Assessment of length and age composition of commercial kingfish landings

J. Stewart, D. J. Ferrell, B. van der Walt, D. Johnson, M. Lowry

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FRDC Project No. 97/126
December, 2001

NSW Fisheries Final Report Series
No. 36
ISSN 1440-3544

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ACKNOWLEDGEMENTS

This study was made possible due to the assistance of many people. In particular we would like to thank Michael Middleton, Glenn Cuthbert, Darrin Nobbs and Dean Hiscox for measuring kingfish and collecting otoliths for us.

We thank all those commercial fishers who co-operated in the project by providing us with trips to sea and by keeping log-books. In particular we thank Graham Bates, Tony Campisi, Greg Cliff, John Harrington, Bill and Chris Innes, Allan Knight, Bill Robins, George Thornton and Darcy Wright.

Thanks to the following for providing us with kingfish frames: Nippon Seafood, Campsie Fish market, Jolly Roger Seafood, Claudio's Quality seafood, Musumeci Seafoods, Decosti Seafood, Peters Fish Market, Pinetrees Lord Howe Island, and Bianca Fishing Charters. Tim Dempster provided specimens of very small kingfish.

The lengths of kingfish between 1985 and 1989 were collected by Col Moore during the market measurement program and were supplied by Dr Kevin Rowling.

Andrew Penney (Pisces Consulting, South Africa) and Dr Bronwyn Gillanders provided useful discussions concerning ageing techniques for kingfish.

Carolyn Bland and Kathy Bown from the library at the Cronulla Fisheries Centre assisted with finding reference material for the project. Dr Duncan Worthington provided assistance with MATLAB analyses of growth estimation. John Matthews assisted in the cover design.

We thank Dr's Kevin Rowling, Kimberly Smith and Steve Kennelly for useful comments on drafts of this report.

The research presented in this report was funded by the Fisheries Research and Development Corporation (Project 98/138) and NSW Fisheries.

NON-TECHNICAL SUMMARY

97/126 Assessment of length and age composition of commercial kingfish landings

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OBJECTIVES:

1) To accurately document the size and age composition of kingfish landed by commercial fishers in NSW.

2) To refine existing estimates of kingfish growth with new information on size at age, with a focus on large fish.

3) To examine the suitability of the current minimum legal length with yield models, utilizing the improved information on kingfish growth and information on kingfish size and age composition.

4) To examine the possibility of using age-structured modelling in future assessments of yellowtail kingfish.

NON TECHNICAL SUMMARY:

Outcomes achieved

This study has provided fishery managers, scientists, commercial and recreational fishers with information on the biology and fishery for kingfish off New South Wales. This information should form the basis for discussions on the appropriateness of the minimum legal length for kingfish, and any impacts that changes may have on the fishery and the kingfish stock. Future monitoring of the kingfish fishery will be based on the information provided in this report.

Yellowtail kingfish are one of the most popular commercially and recreationally targeted fish in NSW. A lack of information on the recreational catch has meant that the only information available to assess the status of the kingfish stock has come from commercial landings. Since the 1980's, landings of kingfish by commercial fishers have declined from around 600 tonnes to less than 100 tonnes. During this time there have been 2 controversial management changes: (i) the introduction of a minimum legal length of 60 cm total length, and; (ii) the banning of pelagic kingfish traps. The debate about the appropriateness of these management measures has been ongoing, but has been limited by a lack of understanding of the status of the fishery and the composition of commercial landings. The research described in this report assists this debate by detailing the sizes and ages of kingfish in commercial landings, refining estimates of growth rates, estimating mortality rates, modeling the yield per recruit for a range of mortality rates and minimum legal lengths and discussing future monitoring of the kingfish fishery in NSW.

The sizes of kingfish landed by commercial fishers in NSW were documented between 1998 and 2000. Forty seven tonnes of kingfish, representing 16% of total landings, were measured during the study. The results showed that the fishery was dominated by fish smaller than 65 cm fork length. The sizes of kingfish larger than the current minimum legal length which are available to the fishery do not appear to have changed since the late 1980's. Estimates of kingfish ages were made by counting annual marks in otoliths. Estimated ages ranged up to 21 years, however the fishery was dominated by 2 and 3 year old fish e.g. in 1999/00 78% of the fishery consisted of 2 and 3 year old fish.

Refined estimates of the growth rates of kingfish were made using sections of otoliths. The results showed that previous studies, which estimated kingfish ages using whole otoliths, may have under-estimated the age of older kingfish. There were no differences in the growth rates of kingfish along the NSW coast, from Lord Howe Island, or between males and females. The results showed that kingfish grow rapidly and reach their minimum legal length of 60 cm total length at around 2 years of age.

