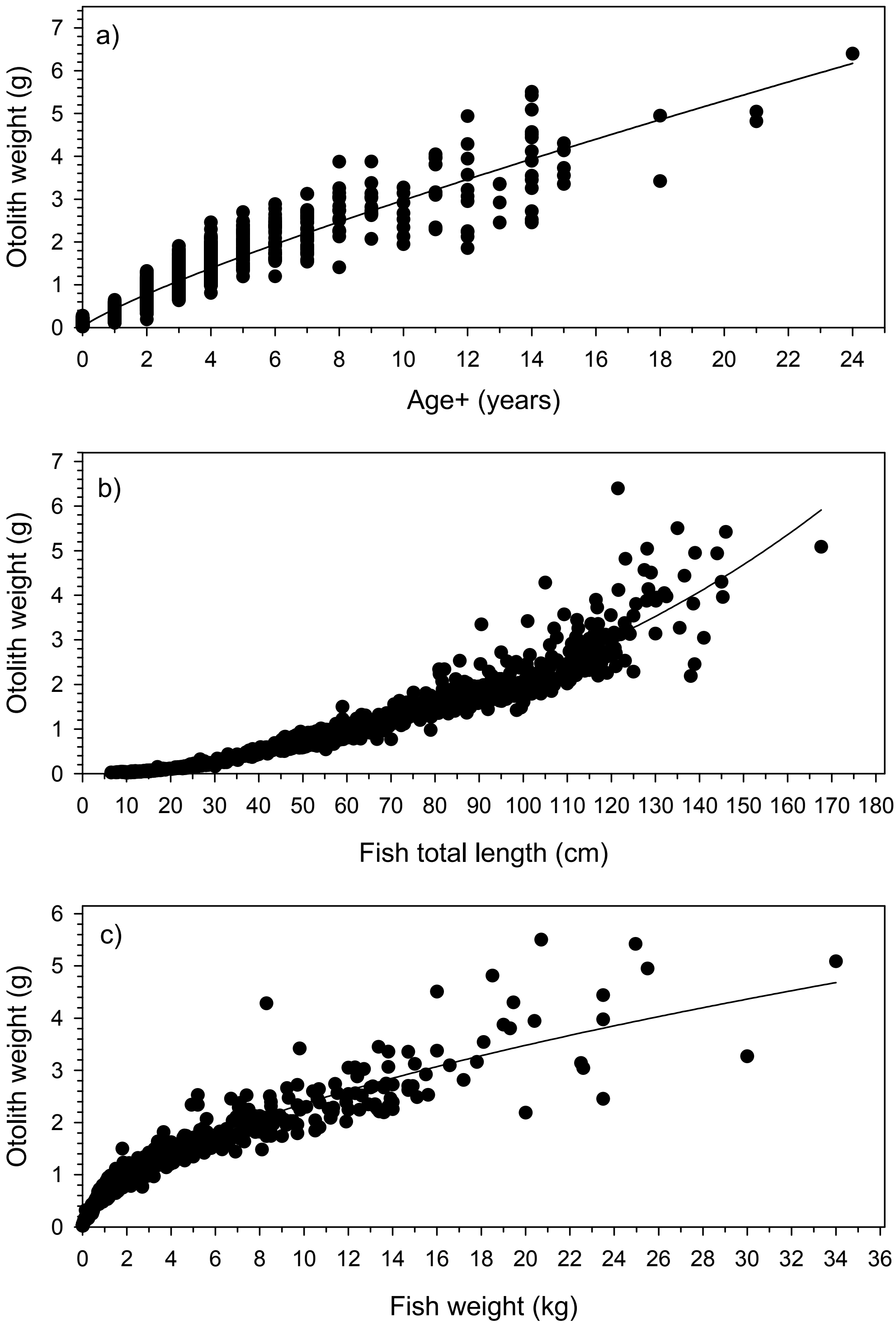


Figure 3.4. Relationship between otolith weight and a) age (n = 3030), b) fish total length (n = 3028), and c) fish weight (n = 1372) of mulloway sampled in NSW.

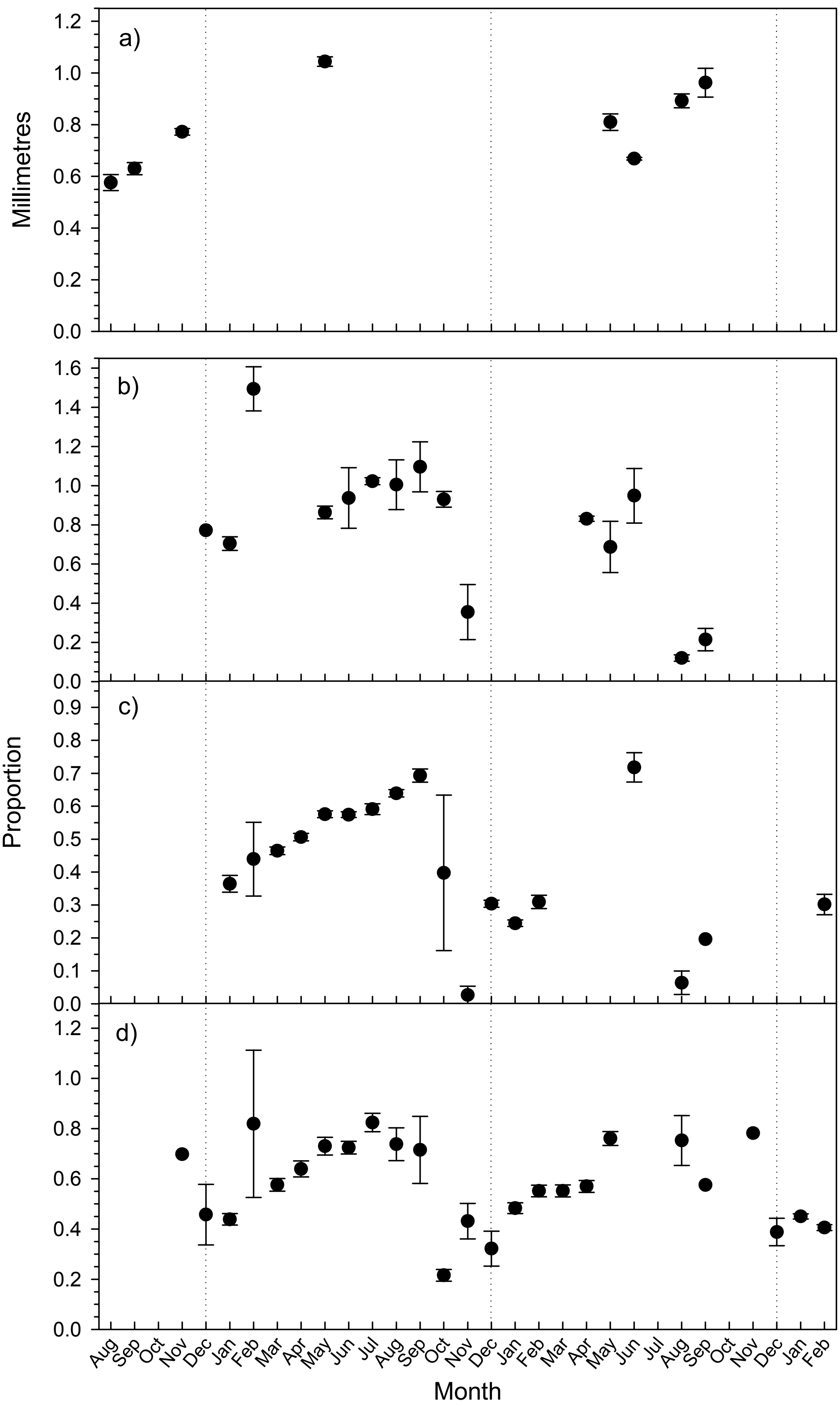


Figure 3.5. Marginal increment analysis for a) 0^+ (n = 317), b) 1^+ (n = 133), c) 2^+ (n = 1425), and d) 3^+ or older (n = 682) aged fish for the 2002 - 2005 period. Mean ± standard errors are presented. Dotted lines indicate annual cycle. Note difference in y-axis scales.

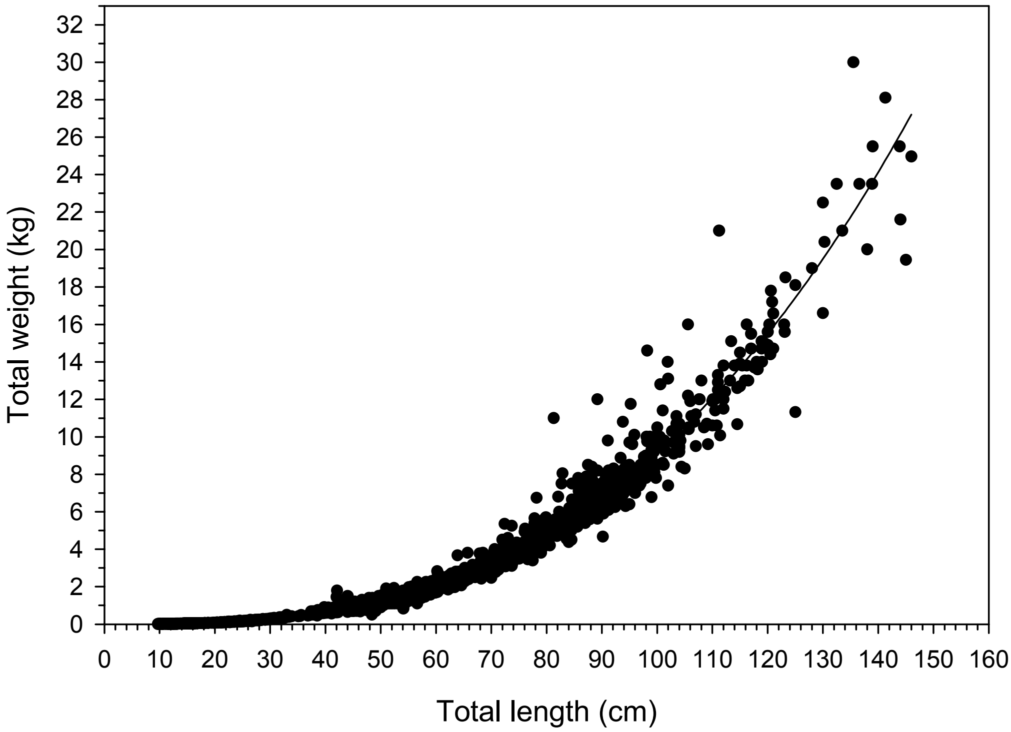


Figure 3.6. Length-weight relationship of mulloway sampled in NSW (n = 2865).

3.3.2. Timing of spawning and size at maturity

Size at sexual maturity (L_{50}) was estimated to be 51.26 ± 1.35 cm TL for male and 67.86 ± 1.05 cm TL for female mulloway (Fig 3.7a,b). This is equivalent to the 51.0 - 52.9 cm size class for males and the 67.0 - 68.9 cm size class for females. All males sampled in the 63.0 - 64.9 cm size class or greater were mature and all females were mature at 79.0 - 80.9 cm or greater. Approximate age at maturity was estimated to be 2^+ and 3^+ years for males and females respectively (Fig 3.8a,b).

Spawning may take place in estuaries as well as ocean waters as 53% of mature male and 33% of mature female mulloway sampled were observed in estuarine catches. Fish in spawning condition (macroscopic staged 5, 6 and 7 fish) were mostly observed between November and March.

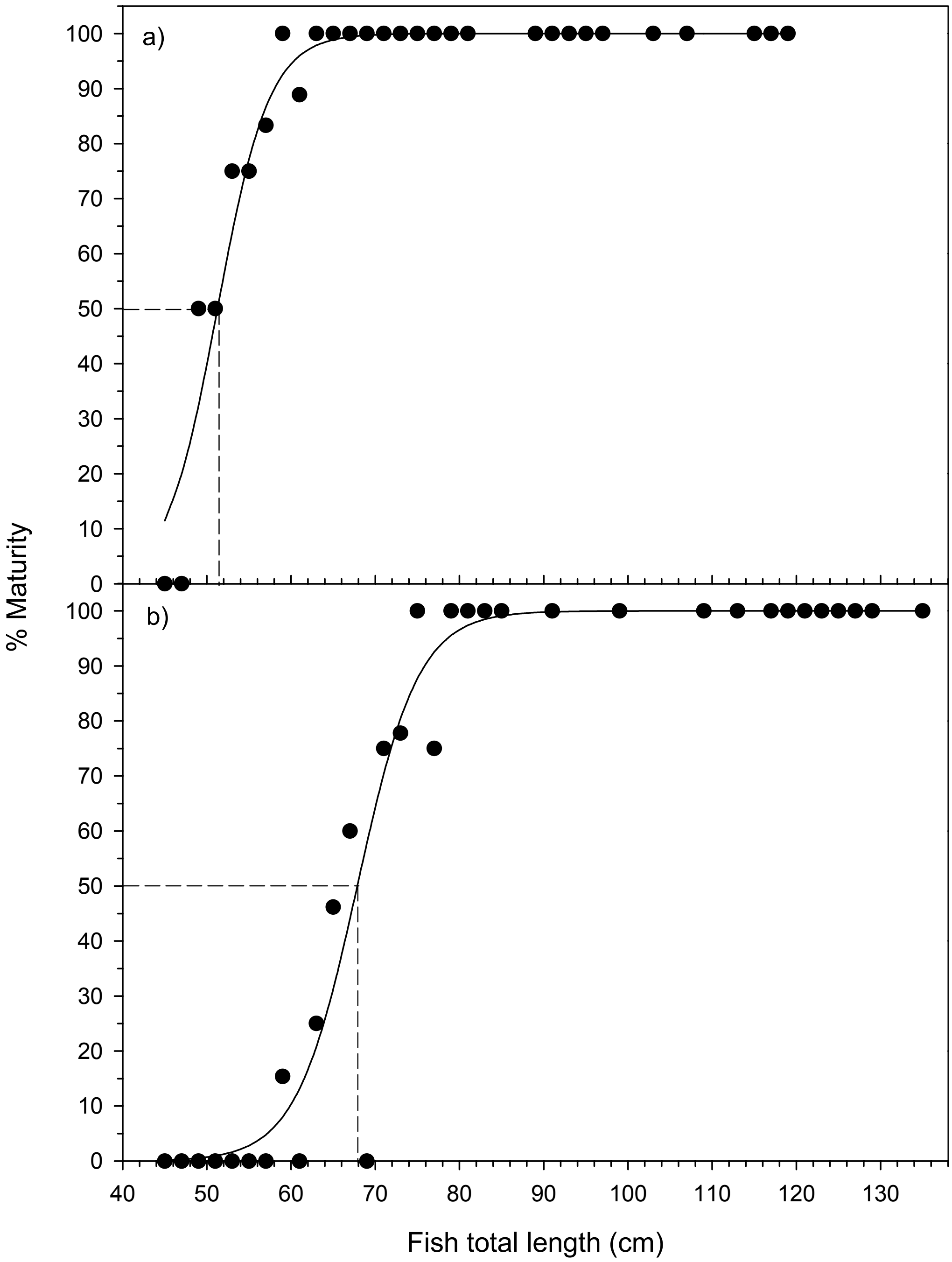


Figure 3.7. Estimated size at maturity of a) male and b) female mulloway based on 2 cm size classes (n = 91 males and 162 females).

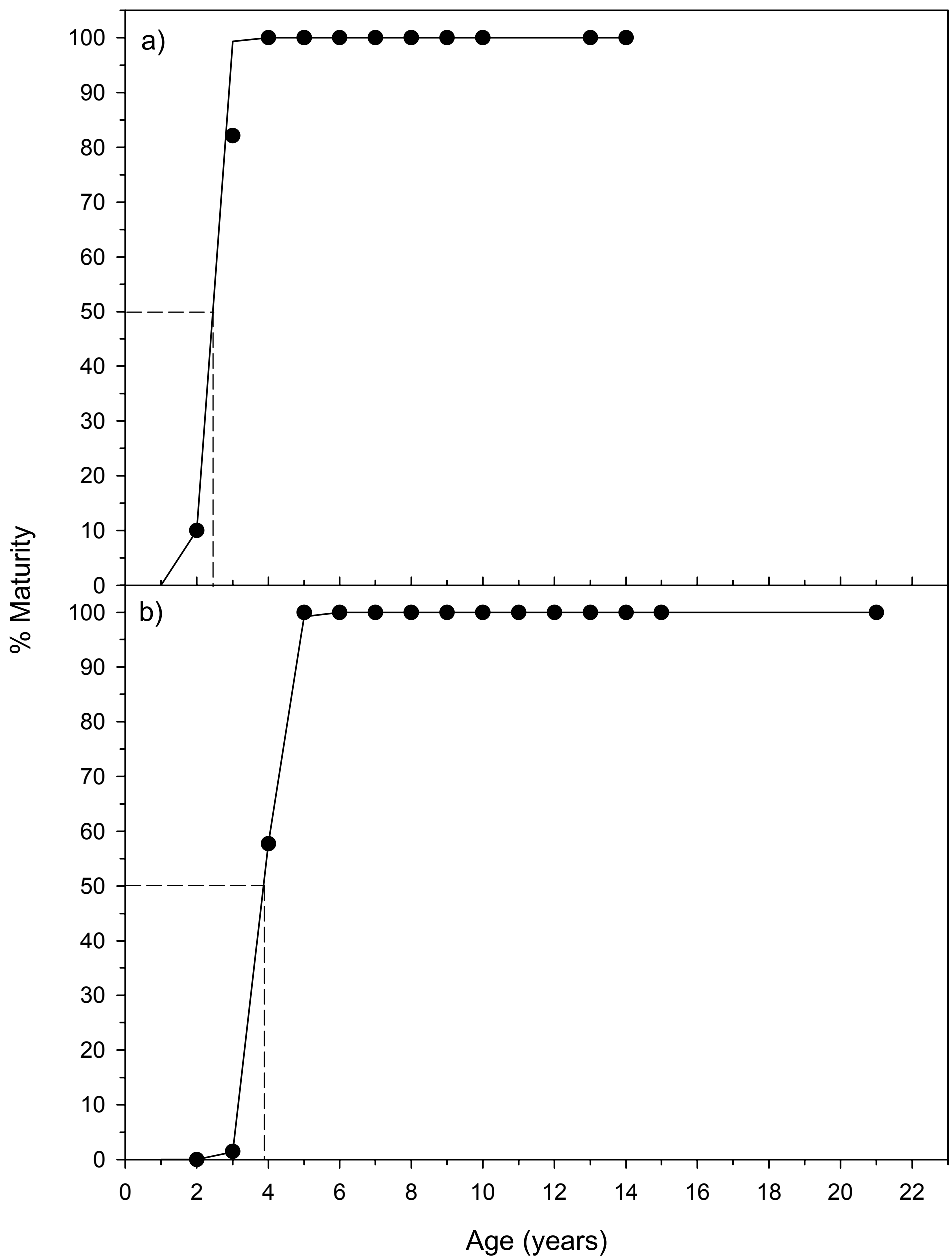


Figure 3.8. Estimated age at maturity of a) male and b) female mulloway based on yearly age classes (n = 91 males and 162 females).

3.4. Discussion

The oldest mulloway we aged in this study (24 years) was much less than the maximum reported age of 42 years (Griffith & Hecht 1995). This may have been due to limited sampling of large individuals in the current study, or alternatively, mulloway in south-eastern Australia may not live as long as those in southern Africa. Previously however, a mulloway caught in Port Stephens was aged at 32 years (unpublished). As described for many species of fish, length at age of mulloway was variable, but the patterns and rates of growth of mulloway observed in the current study were similar to those described for mulloway in southern Africa by Griffith & Hecht (1995). In both these studies, otolith-based age estimation was used and mulloway were estimated to reach approximately 35 - 40 cm TL in 1 year and about 100 cm TL in 6 years (Table 3.5). Growth is particularly rapid in the first 5 years of life. Griffiths & Hecht (1995) showed that after about the second year of life, females grew faster to attain an overall greater length (165 - 170 cm) and age (42 years) than males (140 - 145 cm and age 30 years). Although we could not validate our ageing procedure, the similarity of our results and those of Griffith & Hecht (1995) add weight that our ageing was correct.

Comparisons of estimates of age and growth of populations of mulloway elsewhere in Australia could not generally be made. Previously, Gray & McDonall (1993) followed juvenile cohorts of mulloway in estuaries and estimated that juveniles grew from a mean length of 7 to 15 cm TL and 16 to 25 cm TL in 6 months between April and October and that fish 15 cm in length were 6 months old. Based on tag-recapture data and scale readings, Hall (1984) estimated that mulloway grew to 46 cm (1.5 kg) in 2 to 3 years and a length of 80 cm (8 kg) in 5 to 6 years. West (1993) analysed tag-recapture data for mulloway off south-eastern Australia and estimated that they grew to 49 cm TL in 2 years and 56 cm TL in 3 years, which is smaller than we estimated.

Table 3.5. Comparisons of estimated length (TL; cm) at age for mulloway from published growth equations based on otolith-based age estimates. Lengths derived using the growth equation and parameters given in the manuscript (Griffiths & Hecht 1995) and from the current study.

Age in years	**Griffiths & Hecht (1995)**		**Current study**
	Male	**Female**	
1	35.6	35.5	34.7
2	50.3	51.1	52.0
3	64.6	66	66.3
4	77.6	79.5	78.0
5	89	91.3	87.6
6	98.6	101.5	95.5
7	106.6	110	102.0
8	113.1	117.1	107.3
9	118.3	122.9	111.6
10	122.4	127.7	115.2
15	133.1	140.8	125.5
20	136.1	145.2	129.4
25	136.9	146.6	130.8

Our estimates of length at maturity were considerably less than those reported for mulloway in southern Africa by Griffiths (1996). We found that 50% of female and male mulloway matured at 68 and 51 cm TL respectively, compared to 107 and 92 cm TL respectively, by Griffiths (1996). Our data also suggest that mulloway in NSW spawn at a much younger age than elsewhere. For example, the 50% maturity levels observed in our study corresponded to fish aged approximately 2 and 3 years, whereas it was 5 to 6 years in southern Africa. Hall (1986) and Anon (1993) estimated that mulloway in South and Western Australia do not become sexually mature until they attain about 75 cm TL and are approximately 4 kg and 5 to 6 years old. Clearly, the length and age that mulloway mature varies between and among regions and, as such, local data may be required for determining best management options for conserving stocks.

The time of spawning appears to vary between geographic regions and with latitude and is probably related to water temperature and oceanography. Although not definitive, our data concerning the prevalence of fish with mature gonads suggests that mulloway primarily spawn between November and March in NSW waters. This conclusion is further corroborated by reported larval occurrence between February and April in coastal waters off NSW (Gray & Miskiewicz 2000) and that small juveniles 2 - 8 cm TL occur in estuaries between April and June (Anon 1981a). West & Walford (2000) however, reported that juvenile mulloway (< 10 cm TL) were present year round in two estuaries in northern NSW (between 28°50' and 29°30'S). Further, both Broadhurst (1993) and Gray & McDonall (1993) reported two distinct 0^+ juvenile cohorts in an estuarine population which suggests that not all spawning is synchronous within a region. The protracted summer spawning season observed for mulloway in NSW is comparable to that described for mulloway elsewhere. For example, in southern Africa, Griffiths (1996) found that spawning varied along the coast from August to November (winter to spring) in the northern KwaZulu region (30 - 31°S), and from October to January (summer) in the southern and south-east Cape regions (33 - 35°S). Similarly, along the Western Australian coast, Penn (1977) reported fish with mature gonads in September and October in Shark Bay (26°S), whereas Anon (1993) reported that mature fish occurred between December and January in the Swan River (32°S). In South Australia, mulloway appear to spawn throughout summer (November to February) (Hall 1986).

Several authors have hypothesised that mulloway spawn in nearshore coastal waters around the mouths of estuaries and in surf zones. This is based on observations in South Africa (Griffiths 1996) and South and Western Australia (Hall 1984, 1986, Anon 1993) that fish with mature or spent gonads have been caught only in ocean waters, whilst fish in estuaries did not show development of mature gonads. Further, off the east coast of South Africa, eggs have only been collected in nearshore waters and not in the offshore Agulhas Current (see Griffiths 1996) and larvae (but not eggs) have only been collected in low numbers in estuaries. This is also corroborated by a study in Botany Bay (central NSW) in which all mulloway collected (< 64 cm TL) had immature gonads (Anon 1981a) although timing of capture may have been inconsistent with spawning period. Our work shows that about half the mature males and one third of the mature females sampled came from the estuary, indicating that mulloway throughout NSW spawn predominantly at sea but may spawn in the estuary or move between these two areas. It is unclear whether mature fish in the estuary will then travel to ocean waters to spawn or remain in the estuary. Hall (1984) suggested spawning might take place near the mouths of estuaries as large fish (80 - 150 cm TL) in spawning condition have been caught in the mouth of the Murray River in South Australia. A separate population of mulloway is thought to occur in South Australia in western waters in the Great Australian Bight (Jones *et al*. 1990). Location and timing of spawning is unknown for this suspected population and further research is needed. Hall (1984) further postulated that freshwater outflow during summer may promote aggregations of spawning fish near the mouths of estuaries as peak freshwater discharge generally coincided with, or just preceded, the spawning season. The spring/summer-spawning season in South Africa also coincides with the highest periods of rainfall and river discharge in that region. Griffiths (1996) hypothesised that mulloway may have adapted a river discharge-spawning relationship as an evolutionary tactic to enhance recruitment of juveniles to estuaries.

4. ASPECTS OF THE COMMERCIAL FISHERY FOR MULLOWAY IN NSW

4.1. Introduction

Commercial and recreational fisheries for mulloway occur in estuarine and coastal waters of NSW. Mulloway is a key secondary species in the Estuary General and Ocean Trap & Line fisheries in NSW. The Fishery Management Strategy (Anon 2003, OT&L in prep) for each of these fisheries list the exploitation status of mulloway as "unknown" and "undefined" respectively. This is primarily due to the limited biological and fishery-related information available for mulloway in south-eastern Australia.

There is little description of the fisheries for mulloway in NSW and how catches vary between fishing sectors, fishing gears and regions. Information of the relative changes in catch and effort can provide indices of changes in populations and potential effects of fishing and changes in targeting on populations. In Chapter 3, we described the growth and reproductive characteristics of mulloway in NSW. More detailed analyses of the length, sex and age compositions of catches and how these vary spatially and temporally can be used to help assess the status of fish populations and is often fundamental to determining the status of exploited fish stocks (Megrey 1989, Richards *et al*. 1997). Such information is known for many coastal and estuarine species of fish in NSW, but similar information is unavailable for mulloway.

In this chapter we explore the commercial fishery for mulloway in NSW. Specifically, we document and describe trends in reported commercial catch and effort of mulloway and assess the length and age composition of landed catches. We then estimate rates of total mortality and provide yield-per-recruit analyses to assess the exploitation status of mulloway in NSW. We conclude by using these data to provide future management options to help conserve and sustain the mulloway stocks in NSW.

4.2. Methods

4.2.1. *Trends in reported catch and effort*

Commercial fishers in NSW are required to submit monthly forms detailing their catch and effort. The information recorded on these forms has changed since their inception. Reporting forms are customised for each commercial fishery and currently provide information on the areas fished, the number of days each method of fishing was used and the quantity of each species landed by that method in that month. These current forms were implemented in 1997 and provide the best information on reported catch and effort to date. Forms used between 1990 and 1996 did not associate species catch with days of effort or fishing method and, prior to 1990, it was only possible to determine species catch per month.

The quality of this self-reported information is difficult to ascertain but is probably more reliable since 1997. Misreporting, either deliberately or unintentionally, may be a problem. For example, it is common for ocean and estuary hauling skippers and their crew to report the same total quantities of landing on their individual catch returns thereby multiplying the true amount taken by the number of crew members. Identifying this form of misreporting usual requires the contacting of individual fishers. Many fishers report small quantities of mulloway each year (i.e. <5 kg). Errors in catch statistics, either by multiple reporting, misreporting species, or data entry errors were identified during examination of catch statistics and such errors have been corrected. While some errors have been amended, we assume that there may be others and that there is a constant error rate through time. We have used these catch statistics to describe temporal and spatial patterns in estimated reported landings, and to make inferences about the relative abundance of mulloway.

Reported landings were obtained from the March 2005 extraction of Comcatch (the commercial fisheries catch records database at NSW DPI). Distributions of mulloway landings were divided into fisheries, ocean zones (and the estuaries that are bound by these zones) and two regions (north and south of Sydney). Data from 1940 were used to show long-term trends in reported catches and, where possible, catch statistics from 1984/85 to 2003/04 or from 1997/98 to 2003/04 were used to gain a more comprehensive description of the commercial fishery.

4.2.2. Length and age composition of commercial landings

Commercial landings of mulloway caught in estuaries and ocean waters throughout NSW were sampled for length and age composition on a regular basis between November 2002 and February 2005. Sampling was primarily done at the Sydney Fish Market (SFM) but also at several ports of landings (fishing co-operatives), notably from the Clarence River, Coffs Harbour, Hawkesbury River and Shoalhaven River. These ports signify areas where large quantities of mulloway are caught. Data concerning method and location of capture were obtained for each catch. The length composition of commercial catches was assessed by region with Region 1 comprising waters from Newcastle to the Queensland border and Region 2 was defined as waters south of Newcastle to the Victorian border. Ages of fish were estimated as described in Chapter 2. Age composition of landed catches was determined by applying age-length keys to relevant length composition data of commercial landings. This was done separately for estuary and ocean caught fish, and for all landings.

4.2.3. Estimates of total, natural and fishing-associated mortality

Estimates of the instantaneous rate of total annual mortality (Z) were made from age-based catch curve analysis (Ricker 1975). We used the total age frequency in commercial landings so as to include both the estuary and ocean components of the fishery. Linear regressions were fitted to the plot of natural logarithm of the frequency of fish in each age class against age for ages 2 to 10 and 2 to 15 years. Age 2 was chosen because it was the most abundant age class present (see Figure 4.10), despite mulloway not being fully recruited to the fishery until age 3 (see Figure 3.1 and Table 3.2). This approach will have resulted in slightly low estimates of Z, however we consider it more precautionary than estimating Z from age 3 onwards. We did not include ages 16 to 24 because of the low numbers (< 5 fish in total) observed in these age classes. Natural mortality (M) was estimated using the method of Hoenig (1983) based on maximum age and the assumption that either 5 or 1% of fish attain it. Maximum age was set at 42 years (Griffith & Hecht 1995). Fishing mortality (F) was estimated by subtracting M from Z. These analyses assumed that recruitment and growth of mulloway was constant across years and that the species displayed asymptotic growth patterns.

4.2.4. Yield-per-recruit analyses

Two approaches were used to model the relative yield per recruit (YPR) for mulloway. Firstly, the Beverton-Holt YPR model (Beverton & Holt, 1957) was used to calculate yield per recruit curves for a range of values of natural mortality (M) using the computer program B-H3 (Saila *et al*. 1988). Input parameters were based on the von Bertalanffy growth model and the length-weight relationship, both described in Chapter 3. Mortality rates were varied between M = 0.05, 1.0 and

1.5 and F ranged between 0.35 and 0.6 (see below). Estimates of age at capture were converted to weight at capture using the von Bertalanffy growth function parameters.