Estimates of total mortality rates suggested that a large proportion (between 35% and 55%) of kingfish die each year. Fishing mortality (which included both commercial and recreational components) was relatively high and may account for up to 80% of the total mortality. These estimates of mortality rates were combined with the refined estimates of growth rates to calculate yield per recruit models. The models showed, for the plausible ranges of mortality rates, that kingfish are currently "growth overfished". In other words, kingfish are, on average, caught at sizes smaller than that which would provide the optimal biological yield. The models estimated that removing the minimum legal length on kingfish may reduce the yield per recruit by around 30%. This reduction in yield per recruit, together with the potential for increases in effort and an over-supply of small kingfish to markets, indicates that the minimum legal length for kingfish should not be removed. Increasing the minimum legal length to the size at sexual maturity (approximately 80 cm total length) may increase the yield per recruit, but would not be appropriate in this fishery because of limited availability of these larger fish. The introduction of a maximum legal length may help to protect the spawning population of kingfish while having minimal impact on the commercial fishery.

It is considered that age-based assessments to model annual recruitment of kingfish are inappropriate. The fishery is based on a couple of early year classes and estimating ages is both expensive and uncertain. It is suggested that the fishery for kingfish in NSW be monitored through a combination of assessing the annual reported landings and a daily fisher logbook. The mean size of kingfish landed on any fisher day was accurately reported by fishers recording their daily catch and the numbers of retained and discarded kingfish. Logbooks may provide a cost-effective method for assessing (i) recruitment in terms of the abundance of undersized kingfish, and (ii) any changes in the mean sizes of kingfish landed.

1. INTRODUCTION

1.1. Background

The yellowtail kingfish (*Seriola lalandi*) is one of the more valuable commercial species in New South Wales (NSW), commanding high market prices (up to $15 per kg) because it is one of the preferred species used in preparation of 'sashimi' dishes. Prior to the mid 1980's, commercial landings of kingfish in NSW ranged between approximately 200 to 300 tonnes (t) per annum. The development of fishing using pelagic traps in the 1980's resulted in significant increases in annual landings of kingfish to around 500 to 600 t. In recent years, in response to concerns about a possible decline in the kingfish resource and the effect of different methods of capture, a minimum legal length (MLL) of 60 cm total length (TL) has been imposed for yellowtail kingfish in NSW, and the use of pelagic traps was prohibited from March, 1996. The imposition of these management measures has been controversial, and debate about their appropriateness continues in the absence of an understanding of the status of the fishery. A description of the size and age composition of commercial landings, together with estimates of growth rates, will assist fishery managers to assess the impact that any management changes may have on landings and the kingfish stock.

During the FRDC Project 94/053 (Steffe et al. 1996), estimates were made of the size distribution of kingfish caught by recreational trailerboat fishers, as well as estimates of their total harvest. The National angling survey currently being done, as well as work by NSW Fisheries and charter boat operators, will result in better information on this important harvest sector. Measurements of kingfish sold in the Sydney Fish Markets from 1985 to 1989 provide some insight about the size composition of commercial landings prior to the introduction of the MLL. Prior to the present study there was no similar information from commercial landings for the period since the introduction of the MLL in 1990.

The recent catch and management history of kingfish suggests an examination of yield will be important to any discussions on whether the current MLL is appropriate. Market measurement data suggests that as much as 40% of the weight of commercial landings from 1985 to 1989 was comprised of fish which were smaller than the 60 cm TL MLL imposed in 1990. However, the introduction of the MLL was not associated with a dramatic downturn in landings. One possible reason that the effect on landings was not as large as might have been expected could be that the growth rate of small kingfish is sufficiently rapid to compensate for the MLL. This suggestion is supported by the estimates of growth provided by Gillanders et al. (1997) and by the movement in the average peak month of capture from November before the introduction of the MLL, to a peak in January after this occurred (NSW Fisheries Commercial Catch Statistics).

The discussion of management options within the kingfish catching sector continues, including a call for the use of a maximum legal size in addition to, or replacing, the MLL. Discussion between industry and management is severely restricted by the current lack of understanding of catch composition.

The size distributions of kingfish measured at the Sydney Fish Markets between 1985 and 1989 supports the anecdotal evidence of commercial and recreational fishers that the average size of kingfish caught during the peak season around December is very close to the current MLL of 60 cm TL. This is seen as awkward and potentially damaging because a large proportion of all kingfish caught are undersized and must be released. Mortality of discarded kingfish is unknown.

1.2. Need

Following a decision in 1990 to impose a minimum legal length of 60 cm TL on kingfish, and the banning of pelagic traps in 1996, there has been considerable controversy concerning the appropriateness of the current management measures. Gillanders et al. (1999) demonstrated that the current MLL is about 15 cm below the length at which 50% of female kingfish are sexually mature. However, the absence of adequate size and age composition data for commercial landings means it is not possible to determine the impact on landings of possible changes in MLL. Yield modelling, combined with information on composition of landings, is an appropriate and important first stage in examining the suitability of MLL settings.

The nature of the commercial fishery for kingfish presents significant difficulties for the design of unbiased and cost effective sampling of landings. Kingfish are caught in significant quantities in small, localised fishing operations, mainly south of 30°S latitude. There appears to be considerable annual and seasonal variation in the catches by the various sectors, however it is known that when large densities of kingfish are located, very high catches can be taken during short time periods. The dispersed, yet intense, nature of the fishery has great potential to cause bias in collections aimed at estimating the length and age compositions of the total catch of kingfish. A major aim of this study is to develop cost effective sampling strategies which will minimize bias in ongoing monitoring of kingfish by New South Wales Fisheries.

1.3. Objectives

1) To accurately document the size and age composition of kingfish landed by commercial fishers in NSW.

2) To refine existing estimates of kingfish growth with new information on size at age, with a focus on large fish.

3) To examine the suitability of the current minimum legal length with yield models, utilizing the improved information on kingfish growth and information on kingfish size and age composition.

4) To examine the possibility of using age-structured modelling in future assessments of yellowtail kingfish.

1.4. Achievement of objectives

Objective 1. Development of a stratified sampling protocol enabled us to document the sizes and ages of kingfish landed by commercial fishers in NSW between 1998 and August 2000. Lengths of kingfish were measured at the Sydney Fish Markets and at the point of landing at various ports. This sampling strategy enabled us to document the sizes of kingfish landed in each of three regions: (i) Northern region – NSW/Queensland border to Nelson Bay; (ii) Central region – Newcastle to Wollongong, and; (iii) Southern region – Wollongong to NSW/Victoria border, for each yearly quarter of the study. The results showed that the compositions of landings varied between regions and periods sampled, but overall the fishery was dominated by fish smaller than 65 cm fork length. The sizes of fish greater than the current MLL available to the fishery do not appear to have changed since the late 1980's.

Estimates of the age compositions of commercial landings were made using estimates of age made from sectioned otoliths and the size compositions of landings. Estimates of ages in commercial landings ranged from 1 up to 19 years, however the fishery was dominated by 2 and 3 year old fish. In 1999/00, 78% of the fishery consisted of 2 and 3 year old fish.

Objective 2. Estimates of the growth rates of kingfish were made using size at age data, with ages estimated from sectioned otoliths. Kingfish smaller and larger than those commonly landed by commercial fishers were obtained from recreational fishers, charter boat fishers and from Lord Howe Island. The results suggested that previous studies using whole otoliths may have under-estimated the age of older kingfish. Kingfish reached an average size of around 50 cm fork length after 1 year and around 72 cm fork length after 5 years. The maximum age recorded was 21 years. We found no differences in the growth rates of kingfish along the NSW coast, off Lord Howe Island, or between males and females.

Objective 3. Improved estimates of growth were combined with estimates of mortality rates in yield per recruit calculations. Total mortality rates were estimated from catch curves for the years 1985 to 1989 and for 1998 to 2000. Natural mortality rates were estimated using several fishery independent techniques and an estimate of fishing mortality was made by subtracting natural mortality from total mortality. Our best estimates of mortality rates were a natural mortality rate of $M = 0.12$ and a fishing mortality rate of between $F = 0.31$ and 0.67. These mortality rates result in total mortality rates of between 0.43 and 0.79, suggesting that a large proportion of kingfish (between 35% and 55%) die each year.

Estimates of yield per recruit showed that the kingfish stock can be considered to be growth overfished. Removing the minimum legal length on kingfish would reduce the yield per recruit by around one third and may increase fishing effort and mortality. Setting the minimum legal limit at the estimated size at sexual maturity (approximately 70 cm FL) may significantly increase the yield per recruit. The availability of larger kingfish to the fishery is unknown and setting a size limit based on sexual maturity may not be appropriate for the fishery, as up to 90% of the commercial fishery were observed to be smaller than this size during the study. The yield per recruit calculations suggest that if the minimum legal length is to be changed in order to reduce the bycatch of small kingfish, that it should be increased.