Yield per recruit analyses were also done using the program "YPER" (Ault *et al.*, 1996). YPER calculates relative YPR isopleths using the Beverton & Holt model. Input parameters included a range of ratios of M/K, L_c/L_{inf} and Exploitation rate, and a range of values for F and M.

4.3. Results

4.3.1. Temporal trends in reported catch and effort

Between 1940/41 and 1970/71 reported catches of mulloway varied between approximately 50 and 150 tonnes per annum (Fig. 4.1). During the early 1970's catches greatly increased to peak at approximately 400 tonnes in 1973/74. Since 1973/74 reported catches have continued to decline to the current 60 tonnes per annum. The peak in catches in 1970's coincided with the abolition of a size limit on mulloway and with the development of the ocean demersal fish trawl fishery.

Despite the recent declining levels of reported commercial catch, CPUE of all commercial fisheries combined (kg/fisher month) has remained fairly stable between 1984/85 and 2003/04 and this is mirrored by the more recent CPUE of kg/day (Fig. 4.2). Thus, the recent decline in reported commercial catch of mulloway may largely be due to the decline in the number of fishers reporting landings of this species (Table 4.1).

Better reporting of commercial catches of fish since 1997/98 has allowed this harvest to be assessed on a fishery basis. Since 1997/98, both the Estuary General and Ocean Trap & Line fisheries have been the largest harvesters of mulloway (Fig 4.3). Opportunistic catches of this species by fishers in the Ocean Hauling Fishery can manifest itself as small peaks in catch through time as occurred in 2000/01. Catches of mulloway are still within historic levels although catches will still need to be monitored to examine whether the recent declines seen in the Ocean Trap & Line fishery continue.

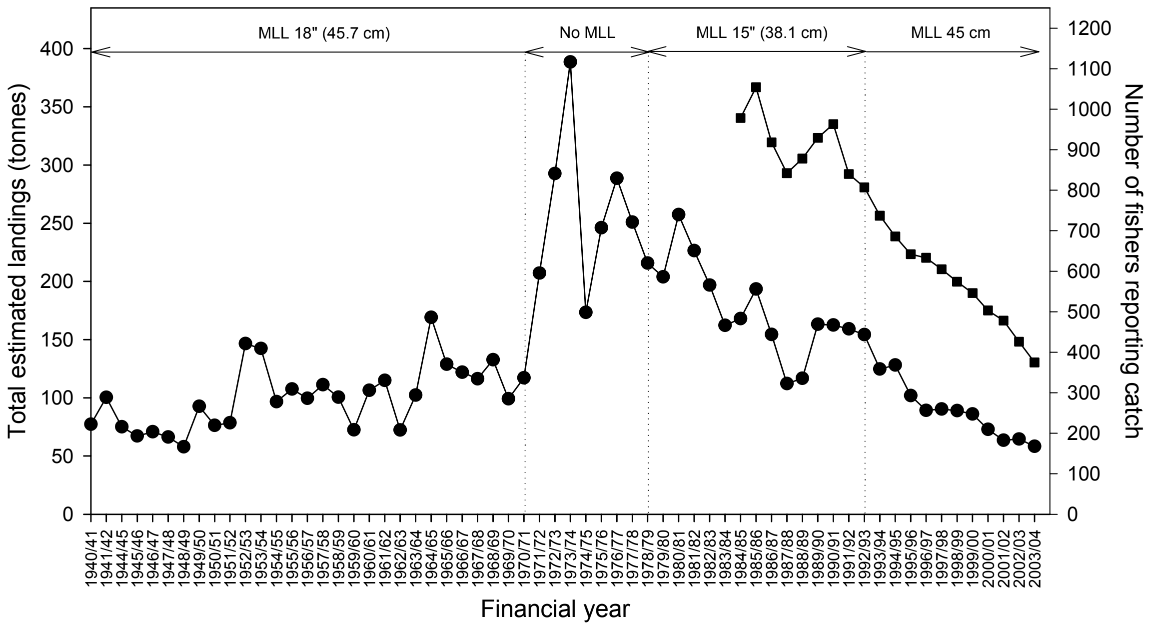


Figure 4.1. Reported total commercial catches of mulloway in NSW between 1940/41 and 2003/04 and associated changes in MLL.

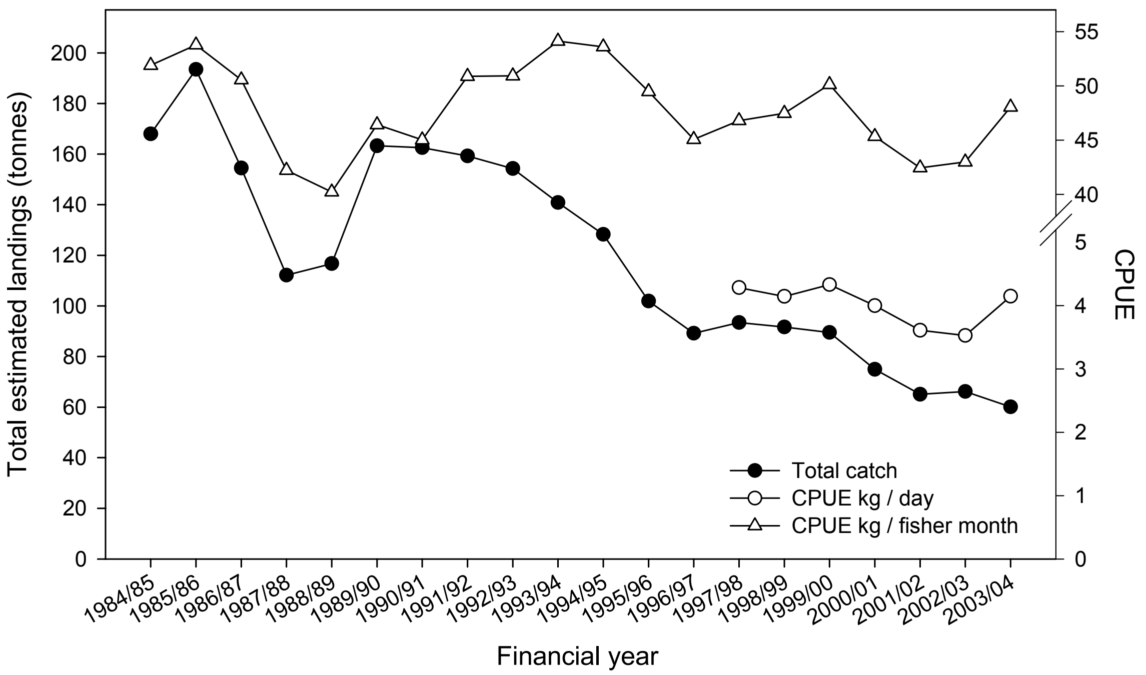


Figure 4.2. Total reported commercial landed catch (kg) and catch per unit of effort (kg per month) in NSW from 1984/85 to 2003/04.

Table 4.1. Number of commercial fishers that reported catching mulloway from 1984/85 to 2003/04.

Financial year	Number of fishers
1984/85	978
1985/86	1054
1986/87	918
1987/88	842
1988/89	878
1989/90	929
1990/91	963
1991/92	840
1992/93	807
1993/94	737
1994/95	686
1995/96	642
1996/97	633
1997/98	605
1998/99	574
1999/00	546
2000/01	503
2001/02	478
2002/03	428
2003/04	380

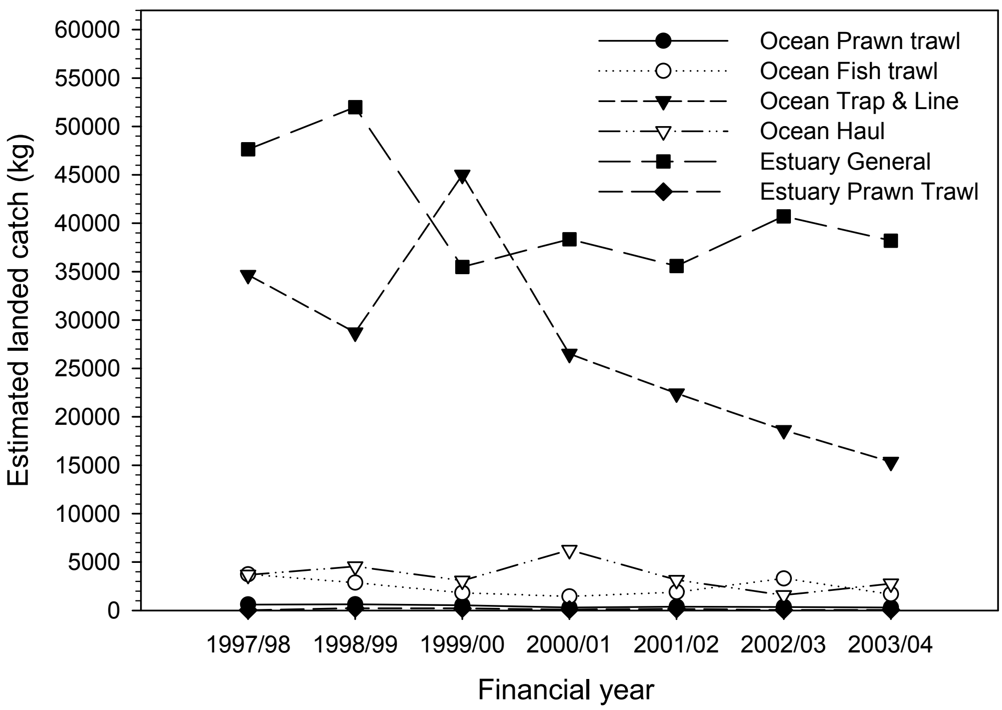


Figure 4.3. Total estimated landed catch (kg) by fishery in NSW from 1997/98.

4.3.2. Spatial trends in reported catch and effort

Table 4.2 shows the proportion of the reported mulloway catch attributed to each commercial fishery between 1997/98 and 2003/04, and clearly shows that the Estuary General and Ocean Trap & Line fisheries catch the majority of fish (by weight). It also highlights that the majority of fish caught within each fishery is by one method.

Table 4.2. Mean proportion of total reported mulloway catch attributed to each fishery and the proportion attributable to the main method within each separate fishery between 1997/98 and 2003/04.

Fishery	**Percent contribution to total commercial catch**	**Main method**
Ocean Prawn Trawl	0.6	Prawn trawl net
Ocean Fish Trawl	3.1	Fish trawl net
Ocean Trap & Line	37.3	Handline
Ocean Hauling	4.7	Beach haul net
Estuary General	54.1	Mesh net
Estuary Prawn Trawl	0.1	Prawn trawl net

Despite the declines in catch shown above, CPUE (kg/day) for mulloway has remained stable since 1997/98 in the two main fisheries for this species (Fig. 4.4). CPUE in the Ocean Trap & Line fishery was consistently between 6 and 7 kg/day between 1997/98 and 2003/04 with a sharp increase in 1999/00 of closer to 10 kg/day. During this same period, CPUE in the Estuary General fishery was typically between 3 and 4 kg/day. The higher CPUE in the Ocean Trap & Line fishery is probably due to larger fish being caught in ocean waters compared to estuaries.

Commercial reported landings for mulloway from 2003/04 show that ocean zones 6, 5 and 2, and the catches from estuaries that are bound by these zones, land the majority of mulloway in NSW (Fig. 4.5). Estuaries that contribute much of the catch within each of these three primary ocean zones are the Hawkesbury River (12.4 tonnes) in zone 6, Hunter River (6 tonnes) in zone 5 and Clarence River (8.3 tonnes) in zone 2. The catch of mulloway in the Shoalhaven River is comparable to these estuaries (6.2 tonnes) however the weight of fish caught in ocean zone 7 is negligible (0.2 tonnes). The 2003/04 financial year is the most recent year for which data is predominantly complete (85%) and is the first entire financial year after the buy-out of commercial fishing businesses for the creation of recreational fishing havens was completed.

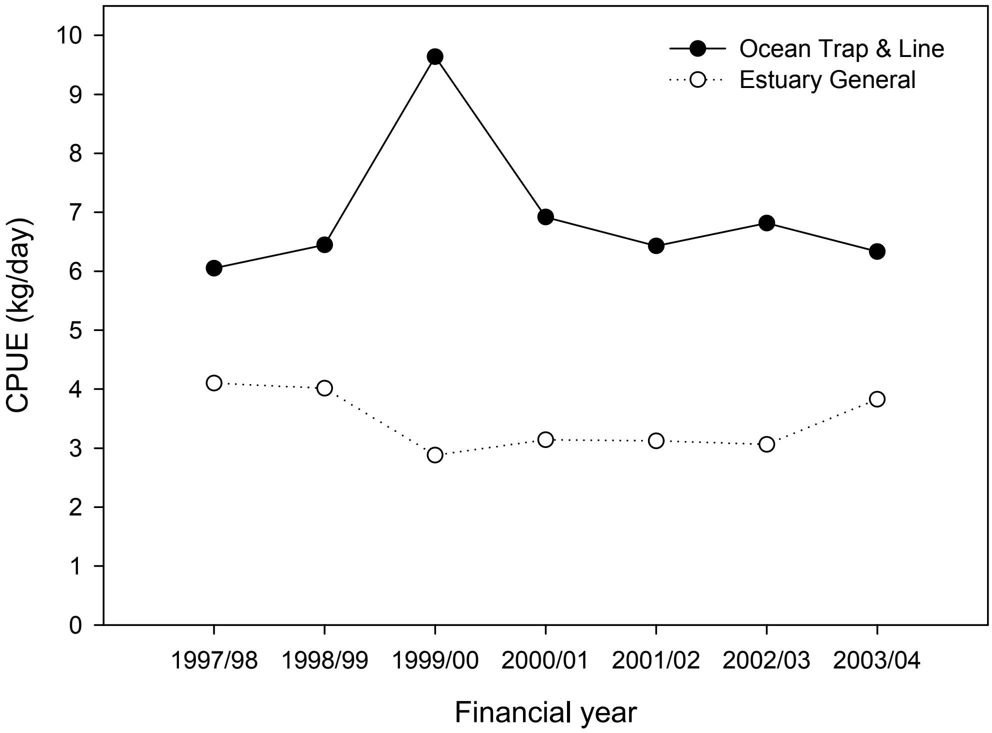


Figure 4.4. CPUE (kg/day) of mulloway for the Estuary General and Ocean Trap & Line fisheries for each year between 1997/98 and 2003/04.

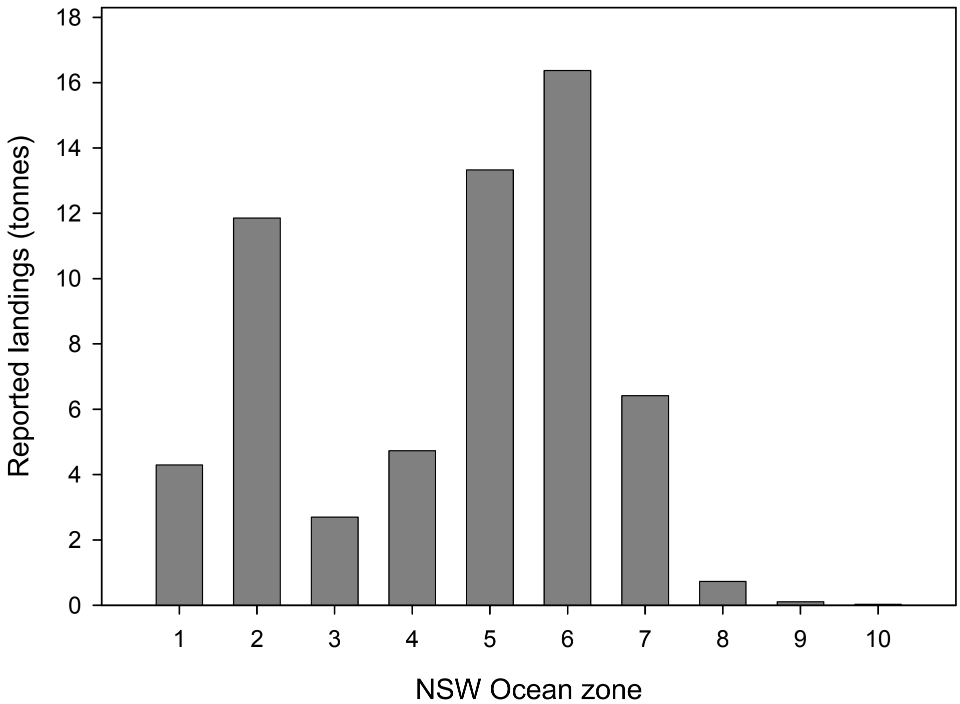


Figure 4.5. Total reported estuarine and coastal landings of mulloway by ocean zone for 2003/04. Landings for ocean zones include estuarine landings from that area.