Objective 4. Age-structured modelling was considered inappropriate for future assessments of the kingfish fishery. The high costs involved in using sectioned otoliths to estimate age, together with the uncertainties and errors associated with ageing kingfish, suggest that age-based models may be of little use for a fishery based on a couple of early year classes. Future monitoring involving catch data and size-based assessments can identify changes in yearly recruitment strength and any targetting of larger/older fish. Fisher logbooks may be the most cost-effective way to monitor recruitment in terms of the abundance of undersized kingfish and any changes in the mean size of fish landed. Trials of fisher logbooks recording daily catch and the numbers of retained and discarded kingfish produced similar estimates of the mean sizes of fish landed to those from the dedicated fishery sampling.

2. LENGTH AND AGE COMPOSITIONS OF COMMERCIAL LANDINGS OF YELLOWTAIL KINGFISH IN NSW

This chapter addresses objective 1 of the study.

Objective 1. To accurately document the size and age composition of kingfish landed by commercial fishers in NSW.

A stratified sampling protocol resulted in spatial and temporal descriptions of the sizes and ages of kingfish in commercial landings. The compositions of landings varied between regions and periods sampled, but overall the fishery was dominated by fish smaller than 65 cm fork length and consisted mostly of 2 and 3 year old fish. The size composition of fish greater than the minimum legal length does not appear to have changed since the late 1980's.

2.1. Introduction

Information on the sizes and ages of yellowtail kingfish landed by commercial fishers in NSW will form the basis for assessments of the status of this fishery. Until now, assessments of the status of the fishery have been limited to catch and effort data, which may have been unreliable and influenced by management changes. There have been 3 different recording systems for catch and effort data during the previous 10 years, in addition to two major changes in the management of kingfish fishing (an imposition of a 60 cm total length size limit and the banning of pelagic kingfish traps). These factors make interpretation of catch and effort statistics difficult.

Kingfish are acknowledged as being a highly mobile and wide ranging species. Results from the NSW Gamefish Tagging Programme, which has operated since 1973, suggests that kingfish in the NSW fishery are well mixed and should be treated as a single unit (Smith et al., 1991; Gillanders et al., 2001). Recaptured tagged kingfish have shown movements from NSW to New Zealand and from New Zealand to NSW. Large-scale movements (>500km) along the NSW coast have also occurred. The majority of recaptured kingfish, however, were recaptured within 50 km of where they were tagged and small fish showed less movement than large fish. The potential for kingfish to be wide ranging along the NSW coast suggests that the fishery for them would exploit similar sized and aged fish at all locations. Unfortunately, we have little direct information on the size or age structure of the kingfish population along the NSW coast, or on the size and age composition of landings.

Measurements of the sizes of kingfish sold at the Sydney Fish markets were made on an *ad hoc* basis between 1985 and 1989, prior to the introduction of a size limit of 60 cm total length in February 1990. While many of these measurements probably came from kingfish caught in kingfish traps, they at least represent some historical landings data with which to compare the sizes measured during the present study. These measurements were used by Gillanders et al. (1999a) to follow cohorts through time to provide an estimate of growth rate.

Approximately 99% of kingfish currently landed in NSW are caught using hook and line methods. Since 1998' approximately 65% of commercial landings have been from handlining, 22% from droplining and 12% from trolling. While many fishers land kingfish (194 fishers during 2000), there are relatively few who can be considered as dedicated kingfish fishers. Thirty five fishers took 90% of the catch during 2000, 39 fishers during 1999 and 50 fishers during 1998. This is in contrast to more than 100 fishers taking 90% of the catch during the early 1990's. Identifying these relatively few dedicated kingfish fishers enabled targeted sampling to be more efficient and made monitoring of the fishery easier.

Since kingfish traps were banned in April 1996, the fishery has tended to be sporadic at any one location. When large schools of kingfish are detected off any particular location, many fishers will redirect their effort from other fisheries (such as trapping, droplining, estuarine netting etc.) to target kingfish until they are no longer available in large numbers. This behaviour makes sampling of landings difficult to plan. In addition, sampling based only at the major market in NSW, the Sydney Fish Market, would certainly produce biased estimates of the sizes of kingfish landed from some locations. It is known that some of the largest catchers of kingfish send small fish to local markets and the Melbourne Fish Market and the remainder to the Sydney Fish Markets. The only way to gain accurate estimates of the sizes of fish from these locations was therefore to sample catches at the point of landing.