Catches of mulloway differ both among months and between the Ocean Trap & Line and Estuary General fisheries (Fig. 4.6). The greatest reported landings of mulloway harvested in the OT&L fishery occurs in the summer months when the fishery targets those fish that have aggregated in ocean waters to spawn. The greatest reported landings of fish harvested in the Estuary General fishery occurs during autumn and winter.

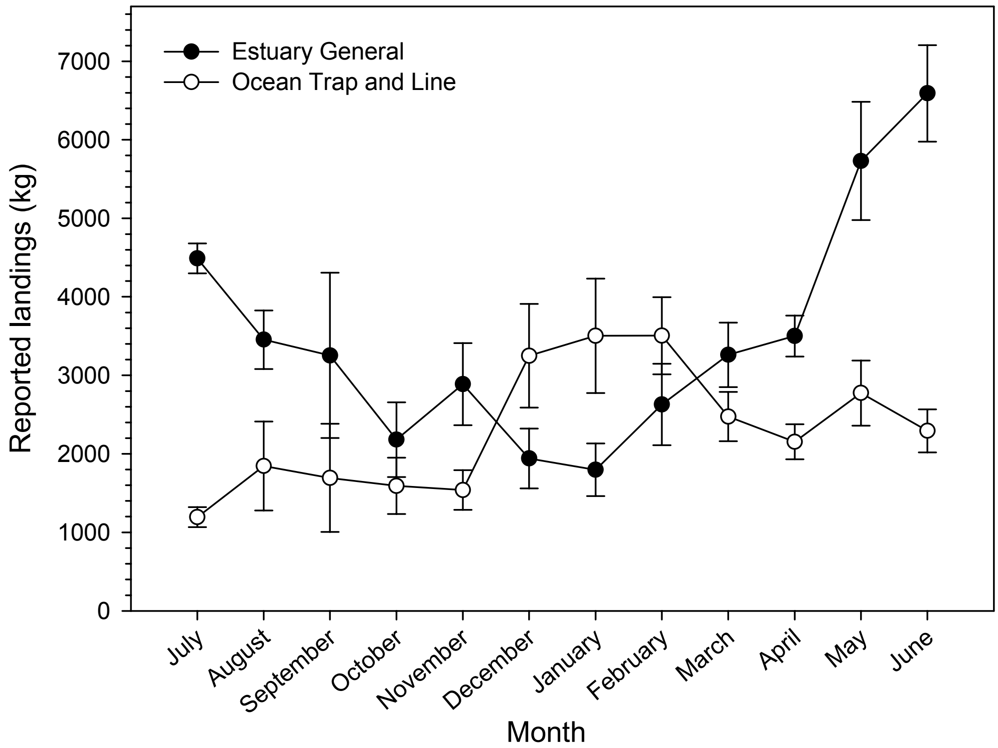


Figure 4.6. Mean (± standard errors) of reported landings by month for the Estuary General and Ocean Trap & Line fisheries between 1997/98 and 2003/04.

The estimated length composition of mulloway retained in commercial catches between 2003 and 2005 is given in Fig. 4.7. Region 2 had a higher frequency of smaller fish and a lower frequency of larger fish than Region 1. The majority of fish caught (83%) were within 15 cm of the minimum legal length (MLL = 45 cm) in all regions.

The estimated length compositions of retained commercial catches of mulloway have changed through time and reflect changes in the MLL (Fig. 4.8). Between 1972 and 1990 fish between 30 and 40 cm TL dominated catches when there was no MLL. Since then, larger fish have dominated catches because of the increased MLL to 45cm TL. A greater proportion of smaller fish between 45 and 60 cm were measured in catches in 2003 - 05 than in 1996 - 99.

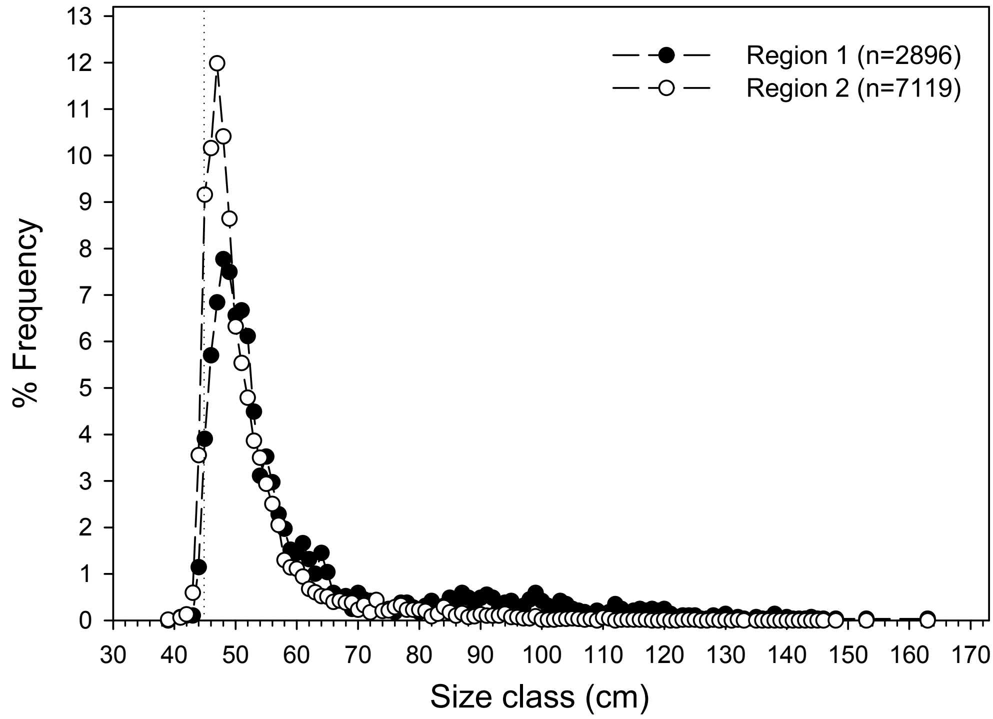


Figure 4.7. Length class distribution (1 cm size classes) of sampled commercial retained catches of mulloway by region. Dotted line indicates 45 cm MLL.

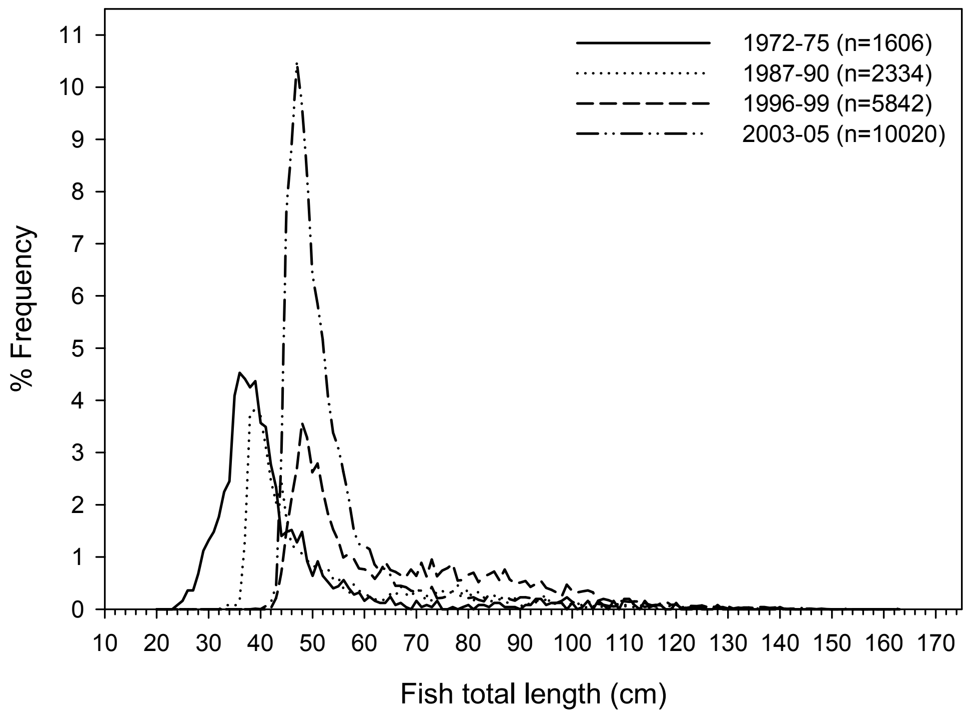


Figure 4.8. Estimated length compositions of retained commercial catches of mulloway in NSW for four periods between 1972 and 2005.

The length composition of sampled catches of mulloway taken in estuaries and ocean waters was very similar (Fig. 4.9). A greater proportion of larger (> 70 cm TL) individuals were caught in ocean waters. It is also interesting to note that, when converting fish lengths to weights using the equation in Chapter 3, approximately 69% of fish measured were caught in estuaries compared to 31% caught in the ocean. This corresponds to the total weight of mulloway caught in each class of water in 2003/04 where 65% of mulloway landed were caught in estuaries and 35% were caught in ocean waters.

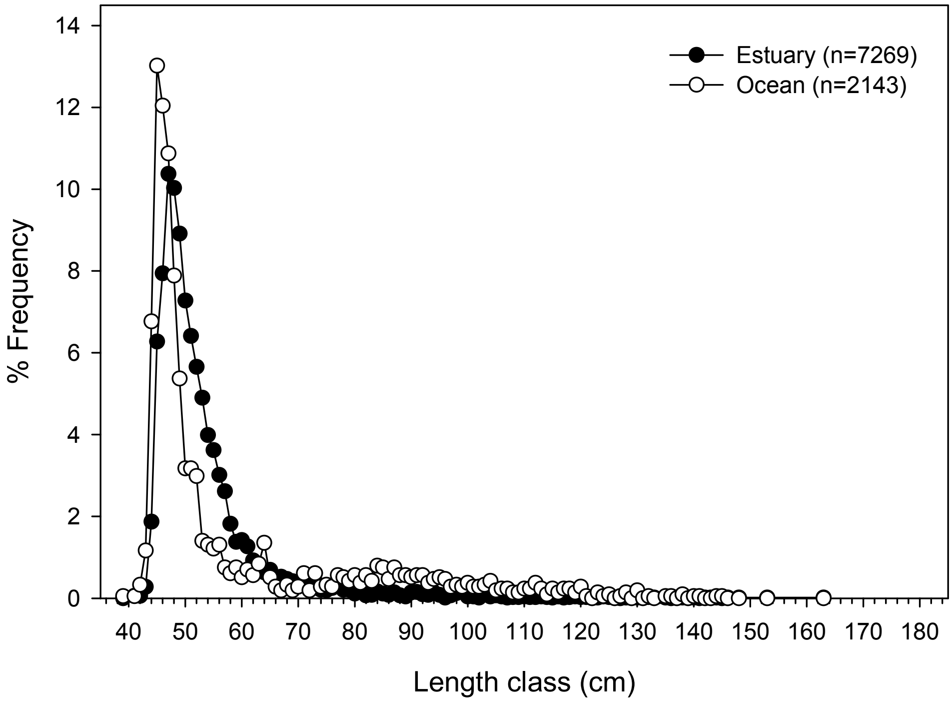


Figure 4.9. Length composition of sampled estuarine and ocean commercial catches of mulloway (pooled across regions).

4.3.3. Age Compositions of landings

The age composition of commercial landings was estimated using the age-length key (Table 3.2) and the size composition in landings (Fig. 4.9). Retained commercial catches taken in estuarine and coastal waters were dominated (> 70%) by 2-year-old fish (Fig. 4.10). Fish aged between 2 and 5 years contributed approximately 98% to total landings. Fifty-five fish older than 8 years were sampled (Table 3.2), but because they contributed less than 0.3% in any age class they are not visible in Fig. 4.10.

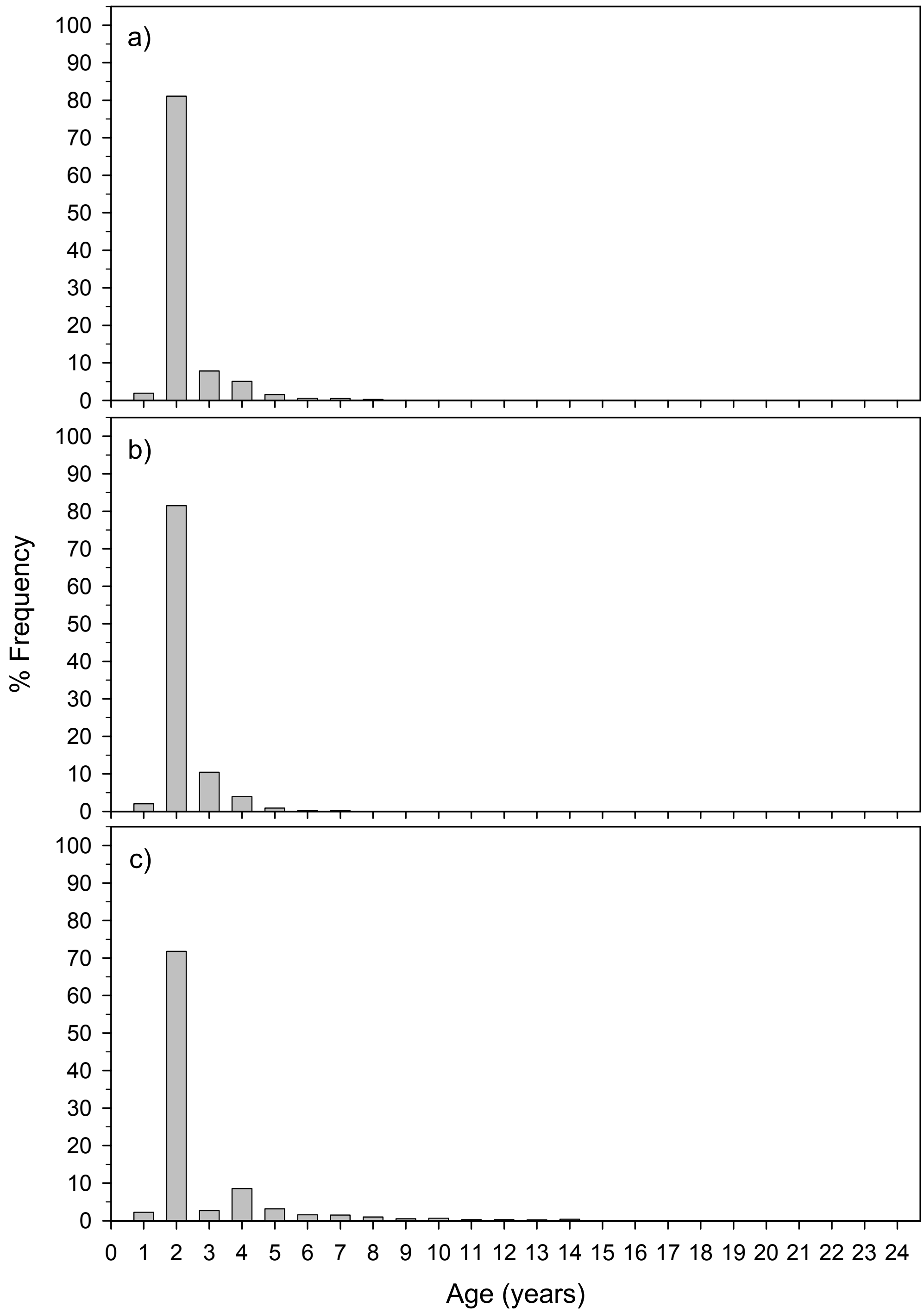


Figure 4.10. Estimated age compositions of samples of a) the total commercial catch (n = 2605), b) the estuarine catch (n = 1681), and c) ocean retained commercial catches (n = 381) of mulloway in NSW 2003 to 2005. Note that 3 fish could not be assigned to a class of water.

4.3.4. *Estimated total, natural and fishing-related mortality*

Estimates of total mortality from the slope of the descending limb of the catch curve were 0.7 for ages 2 to 10 and 0.45 for ages 2 to 15 (Fig. 4.11).

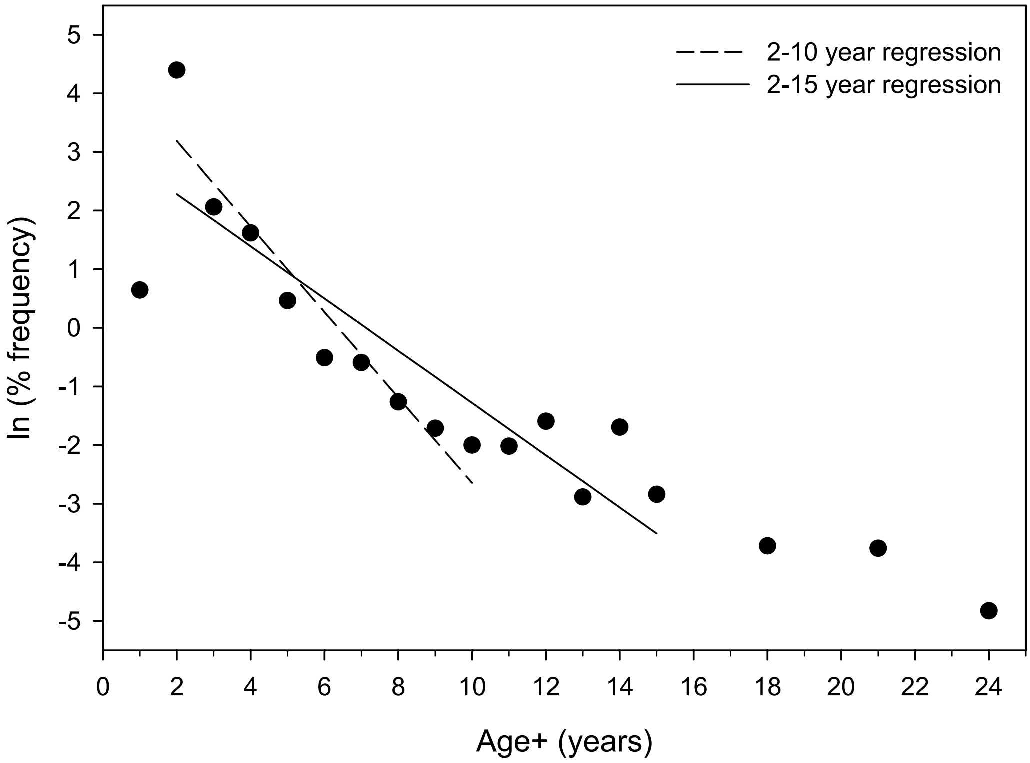


Figure 4.11. Linear regressions fitted to the natural logarithms (ln) of age composition for mulloway. Curves were fitted between the ages of 2 and 10 and 2 and 15 years.

4.3.5. *Yield-per-recruit analyses*

Yield-per-recruit trajectories for a range of sizes at first capture at 3 different estimates of M are presented in Fig. 4.13. Yield per recruit estimates at any given F were influenced by M, being much greater at lower values of M. Despite this, the shape of the trajectories was similar in each case. The analyses indicate that at present levels of F (0.35 to 0.6) and at the current MLL (45cm) that mulloway are growth overfished. Substantial increases in yield-per-recruit are predicted with increases in the length at first capture.

Yield per recruit isopleths for our best estimate of M/K (0.1/0.197 = 0.5) show that at the current exploitation rate (E ranges from 0.77 to 0.85) that substantial increases in yield per recruit are predicted by increasing the length at first capture (Fig. 4.14). At the most likely situation of M/K = 0.5 the model predicts, at current exploitation levels, an increase in yield per recruit of approximately 40% by increasing the minimum legal length to 70cm. Any increase in minimum legal length is likely to reduce overall exploitation rates resulting in even greater increases in yield per recruit with increases in the minimum legal length. Scenarios for M/K = 0.25 and M/K = 0.75 are also presented in Figs. 4.14. Once the length at first capture increases to greater than around 70% of the maximum size (i.e. approximately 90 cm TL) exploitation rate has little affect on yield per recruit.

Predicted optimum lengths at first capture are provided in Table 4.3. These data indicate that the smallest optimum length to harvest mulloway would be 76 cm TL at an exploitation rate of 0.4 and M/K ratio of 0.7. The optimum exploitable length at an exploitation rate of between 0.77 and 0.85 and at the best estimate of M/K of 0.5, is between 98 to 103cm.

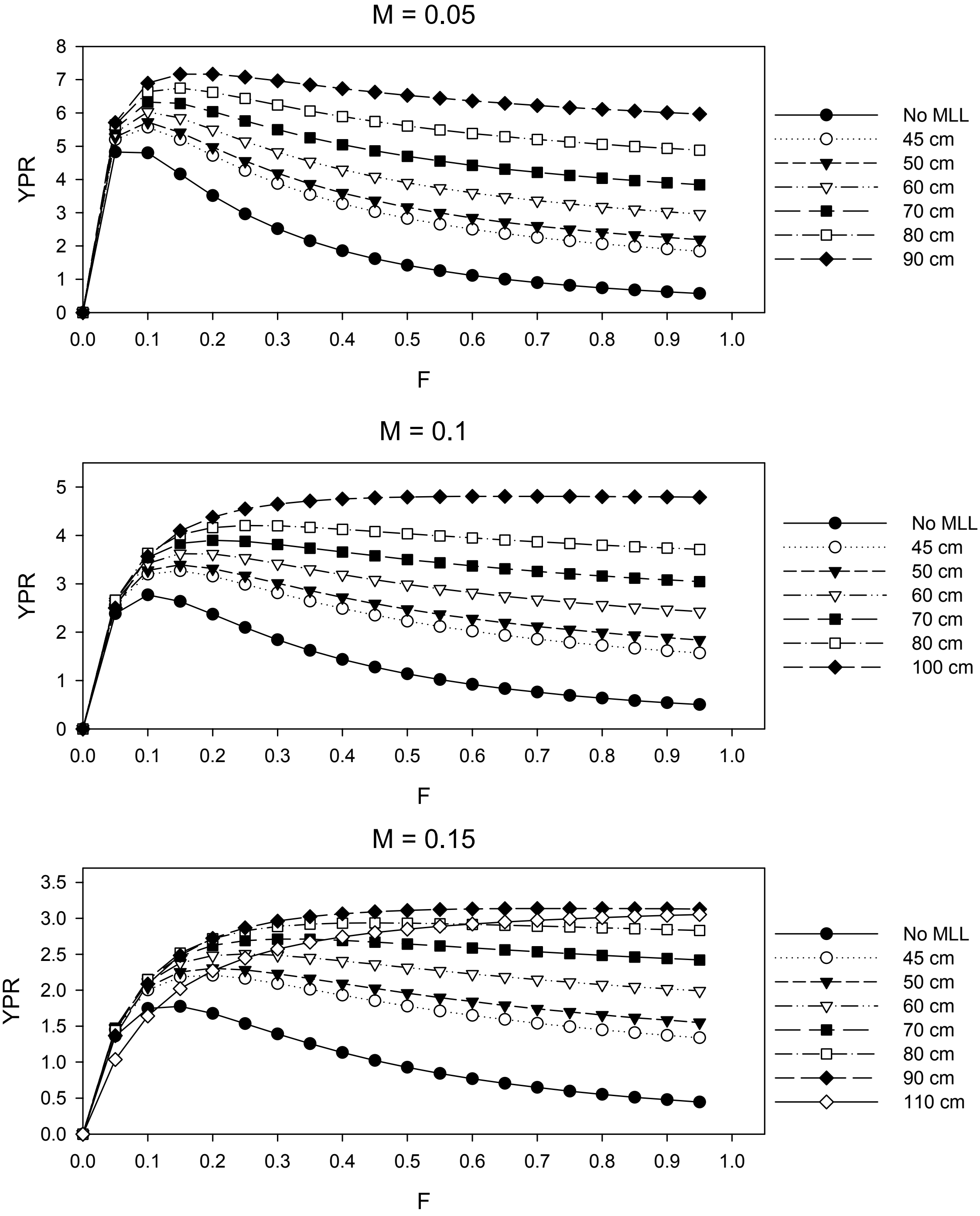


Figure 4.12. Yield per recruit trajectories for mulloway calculated using the program B-H3 (Saila *et al*. 1988). Note different scales on the y-axes at different values of M.

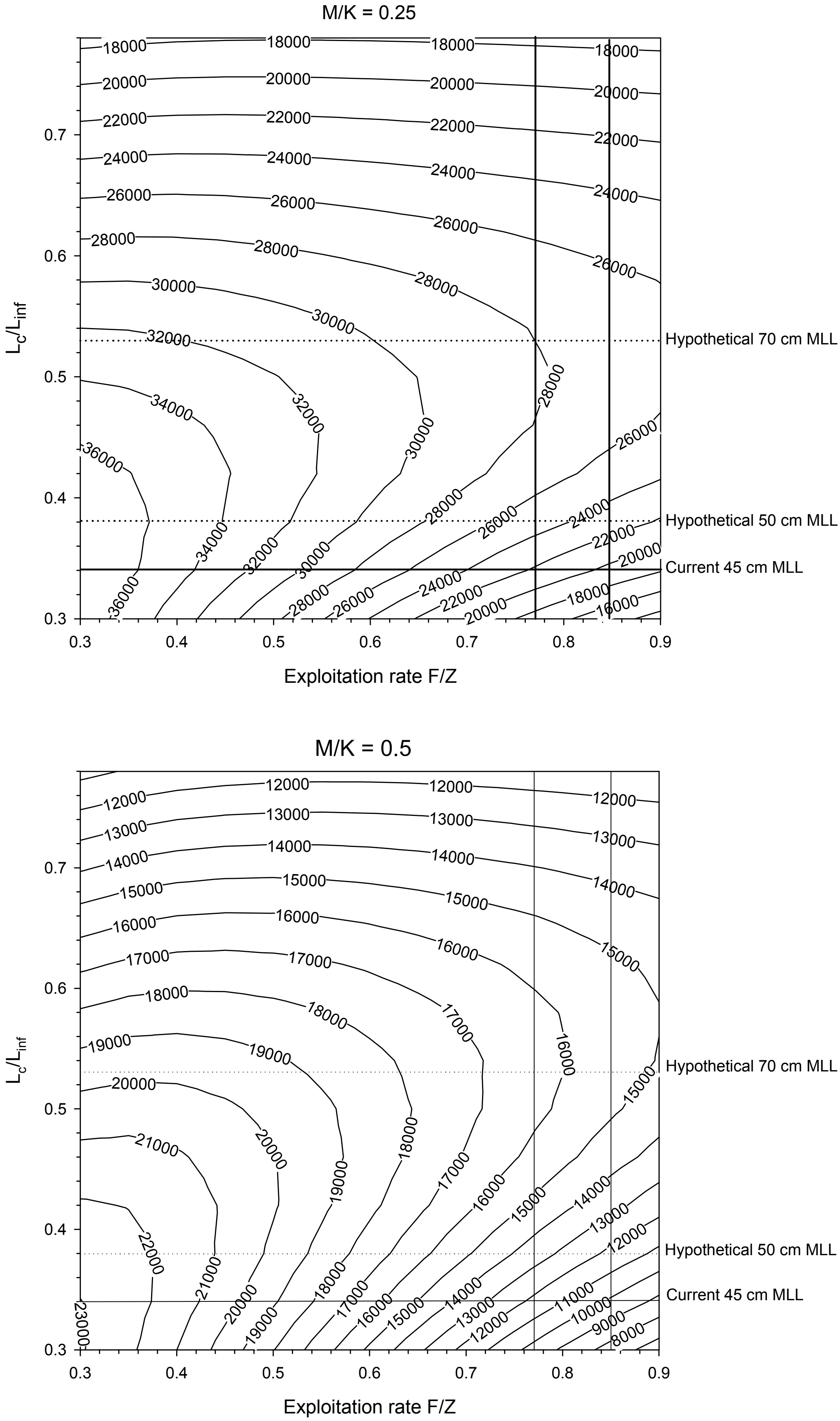


Figure 4.13. Yield-per-recruit isopleths for mulloway for different scenarios of M/K.

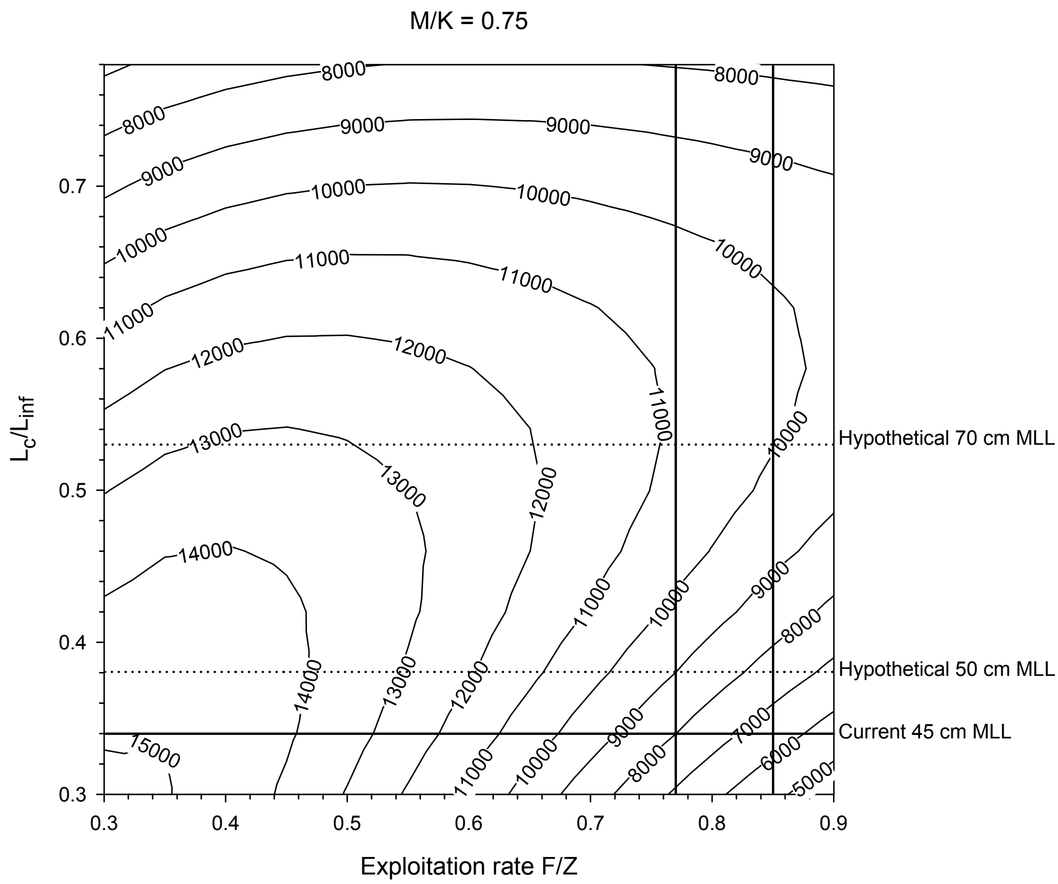


Figure 4.13 (cont). Yield-per-recruit isopleths for mulloway for different scenarios of M/K.

Table 4.3. Optimum lengths at first capture (cm TL) for mulloway in relation to exploitation rate and M/K. Linf = 131.

	Exploitation rate E				
M/K	**0.4**	**0.5**	**0.6**	**0.7**	**0.8**
0.3	86.06	92.95	99.06	104.52	109.46
0.4	83.33	90.09	96.07	101.4	106.21
0.5	80.73	87.36	93.21	98.41	103.22
0.6	78.26	84.76	90.48	95.68	100.23
0.7	76.05	82.42	88.01	92.95	97.50

4.4. Discussion

Mulloway has been commercially harvested in significant quantities in NSW since at least the 1940's. There was a significant increase and peak in reported total catches in the early to mid 1970's, after which total reported catches have declined. This decline may be indicative of population abundance but may in part be due to the reduced levels of fishing effort, as the available CPUE data have been relatively stable since the late 1980's. Unfortunately, there are no comparable data concerning the recreational fishery for mulloway in NSW, which in recent years has been estimated to be at least three times greater than the corresponding commercial fishery (Henry & Lyle 2003).

The commercial fishery for mulloway varies spatially and temporally. Mulloway are mostly caught in estuaries during winter when mesh nets can be set overnight. In contrast, mulloway are predominantly caught in ocean waters between summer and autumn when fish aggregate to spawn. Greatest estuarine catches of mulloway are reported in the large riverine systems, which have significant depth and catchments that allow for large freshwater discharge, notably the Clarence and Hawkesbury rivers. In coastal waters, greatest quantities of mulloway are taken in ocean fishing zones 5 and 6, between 32 and 34° S (Crowdy Head to Botany Bay).

The estimated length and age compositions of the estuarine and coastal catches of mulloway were very similar, being dominated by fish very close to the minimum legal length (MLL) of 45 cm and age of 2 years. The relatively small proportion of fish aged > 2 years in landings, despite having the potential to live for more than 40 years, is indicative of a fishery that is heavily exploited. Our estimates of F are between 3 and 6 times greater than our best estimate of M, a situation that is likely to be unsustainable. Estimates of total mortality (0.45 to 0.7) are high and indicate that between 36 and 50 % of mulloway die each year. This estimate of Z is more than 5 times greater than that estimated for black drum (*Pogonias cromis*) in the USA (Jones & Wells 1998), but is similar to that estimated for inshore mulloway (*A. japonicus*) in South Africa (Griffiths 1997c). These high mortality rates, in conjunction with spawner biomass-per-recruit analyses, led to the conclusion that this species in South Africa has been severely depleted and is recruitment overfished (Griffiths 1997c). Sciaenids, in general, are prone to overfishing (Sadovy & Cheung 2003, Piner & Jones 2004). The data presented in this report show that mulloway in NSW are growth overfished and, if similar to the South African stock, possibly recruitment overfished. Further work to assess the current spawner biomass-per-recruit levels and any spawner biomass-recruitment relationship should be done as a priority for mulloway in NSW.

4.4.1. Management implications

Because sciaenids are prone to overfishing, it has been recommended that the spawning stock, particularly identifiable spawning aggregations, be protected from harvesting to sustain wild populations of some species (Sadovy & Cheung 2003). This report indicates that mulloway in NSW are currently being exploited at unsustainable levels and are in urgent need of greater protection. This could potentially be achieved by (1) increasing the minimum legal length of the species to at least 70 cm TL, (2) introducing spatial and temporal fishing closures around spawning aggregations or on prohibiting the taking of mulloway during the summer-autumn spawning season as it is during this time that fish are most vulnerable to capture in the coastal line fishery, (3) introducing a mandatory bycatch reduction device (see Broadhurst & Kennelly 1994, 1995) in the estuarine and coastal prawn trawl fleet, and (4) reducing the bag-limit for recreational anglers in conjunction with research into release mortality (5) using a combination of all of these options.

All such options will create negative economic impacts on estuary and coastal commercial fishers that catch mulloway in significant numbers, impact on the recreational fishery and may be hard to regulate. Specifically, the introduction of a significant increase in the MLL of mulloway would virtually eliminate the estuary fishery for mulloway. Since 2000/01, 32% of all commercial fishers reporting mulloway harvest 90% of the total commercial catch. During this time, between 31 and 35% of estuary fishers harvested 90% of the estuary mulloway catch and this is a significant part of their fishing income. In the ocean, 30 – 37% of fishers in this sector harvested 90% of the ocean mulloway caught since 2000/01. Such a size limit increase would also negatively impact many coastal fishers as most mulloway caught in ocean waters are also < 70 cm TL. Such an impact may only be short-term (< 5 years) since growth from 45 cm to 70 cm will take less than 5 years, and the yield-per-recruit analyses indicated that the total weight of harvests should be significantly greater once fish grow to a larger size. However, any potential benefits to protect the stock may be negated if mulloway are still caught and subsequently discarded in poor condition in significant quantities in these fisheries. For example, mulloway will still be caught in mesh nets in estuaries unless the minimum mesh size is increased greatly (but this would affect retained catches of most other species) and the effects of the capture and discarding of mulloway in these nets is not known. Current studies on survival of mulloway following hook and release show mortalities can be high dependent on hooking location, exposure to air and handling practices, but this work has only been done in estuaries. The additional effects of barotrauma on the survival of mulloway caught and released in coastal waters is unknown. This information would be needed prior to any such fishing closures and increases in MLL. Nonetheless, management interventions such as those discussed above are required to adequately conserve the population of wild mulloway in NSW.

5. OUTCOMES AND RECOMMENDATIONS

5.1. Benefits

This project has provided valuable biological information on the growth, size and age at maturity and fisheries-related data on length and age compositions of commercial catches for mulloway in NSW. Such information will benefit fisheries managers, conservation agencies and the commercial and recreational fishing industries in determining future management arrangements for the conservation and sustainable harvesting of the species.

5.2. Further Development

Further work is required to determine the size and demographic characteristics of the recreational fishery of mulloway in NSW. The data contained in the National Survey of Recreational and Indigenous Fishing suggests that the recreational catch of mulloway in NSW is larger than the commercial sector. A long-term strategy to monitor and assess the population and fisheries of mulloway and to assess impacts of any changes in management regimes on the species is required. The effects of the current experimental stock enhancements of mulloway and their potential to rebuild the mulloway population need to be assessed. The conclusions and recommendations of this study and their potential impacts on the fisheries for mulloway need to be discussed with industry.

5.3. Planned Outcomes

The planned outcomes of this project were:

(1) The publication of a review of the biology and fishery of mulloway in an international scientific journal: - A scientific manuscript has been submitted to an international journal for consideration for publication.
(2) A synthesis and assessment of the commercial fishery of mulloway in NSW: - This was achieved (Chapter 4).
(3) A description of the reproductive biology, growth and age and yield-per-recruit analyses of mulloway: - This was achieved (Chapters 3 and 4)
(4) Provide advice and recommendations concerning the biology and fisheries of mulloway in NSW to the relevant fisheries managers, MACs and industry in general: - This has been done throughout the project and is ongoing.

5.4. Conclusions

The key objectives of assessing the age, growth and reproductive biology of mulloway in NSW have been achieved. A review of the scientific literature revealed a dearth of information on mulloway, except for southern Africa. Our studies show that mulloway grow relatively fast, attain sexual maturity at a reasonable size (approximately 68 cm and 51 cm TL for female and male respectively) but at a relatively young age (2 – 4 years) and that the current minimum legal length of 45 cm TL is too small to protect the spawning population of mulloway in NSW. Mulloway are growth overfished and changes in the management arrangements of the species are required for the conservation and sustainable harvesting of the species. In particular:

- The spawning stock requires greater protection. This will be achieved partially through the formation of a series of marine parks along the NSW coast. There will also be some flow-on benefits to mulloway from fishing closures on highly productive reefs in order to protect grey nurse sharks. These changes will probably suffice in providing protection to the spawning stock in the short term.

- Fishing mortality needs to be reduced in order to achieve optimal yield. This will impact both commercial and recreational fishers. The bag limit for recreational fishers may need to be reduced and an increase in the MLL to 70 cm will (1) protect juveniles and give them the chance to spawn before being recruited to the fishery; (2) increase egg production; (3) increase the yield per recruit by more than 40%, and (4) increase the number of trophy fish for recreational anglers.

The effectiveness of the proposed increase in MLL will be determined, in part, by the discard mortality rates of mulloway from both commercial and recreational fishing gears. Therefore research to assess rates of mortality of discarded juvenile mulloway would be necessary before such an increase in MLL is implemented.

6. LITERATURE CITED

Anon. 1981a. The ecology of fish in Botany Bay – Biology of commercially and recreationally valuable species. Report No. BBS 23B. State Pollution Control Commission. Sydney, Australia.

Anon. 1981b. Amateur angling in Botany Bay. Report No. BBS 24. State Pollution Control Commission. Sydney, Australia.

Anon. 1993. Mulloway. Fisheries Department of WA, Western Australia.

Anon. 2003. Fishery Management Strategy for the Estuary General Fishery. NSW Fisheries, Cronulla. 155 pp.

Arnold, C.R., Holt, G.J. & Thomas, P. 1988. Red Drum Aquaculture, Proceedings of a symposium on the culture of red drum and other warm water fishes. *Contributions in Marine Science*. Supplement to Volume 30.

Ault, J.S., McGarvey, R., Rothschild, B.J. and Chavarria, J.B. 1996. Stock assessment computer algorithms. Annex B, pp 501-51. In Gallucci, V.F., Saila, S.B., Gustafson, D.J and Rothschild, B.J. (eds) Stock assessment - quantitative methods and applications for small-scale fisheries. CRC Press, Boca Raton, Florida.

Battaglene, S.C. & Talbot, B.R. 1994. Hormone induction and larval rearing of mulloway, *Argyrosomus hololepidotus* (Pisces: Sciaenidae). *Aquaculture*. 126: 73-81.

Battaglene, S.C. 1996. Hatchery production of juvenile snapper and mulloway. In Quartararo, N. Marine finfish farming – Proceedings of a workshop. NSW Fisheries Research Institute, Cronulla, NSW. pp 9-36.

Beckley, L.E. 1990. A description of the early life history stages of the kob, *Argyrosomus hololepidotus* (Pisces: Sciaenidae), from southern Africa. *South African Journal of Zoology*. 25(4): 224-228.

Beverton, R.J. and Holt, S.J. 1957. On the dynamics of exploited fish populations. Ministry of Agriculture, Fisheries and Food, Fishery Investigations Series II, Volume 19. 533 pp Fisheries Laboratory, Lowestoft.

Black, M. & Dixon, P.I. 1992. Stock identification and discrimination of mulloway in Australian waters. FIRTA 86/16. Centre for Marine Sciences. The University of New South Wales, Australia.

Broadhurst, M.K. 1993. Aspects of the biology, distribution and selectivity of juvenile mulloway *Argyrosomus hololepidotus*: an important by-catch species from estuarine prawn-trawling in New South Wales, Australia. MSc thesis.

Broadhurst, M.K. 2000. Modifications to reduce bycatch in prawn trawls: A review and framework for development. *Reviews in Fish Biology and Fisheries*. 1: 27-60.

Broadhurst, M.K. & Barker, D.T. 2000. Effects of capture by hook and line on plasma cortisol, scale loss and survival in juvenile mulloway, *Argyrosomus hololepidotus*. *Archive of Fishery Marine Research*. 48(1): 1-10.

Broadhurst, M.K. & Kennelly, S.J. 1994. Reducing the by-catch of juvenile fish (mulloway *Argyrosomus hololepidotus*) using square-mesh panels in codends in the Hawkesbury River prawn-trawl fishery, Australia. *Fisheries Research*. 19: 321-331.

Broadhurst, M.K. & Kennelly, S.J. 1995. A trouser-trawl experiment to assess cod-ends that exclude juvenile mulloway (*Argyrosomus hololepidotus*) in the Hawkesbury River prawn-trawl fishery. *Marine and Freshwater Research*. 46: 953-958.

Brouwer, S.L., Mann, B.Q., Lamberth, S.J., Sauer, W.H.H., Erasmus, C. 1997. A survey of the South African shore-angling fishery. *South African Journal of Marine Science*. 18: 165-177.

Chamberlain, G.W., Miget, R.J. & Haby, M.G. 1990. Red Drum Aquaculture. Accompanying publication to No. 132.

Connolly, R.M. 1994. A comparison of fish assemblages from seagrass and unvegetated areas of a southern Australian estuary. *Australian Journal of Marine and Freshwater Research*. 45: 1033-1044.

FAO. 2002. FAO Fishery Information, Data and Statistics Unit. Aquaculture production statistics 1991-2000. Vol 90/2.

Ferrell, D.J., McNeill, S.E., Worthington, D.G. & Bell, J.D. 1993. Temporal and spatial variation in the abundance of fish associated with the seagrass *Posidonia australis* in south-eastern Australia. *Australian Journal of Marine and Freshwater Research*. 44(6): 881-899.

Fielder, D.S. & Bardsley, W.J. 1999. A preliminary study on the effects of salinity on growth and survival of mulloway *Argyrosomus japonicus* larvae and juveniles. *Journal of the World Aquaculture Society*. 30(3): 380-387.

Fielder, D.S., Bardsley, W.J. & Allan, G.L. 1999. Enhancement of mulloway (*Argyrosomus japonicus*) in intermittently opening lagoons. FRDC Project No. 95/148. Final Report Series No. 14. NSW Fisheries, Australia.

Froese, R. and D. Pauly. Editors. 2003. FishBase. World Wide Web electronic publication. www.fishbase.org, version 16 June 2003.

Gartside, D.F., Harrison, B. & Ryan, B.L. 1999. An evaluation of the use of fishing club records in the management of marine recreational fisheries. *Fisheries Research*. 41: 47-61.

Gooley, G.J., De Silva, S.S., Hone, P.W., McKinnon, L.J. & Ingram, B.A. 2000. Cage aquaculture in Australia: A developed country perspective with reference to integrated aquaculture development within inland waters. In Liao, I.C. & Lin, C.K. (eds) Cage aquaculture in Asia: Proceedings of the First International Symposium on Cage Aquaculture in Asia. Asian Fisheries Society, Manila and World Aquaculture Society - Southeast Asian Chapter. Bangkok. pp 21-37.

Gold, J.R., Stewart, L.B. & Ward, R. 2002. Population structure of spotted se trout (*Cynoscion nebulosus*) along the Texas Gulf cast as revealed by genetic analysis. pp 17-30. In Bortone, S. A. Biology of spotted sea trout. CRC Press, Boca Raton, Fla.

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

Gray, C.A. 2002. Management implications of discarding in an estuarine multi-species gill net fishery. *Fisheries Research*. 56: 177-192.

Gray, C.A. & Kennelly, S.J. 2003. Catch characteristics of the commercial beach-seine fisheries in two Australian barrier estuaries. *Fisheries Research*. 63: 405-422.

Gray, C.A., Kennelly, S.J. & Hodgson, K.E. 2003. Low levels of bycatch from estuarine prawn seining in New South Wales, Australia. *Fisheries Research* 64: 37-54.

Gray, C.A. & McDonall,V.C. 1993. Distribution and growth of juvenile mulloway, *Argyrosomus hololepidotus* (Pisces: Sciaenidae), in the Hawkesbury River, South-eastern Australia. *Australian Journal of Marine and Freshwater Research*. 44: 401-409.

Gray, C.A., McDonall, V.C. & Reid, D.D. 1990. By-catch from prawn trawling in the Hawkesbury River, New South Wales: Species composition, distribution and abundance. *Australian Journal of Marine and Freshwater Research*. 41(1): 13-26.

Gray, C.A. & Miskiewicz, A.G. 2000. Larval fish assemblages in south-east Australian coastal waters: Seasonal and Spatial Structure. *Estuarine, Coastal and Shelf Science*. 50(4): 549-570.

Griffiths, M.H. 1996. Life history of the dusky kob *Argyrosomus japonicus* (Sciaenidae) off the east coast of South Africa. *South African Journal of Marine Science*. 17: 135-154.

Griffiths, M.H. 1997a. Feeding ecology of the South African *Argyrosomus japonicus* (Pisces: Sciaenidae), with emphasis on the eastern cape surf zone. *South African Journal of Marine Science*. 18: 249-264.

Griffiths, M.H. 1997b. Influence of prey availability on the disturbance of dusky kob *Argyrosomus japonicus* (Sciaenidae) in the Great Fish River Estuary, with notes on the diet of early juveniles from three other estuarine systems. *South African Journal of Marine Science*. 18: 137-145.

Griffiths, M.H. 1997c. Management of South African dusky kob *Argyrosomus japonicus* (Sciaenidae) based on per-recruit models. *South African Journal of Marine Science*. 18: 213-228.

Griffiths, M.H. & Hecht, T. 1995. Age and growth of South African dusky kob *Argyrosomus japonicus* (Sciaenidae) based on otoliths. *South African Journal of Marine Science*. 16: 119-128.

Griffiths, M.H. & Heemstra, P.C. 1995. A contribution to the taxonomy of the marine fish genus Argyrosomus (Perciformes: Sciaenidae), with descriptions of two new species from southern Africa. *Ichthyological Bulletin of the J.L.B Smith Institute of Ichthyology*. 65: 1-40.

Hall, D.A. 1984. The Coorong: Biology of the major fish species and fluctuations in catch rates 1976-1983. SAFIC. 8(1): 3-17.

Hall, D.A. 1986. An assessment of the mulloway (*Argyrosomus hololepidotus*) fishery in South Australia with particular reference to the Coorong Lagoon. Department of Fisheries, South Australia.

Henry, G.W. 1984. Commercial and recreational fishing in Sydney estuary. *Fisheries Bulletin*. 1: 16-29.

Henry, G.W. & Lyle, J.M. 2003. The National Recreational and Indigenous Fishing Survey. Final Report to the Fisheries Research & Development Corporation and the Fisheries Action

Program. Project No. 1999/158. NSW Fisheries Final Report Series No. 48. ISSN 1440-3544. 188pp.

Hoenig, J.M. (1983). Empirical use of longevity data to estimate mortality rates. *Fisheries Bulletin*. 81: 898-903.

Jones, G.K., Hall, D.A., Hill, K.L. & Staniford, A.J. 1990. The South Australian Marine Scalefish Fishery. South Australian Department of Fisheries, South Australia.

Jones, C.M. & Wells, B. 1998. Age, growth, and mortality of black drum, *Pogonias cromis*, in the Chesapeake Bay region. *Fishery Bulletin*. 96: 451-461.

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

Kennelly, S.J., Liggins, G.W. & Broadhurst, M.K. 1998. Retained and discarded by-catch from oceanic prawn trawling in New South Wales, Australia. *Fisheries Research*. 36: 217-236.

Krogh, M. & Reid, R. 1996. Bycatch in the protective shark meshing programme off south-eastern New South Wales, Australia. *Biological Conservation*. 77: 219-226.

Lenanton, R.C.J. & Potter, J.C. 1987. Contribution of estuaries to commercial fisheries in temperate Western Australia and the concept of estuarine dependence. *Estuaries*. 10(1): 28-35.

Liggins, G.W. & Kennelly, S.J. 1996. By-catch from prawn trawling in the Clarence River estuary, New South Wales, Australia. *Fisheries Research*. 25: 347-367.

Liggins, G.W., Kennelly, S.J. & Broadhurst, M.K. 1996. Observer-based survey of by-catch from prawn trawling in Botany Bay and Port Jackson, New South Wales. *Marine and Freshwater Research*. 47: 877-888.

Lin, S.Y. 1940. Croakers of the South China Sea. *Journal of the Hong Kong Fisheries Research Station*. 1: 243-254.

Marais, J.F.K. 1984. Feeding ecology of major carnivorous fish from four eastern Cape estuaries. *South African Journal of Zoology*. 19(3): 210-223.

McCarty, C.E., Geiger, J.G., Sturner, L.N., Gregg, B.A. and Rutledge, W.P. 1986. Marine fish culture in Texas: A model for the future. In: Stroud, R. (ed) "The role of fish culture in fishery management. An International Symposium on the use of cultured fish in fishery management. American Fisheries Society, pp. 249-262.

McEachron, L.W., McCarty, C.E. & Vega, R.R. 1995. Successful enhancement of the Texas red drum (*Sciaenops ocellatus*) population. In Collie, M.R. and McVey, J.P. (eds) Proceedings of the Twenty-Second U.S.-Japan Aquaculture Panel Symposium: Interactions between cultured species and naturally occurring species in the environment. August 21-22, 1993. Homer, Alaska. UJNR Technical Report No. 22 / Alaska Sea Grant Report AK-SG-95-03. Accessed 29/10/02 from http://www.lib.noaa.gov/japan/aquaculture/report22/mceachro.html

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

Miller, M. 2002. Survey of prawn trawl bycatch in the Richmond River Oceanic Fishing Closure (April-July 2001). In: Kennelly, S.J. and McVea, T.A. (eds) Scientific reports on the recovery of the Richmond and Macleay Rivers following fish kills in February and March 2001. Pages 295-322. NSW Fisheries final Report series No 39.

Miskiewicz, A. 1987. Taxonomy and ecology of fish larvae in lake Macquarie and New South Wales costal waters. PhD Thesis, University of New South Wales.

NSW Fisheries. 2003. Aquaculture Production Report 2001/2002. NSW Fisheries, NSW.

O'Sullivan, D. & Roberts, N. 2000. Status of Australian Aquaculture in 1997/98. *Austasia Aquaculture*. Trade Directory 2000.

O'Sullivan, D. & Dobson, J. 2001. Status of Australian Aquaculture in 1998/99. *Austasia Aquaculture*. Trade Directory 2001.

O'Sullivan, D. & Ryan, M. 2001. Mulloway trials suggest opportunities for brackish water ponds. *Austasia Aquaculture*. April/May: 22-26.

Paterson, A.W. & Whitfield, A.K. 2000. Do shallow-water habitats function as refugia for juvenile fishes? *Estuarine, Coastal and Shelf Science*. 51: 359-364.

Paxton, J.R. & Eschmeyer, W.N. 1994. Encyclopedia of Fishes. University of New South Wales Press. Sydney, Australia.

Penn, J.W. 1977. Trawl caught fish and crustaceans from Cockburn Sound. Report No. 20. Department of Fisheries and Wildlife Western Australia. Perth, WA.

Piner, K.R. & Jones, C.M. 2004. Age, growth and the potential for growth overfishing of spot (*Leiostomus xanthurus*) from the Chesapeake Bay, eastern USA. *Marine and Freshwater Research* 55: 553-560.

Potter, I.C., Beckley, L.E., Whitfield, A.K. & Lenanton, R.C.J. 1990. Comparisons between the roles played by estuaries in the life cycles of fishes in temperate Western Australia and South Africa. *Environmental Biology of Fishes*. 28: 143-178.

Richards, L.J., Schnute, J.T., & Olsen, N. 1997. Visualizing catch-at-age analysis: a case study. *Canadian Journal of Fisheries and Aquatic Sciences* 54: 1646-1658.

Ricker, W.E. 1975. Computation and interpretation of biological statistics of fish populations. *Bulletin of the Fisheries Research Board of Canada*. No. 191.

Robinson, E.H. 1988. Nutritional requirements of red drum: a review. *Contributions in Marine Science*. 30(suppl): 11-20.

Rutherford, E.S., Thue, E.B. & Buker, D.G. 1982. Population characteristics, food habits and spawning activity of spotted seatrout, *Cynoscion nebulosus*, in Everglades National Park. Report T-688. Homestead, Florida: Everglades NP, South Florida Research Centre. 48pp.

Sadovy, Y. & Cheung, W.L. 2003. Near extinction of a highly fecund fish: the one that nearly got away. *Fish and Fisheries*. 4: 86-99.

Saila, S.B., Recksiek, C.W. & Prager, M.H. 1988. Basic fishery science programs - a compendium of microcomputer programs and manual of operation. Developments in Aquaculture and Fisheries Science No. 18. Elsevier, Amsterdam.

Steffe, A.S. 1991. Larval fish distributions within Botany Bay: Implications for estuarine recruitment and management. PhD thesis. Macquarie University.

Steffe, A.S., Murphy, J.J., Chapman, D.J., Tarlinton, B.E., Gordon, G.N.G. & Grinberg, A. 1996. An assessment of the impact of offshore recreational fishing in New South Wales waters on the management of commercial fisheries. Project No: 94/053. NSW Fisheries. Cronulla, Australia.

Steffe, A.S. & Neira, F.J. 1998. Sciaenidae: Croakers and drums. In: Neira, F.J., Miskiewicz, A.G., Trnski, T. Larvae of Temperate Australian Fishes. University of Western Australia Press. Nedlands, Western Australia. pp 278-283.

Thomas, P. & Boyd, N. 1988. Induced spawning of spotted seatrout, red drum and orangemouth corvina (Family: Sciaenidae) with luteinizing hormone-releasing hormone analog injection. *Contributions in Marine Science*. 30(suppl.): 43-48.

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

Trewavas, E. 1977. The sciaenid fishes (croakers or drums) of the Indo-West Pacific. *Transactions for the Zoological Society of London*. 33: 253-541.

Wallace, J.H. & Schleyer, M.H. 1979. Age determination in two important species of South African angling fishes the kob (*Argyrosomus hololepidotus* Lacep.) and the spotted grunter (*Pomadasys commersonni* Lacep.). *Transactions of the Royal Society of South Africa*. 44: 15-26.

West, R.J. 1993. Estuarine fisheries resources of two southeastern Australian rivers. PhD thesis. University of New South Wales.

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

West, R.J. & Walford, T.R. 2000. Estuarine fishes in two large eastern Australian coastal rivers - does prawn trawling influence fish community structure*? Fisheries, Management and Ecology*. 7(6): 523-536.

7. APPENDICES

7.1. Appendix 1 – Intellectual Property

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

7.2. Appendix 2 – Staff

Staff employed to work on this project by NSW DPI were:

Charles Gray – Principal Investigator
Veronica Silberschneider – Fisheries Technician
Paul Lokys – Fisheries Technician
Glen Cuthbert – Fisheries Technician
Damian Young – Fisheries Technician
Victoria Andrews – Fisheries Technician
James McLeod - Fisheries Technician

Other titles in this series:

ISSN 1440-3544 (NSW Fisheries Final Report 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. Final Report to Fisheries Research and Development Corporation. Project No. 96/139.

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

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

No. 4 Pethebridge, R., Lugg, A. and Harris, J., 1998. Obstructions to fish passage in New South Wales South Coast streams. Final report to Cooperative Research Centre for Freshwater Ecology. 70pp.

No. 5 Kennelly, S.J. and Broadhurst, M.K., 1998. Development of by-catch reducing prawn-trawls and fishing practices in NSW's prawn-trawl fisheries (and incorporating an assessment of the effect of increasing mesh size in fish trawl gear). Final Report to Fisheries Research and Development Corporation. Project No. 93/180. 18pp + appendices.

No. 6 Allan, G.L. and Rowland, S.J., 1998. Fish meal replacement in aquaculture feeds for silver perch. Final Report to Fisheries Research and Development Corporation. Project No. 93/120-03. 237pp + appendices.

No. 7 Allan, G.L., 1998. Fish meal replacement in aquaculture feeds: subprogram administration. Final Report to Fisheries Research and Development Corporation. Project No. 93/120. 54pp + appendices.

No. 8 Heasman, M.P., O'Connor, W.A. and O'Connor, S.J., 1998. Enhancement and farming of scallops in NSW using hatchery produced seedstock. Final Report to Fisheries Research and Development Corporation. Project No. 94/083. 146pp.

No. 9 Nell, J.A., McMahon, G.A. and Hand, R.E., 1998. Tetraploidy induction in Sydney rock oysters. Final Report to Cooperative Research Centre for Aquaculture. Project No. D.4.2. 25pp.

No. 10 Nell, J.A. and Maguire, G.B., 1998. Commercialisation of triploid Sydney rock and Pacific oysters. Part 1: Sydney rock oysters. Final Report to Fisheries Research and Development Corporation. Project No. 93/151. 122pp.

No. 11 Watford, F.A. and Williams, R.J., 1998. Inventory of estuarine vegetation in Botany Bay, with special reference to changes in the distribution of seagrass. Final Report to Fishcare Australia. Project No. 97/003741. 51pp.

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

No. 13 Jackson, K.L. and Ogburn, D.M., 1999. Review of depuration and its role in shellfish quality assurance. Final Report to Fisheries Research and Development Corporation. Project No. 96/355. 77pp.

No. 14 Fielder, D.S., Bardsley, W.J. and Allan, G.L., 1999. Enhancement of Mulloway (*Argyrosomus japonicus*) in intermittently opening lagoons. Final Report to Fisheries Research and Development Corporation. Project No. 95/148. 50pp + appendices.

No. 15 Otway, N.M. and Macbeth, W.G., 1999. The physical effects of hauling on seagrass beds. Final Report to Fisheries Research and Development Corporation. Project No. 95/149 and 96/286. 86pp.

No. 16 Gibbs, P., McVea, T. and Louden, B., 1999. Utilisation of restored wetlands by fish and invertebrates. Final Report to Fisheries Research and Development Corporation. Project No. 95/150. 142pp.

No. 17 Ogburn, D. and Ruello, N., 1999. Waterproof labelling and identification systems suitable for shellfish and other seafood and aquaculture products. Whose oyster is that? Final Report to Fisheries Research and Development Corporation. Project No. 95/360. 50pp.

No. 18 Gray, C.A., Pease, B.C., Stringfellow, S.L., Raines, L.P. and Walford, T.R., 2000. Sampling estuarine fish species for stock assessment. Includes appendices by D.J. Ferrell, B.C. Pease, T.R. Walford, G.N.G. Gordon, C.A. Gray and G.W. Liggins. Final Report to Fisheries Research and Development Corporation. Project No. 94/042. 194pp.

No. 19 Otway, N.M. and Parker, P.C., 2000. The biology, ecology, distribution, abundance and identification of marine protected areas for the conservation of threatened Grey Nurse Sharks in south east Australian waters. Final Report to Environment Australia. 101pp.

No. 20 Allan, G.L. and Rowland, S.J., 2000. Consumer sensory evaluation of silver perch cultured in ponds on meat meal based diets. Final Report to Meat & Livestock Australia. Project No. PRCOP.009. 21pp + appendices.

No. 21 Kennelly, S.J. and Scandol, J. P., 2000. Relative abundances of spanner crabs and the development of a population model for managing the NSW spanner crab fishery. Final Report to Fisheries Research and Development Corporation. Project No. 96/135. 43pp + appendices.

No. 22 Williams, R.J., Watford, F.A. and Balashov, V., 2000. Kooragang Wetland Rehabilitation Project: History of changes to estuarine wetlands of the lower Hunter River. Final Report to Kooragang Wetland Rehabilitation Project Steering Committee. 82pp.

No. 23 Survey Development Working Group, 2000. Development of the National Recreational and Indigenous Fishing Survey. Final Report to Fisheries Research and Development Corporation. Project No. 98/169. (Volume 1 – 36pp + Volume 2 – attachments).

No.24 Rowling, K.R and Raines, L.P., 2000. Description of the biology and an assessment of the fishery of Silver Trevally *Pseudocaranx dentex* off New South Wales. Final Report to Fisheries Research and Development Corporation. Project No. 97/125. 69pp.

No. 25 Allan, G.L., Jantrarotai, W., Rowland, S., Kosuturak, P. and Booth, M., 2000. Replacing fishmeal in aquaculture diets. Final Report to the Australian Centre for International Agricultural Research. Project No. 9207. 13pp.

No. 26 Gehrke, P.C., Gilligan, D.M. and Barwick, M., 2001. Fish communities and migration in the Shoalhaven River – Before construction of a fishway. Final Report to Sydney Catchment Authority. 126pp.

No. 27 Rowling, K.R. and Makin, D.L., 2001. Monitoring of the fishery for Gemfish *Rexea solandri*, 1996 to 2000. Final Report to the Australian Fisheries Management Authority. 44pp.

No. 28 Otway, N.M., 1999. Identification of candidate sites for declaration of aquatic reserves for the conservation of rocky intertidal communities in the Hawkesbury Shelf and Batemans Shelf Bioregions. Final Report to Environment Australia for the Marine Protected Areas Program. Project No. OR22. 88pp.

No. 29 Heasman, M.P., Goard, L., Diemar, J. and Callinan, R., 2000. Improved Early Survival of Molluscs: Sydney Rock Oyster (*Saccostrea glomerata*). Final report to the Aquaculture Cooperative Research Centre. Project No. A.2.1. 63pp.

No. 30 Allan, G.L., Dignam, A and Fielder, S., 2001. Developing Commercial Inland Saline Aquaculture in Australia: Part 1. R&D Plan. Final Report to Fisheries Research and Development Corporation. Project No. 1998/335.

No. 31 Allan, G.L., Banens, B. and Fielder, S., 2001. Developing Commercial Inland Saline Aquaculture in Australia: Part 2. Resource Inventory and Assessment. Final report to Fisheries Research and Development Corporation. Project No. 1998/335. 33pp.

No. 32 Bruce, A., Growns, I. and Gehrke, P., 2001. Woronora River Macquarie Perch Survey. Final report to Sydney Catchment Authority, April 2001. 116pp.

No. 33 Morris, S.A., Pollard, D.A., Gehrke, P.C. and Pogonoski, J.J., 2001. Threatened and Potentially Threatened Freshwater Fishes of Coastal New South Wales and the Murray-Darling Basin. Report to Fisheries Action Program and World Wide Fund for Nature. Project No. AA 0959.98. 177pp.

No. 34 Heasman, M.P., Sushames, T.M., Diemar, J.A., O'Connor, W.A. and Foulkes, L.A., 2001. Production of Micro-algal Concentrates for Aquaculture Part 2: Development and Evaluation of Harvesting, Preservation, Storage and Feeding Technology. Final Report to Fisheries Research and Development Corporation. Project No. 1993/123 and 1996/342. 150pp + appendices.

No. 35 Stewart, J. and Ferrell, D.J., 2001. Mesh selectivity in the NSW demersal trap fishery. Final Report to Fisheries Research and Development Corporation. Project No. 1998/138. 86pp.

No. 36 Stewart, J., Ferrell, D.J., van der Walt, B., Johnson, D. and Lowry, M., 2001. Assessment of length and age composition of commercial kingfish landings. Final Report to Fisheries Research and Development Corporation. Project No. 1997/126. 49pp.

No. 37 Gray, C.A. and Kennelly, S.J., 2001. Development of discard-reducing gears and practices in the estuarine prawn and fish haul fisheries of NSW. Final Report to Fisheries Research and Development Corporation. Project No. 1997/207. 151pp.

No. 38 Murphy, J.J., Lowry, M.B., Henry, G.W. and Chapman, D., 2002. The Gamefish Tournament Monitoring Program – 1993 to 2000. Final report to Australian Fisheries Management Authority. 93pp.

No. 39 Kennelly, S.J. and McVea, T.A. (Ed), 2002. Scientific reports on the recovery of the Richmond and Macleay Rivers following fish kills in February and March 2001. 325pp.

No. 40 Pollard, D.A. and Pethebridge, R.L., 2002. Report on Port of Botany Bay Introduced Marine Pest Species Survey. Final Report to Sydney Ports Corporation. 69pp.

No. 41 Pollard, D.A. and Pethebridge, R.L., 2002. Report on Port Kembla Introduced Marine Pest Species Survey. Final Report to Port Kembla Port Corporation. 72pp.

No. 42 O'Connor, W.A, Lawler, N.F. and Heasman, M.P., 2003. Trial farming the akoya pearl oyster, *Pinctada imbricata*, in Port Stephens, NSW. Final Report to Australian Radiata Pty. Ltd. 170pp.

No. 43 Fielder, D.S. and Allan, G.L., 2003. Improving fingerling production and evaluating inland saline water culture of snapper, *Pagrus auratus*. Final Report to the Aquaculture Cooperative Research Centre. Project No. C4.2. 62pp.

No. 44 Astles, K.L., Winstanley, R.K., Harris, J.H. and Gehrke, P.C., 2003. Experimental study of the effects of cold water pollution on native fish. A Final Report for the Regulated Rivers and Fisheries Restoration Project. 55pp.

No. 45 Gilligan, D.M., Harris, J.H. and Mallen-Cooper, M., 2003. Monitoring changes in the Crawford River fish community following replacement of an effective fishway with a vertical-slot fishway design: Results of an eight year monitoring program. Final Report to the Cooperative Research Centre for Freshwater Ecology. 80pp.

No. 46 Pollard, D.A. and Rankin, B.K., 2003. Port of Eden Introduced Marine Pest Species Survey. Final Report to Coasts & Clean Seas Program. 67pp.

No. 47 Otway, N.M., Burke, A.L., Morrison, NS. and Parker, P.C., 2003. Monitoring and identification of NSW Critical Habitat Sites for conservation of Grey Nurse Sharks. Final Report to Environment Australia. Project No. 22499. 62pp.

No. 48 Henry, G.W. and Lyle, J.M. (Ed), 2003. The National Recreational and Indigenous Fishing Survey. Final Report to Fisheries Research and Development Corporation. Project No. 1999/158. 188 pp.

No. 49 Nell, J.A., 2003. Selective breeding for disease resistance and fast growth in Sydney rock oysters. Final Report to Fisheries Research and Development Corporation. Project No. 1996/357. 44pp. (Also available - a CD-Rom published in March 2004 containing a collection of selected manuscripts published over the last decade in peer-reviewed journals).

No. 50 Gilligan, D. and Schiller, S., 2003. Downstream transport of larval and juvenile fish. A final report for the Natural Resources Management Strategy. Project No. NRMS R7019. 66pp.

No. 51 Liggins, G.W., Scandol, J.P. and Kennelly, S.J., 2003. Recruitment of Population Dynamacist. Final Report to Fisheries Research and Development Corporation. Project No. 1993/214.05. 44pp.

No. 52 Steffe, A.S. and Chapman, J.P., 2003. A survey of daytime recreational fishing during the annual period, March 1999 to February 2000, in Lake Macquarie, New South Wales. NSW Fisheries Final Report. 124pp.

No. 53 Barker, D. and Otway, N., 2003. Environmental assessment of zinc coated wire mesh sea cages in Botany Bay NSW. Final Report to OneSteel Limited. 36pp.

No. 54 Growns, I., Astles, A. and Gehrke, P., 2003. Spatial and temporal variation in composition of riverine fish communities. Final Report to Water Management Fund. Project No. SW1 part 2. 24pp.

No. 55 Gray, C. A., Johnson, D.D., Young, D.J. and Broadhurst, M. K., 2003. Bycatch assessment of the Estuarine Commercial Gill Net Fishery in NSW. Final Report to Fisheries Research and Development Corporation. Project No. 2000/172. 58pp.

No. 56 Worthington, D.G. and Blount, C., 2003. Research to develop and manage the sea urchin fisheries of NSW and eastern Victoria. Final Report to Fisheries Research and Development Corporation. Project No. 1999/128. 182pp.

No. 57 Baumgartner, L.J., 2003. Fish passage through a Deelder lock on the Murrumbidgee River, Australia. NSW Fisheries Final Report. 34pp.

No. 58 Allan, G.L., Booth, M.A., David A.J. Stone, D.A.J. and Anderson, A..J., 2004. Aquaculture Diet Development Subprogram: Ingredient Evaluation. Final Report to Fisheries Research and Development Corporation. Project No. 1996/391. 171pp.

No. 59 Smith, D.M., Allan, G.L. and Booth, M.A., 2004. Aquaculture Diet Development Subprogram: Nutrient Requirements of Aquaculture Species. Final Report to Fisheries Research and Development Corporation. Project No. 1996/392. 220pp.

No. 60 Barlow, C.G., Allan, G.L., Williams, K.C., Rowland, S.J. and Smith, D.M., 2004. Aquaculture Diet Development Subprogram: Diet Validation and Feeding Strategies. Final Report to Fisheries Research and Development Corporation. Project No. 1996/393. 197pp.

No. 61 Heasman, M.H., 2004. Sydney Rock Oyster Hatchery Workshop 8-9 August 2002, Port Stephens, NSW. Final Report to Fisheries Research and Development Corporation. Project No. 2002/206. 115pp.

No. 62 Heasman, M., Chick, R., Savva, N., Worthington, D., Brand, C., Gibson, P. and Diemar, J., 2004. Enhancement of populations of abalone in NSW using hatchery-produced seed. Final Report to Fisheries Research and Development Corporation. Project No. 1998/219. 269pp.

No. 63 Otway, N.M. and Burke, A.L., 2004. Mark-recapture population estimate and movements of Grey Nurse Sharks. Final Report to Environment Australia. Project No. 30786/87. 53pp.

No. 64 Creese, R.G., Davis, A.R. and Glasby, T.M., 2004. Eradicating and preventing the spread of the invasive alga *Caulerpa taxifolia* in NSW. Final Report to the Natural Heritage Trust's Coasts and Clean Seas Introduced Marine Pests Program. Project No. 35593. 110pp.

No. 65 Baumgartner, L.J., 2004. The effects of Balranald Weir on spatial and temporal distributions of lower Murrumbidgee River fish assemblages. Final Report to the Department of Agriculture, Fisheries & Forestry - Australia (National Heritage Trust MD2001 Fishrehab Program). 30pp.

No. 66 Heasman, M., Diggles, B.K., Hurwood, D., Mather, P., Pirozzi, I. and Dworjanyn, S., 2004. Paving the way for continued rapid development of the flat (angasi) oyster (*Ostrea angasi*) farming in New South Wales. Final Report to the Department of Transport & Regional Services. Project No. NT002/0195. 40pp.

ISSN 1449-9967 (NSW Department of Primary Industries - Fisheries Final Report Series)

No. 67 Kroon, F.J., Bruce, A.M., Housefield, G.P. and Creese, R.G., 2004. Coastal floodplain management in eastern Australia: barriers to fish and invertebrate recruitment in acid sulphate soil catchments. Final Report to Fisheries Research and Development Corporation. Project No. 1998/215. 212pp.

No. 68 Walsh, S., Copeland, C. and Westlake, M., 2004. Major fish kills in the northern rivers of NSW in 2001: Causes, Impacts & Responses. NSW Department of Primary Industries - Fisheries Final Report. 55pp.

No. 69 Pease, B.C. (Ed), 2004. Description of the biology and an assessment of the fishery for adult longfinned eels in NSW. Final Report to Fisheries Research and Development Corporation. Project No. 1998/127. 168pp.

No. 70 West, G., Williams, R.J. and Laird, R., 2004. Distribution of estuarine vegetation in the Parramatta River and Sydney Harbour, 2000. Final Report to NSW Maritime and the Australian Maritime Safety Authority. 37pp.

No. 71 Broadhurst, M.K., Macbeth, W.G. and Wooden, M.E.L., 2005. Reducing the discarding of small prawns in NSW's commercial and recreational prawn fisheries. Final Report to the Fisheries Research

& Development Corporation. Project No. 2001/031. NSW Department of Primary Industries - Fisheries Final Report Series No. 71. 202pp.

No. 72. Graham, K.J., Lowry, M.B. and Walford, T.R., 2005. Carp in NSW: Assessment of distribution, fishery and fishing methods. NSW Department of Primary Industries - Fisheries Final Report Series No. 72. 88pp.

No. 73 Stewart, J., Hughes, J.M., Gray, C.A. and Walsh, C., 2005. Life history, reproductive biology, habitat use and fishery status of eastern sea garfish (*Hyporhamphus australis*) and river garfish (*H. regularis ardelio*) in NSW waters. Final report on the Fisheries Research & Development Corporation Project No. 2001/027. 180pp.

No. 74 Growns, I. and Gehrke, P., 2005. Integrated Monitoring of Environmental Flows: Assessment of predictive modelling for river flows and fish. NSW Department of Primary Industries - Fisheries Final Report Series No. 74. 33pp.

No. 75 Gilligan, D., 2005. Fish communities of the Murrumbidgee catchment: Status and trends. Final report to the Murrumbidgee Catchment Management Authority. Project No. BG4_03. 138pp.

No. 76 Ferrell, D.J., 2005. Biological information for appropriate management of endemic fish species at Lord Howe Island. NSW Department of Primary Industries - Fisheries Final Report Series No. 76. 18 pp.

No. 77 Gilligan, D., Gehrke, P. and Schiller, C., 2005. Testing methods and ecological consequences of large-scale removal of common carp. Final report to the Water Management Fund - Programs MFW6 and MUR5. 46pp.

No. 78 Boys, C.A., Esslemont, G.and Thoms, M.C., 2005. Fish habitat and protection in the Barwon-Darling and Paroo Rivers. Final report to the Department of Agriculture, Fisheries and Forestry – Australia (AFFA). 118pp.

No. 79 Steffe, A.S., Murphy, J.J., Chapman, D.J. and Gray, C.C., 2005. An assessment of changes in the daytime recreational fishery of Lake Macquarie following the establishment of a ‘Recreational Fishing Haven’. NSW Department of Primary Industries - Fisheries Final Report Series No. 79. 103pp.

No. 80 Gannassin, C. and Gibbs, P., 2005. Broad-Scale Interactions Between Fishing and Mammals, Reptiles and Birds in NSW Marine Waters. Final Report for a project undertaken for the NSW Biodiversity Strategy. 171pp.

No. 81 Steffe, A.S., Murphy, J.J., Chapman, D.J., Barrett, G.P. and Gray, C.A., 2005. An assessment of changes in the daytime, boat-based, recreational fishery of the Tuross Lake estuary following the establishment of a 'Recreational Fishing Haven'. NSW Department of Primary Industries - Fisheries Final Report Series No. 81. 70pp.

No. 82 Silberschnieder, V. and Gray, C.A., 2005. Arresting the decline of the commercial and recreational fisheries for mulloway (*Argyrosomus japonicus*). Final report on the Fisheries Research & Development Corporation Project No. 2001/027. 72pp.