Comprehensive studies have been done to assess methods by which to estimate age in kingfish in NSW (Gillanders et al., 1996; 1999a). These studies concluded that while all calcified structures contained growth zones, kingfish were extremely difficult to age accurately. Otoliths and vertebrae were considered to produce the most reliable age estimates. Gillanders et al. (1999a) used whole otoliths to estimate age, however it is widely acknowledged that whole otoliths may under-estimate the true age of old fish (Beamish, 1979). A major goal of the present study was to estimate the age of larger and older fish than were sampled by Gillanders et al. (1999a). There have been few validation studies done for any *Seriola spp*. and those that have been done have been based on marginal increment analyses. Gillanders et al. (1999a) used marginal increment analysis for whole otoliths and concluded that one growth zone was deposited per year during August and September. Their data showed considerable individual variation in the timing of the appearance of growth zones on the otolith edge. The use of otolith sections for estimating age in kingfish is yet to be properly validated.

2.2. Materials and methods

To examine spatial differences in the compositions of landings we divided the NSW coast into 3 regions: (i) Northern region – NSW/Queensland border to Nelson Bay; (ii) Central region – Newcastle to Wollongong, and; (iii) Southern region – south of Wollongong to the NSW/Victoria border.

2.2.1 Size composition of landed catch

A sampling protocol to gain unbiased samples of the size compositions of kingfish in commercial landings was developed after consultation with commercial fishers and markets. The dynamics of the marketing side of the fishery revealed that there was a need to sample kingfish at the point of landing at some locations. This was because when prices at the Sydney Fish Markets were low, kingfish from these locations were sent to either Melbourne or to local markets. Fishers often sent boxes of kingfish graded by size to these markets and consequently measuring the remaining fish sent to the Sydney Fish Market would have produced biased estimates of the sizes of fish landed at these locations. To overcome this, casual staff were employed at Narooma, Port Macquarie, Coffs Harbour, Crowdy Head and Wallis Lake to measure kingfish as they were landed. NSW Fisheries' staff measured kingfish from other locations at the Sydney Fish Markets. The sporadic nature of the fishery meant that the numbers of days sampled varied among locations. The sampling protocol was to measure all fish landed from the given location on any day sampled. Fish were measured as fork length (FL) to the nearest whole centimeter (cm) below the true length.

Sampling was done between January 1998 and August 2000. To examine spatial and temporal patterns in size compositions of landings, the data were grouped by region (north, central, south) and by yearly quarter (Jan-Mar, Apr-Jun, Jul-Sep, Oct-Dec) for 1998, 1999 and until August 2000.

Yearly estimates of the sizes of kingfish landed in the fishery were made by calculating the relative contribution of landings in each region and quarter to the overall statewide landings for each financial year (using NSW Fisheries reported landings). The measured size frequencies for each region and quarter were then weighted accordingly.

Historical data for kingfish measured at the Sydney Fish Markets were analysed for comparison with the sizes documented during the present study. Kingfish were measured on an *ad hoc* basis between 1985 and 1990, prior to the introduction of a minimum legal size limit of 60 cm total length. Much of this historical data did not include information on the method used (much was likely caught using kingfish traps which have been banned since 1996) or on sub-sampling of catches or on the potential for representative samples to have been sent to the markets. A total of 16,141 kingfish were measured between 1985 and 1989, however only 7,403 were greater than the present minimum legal length of 60 cm total length (approximately 52.4 cm FL). Only those fish greater or equal to 52 cm FL were used in the analysis. We calculated the percent frequency of each 1 cm size class of fish for the years sampled using equal weighting for each year.

2.2.2 Collection of ageing material

It was not possible to collect ageing material (otoliths) from kingfish at the Sydney Fish Markets as has been done previously for many other species in NSW (Gray et al., 2000). Kingfish are generally sold whole to sashimi markets and to restaurants, and the high prices they bring (commonly up to $15/kg) precluded us from purchasing fish, mutilating them while removing otoliths and reselling them. We initially intended to gather kingfish frames from wholesale outlets by tagging fish of known origin at the Sydney Fish Markets prior to being sold. The tags were highly visible and contained summary information about the project and contact phone numbers. The programme was advertised personally and with posters to major kingfish buyers and through the Master Fish Merchants Association. Most of the kingfish tagged were large fish which were relatively uncommon at the Sydney Fish Markets. The programme continued through winter and spring 1998 and, despite intensive tagging effort, only 13 fish out of a total of 207 (6.3%) large tagged kingfish were returned. The programme was therefore terminated in November 1998. The low level of response could be attributed to the lack of translation for non-English speaking buyers and the reluctance of wholesalers to re-sell kingfish to restaurants which had tags on them.

Most material for ageing was sourced from retail shops that were willing to provide us with kingfish frames once they had filleted the fish. Wherever information was available on when and where the kingfish were caught we were able to use them for estimates of growth from each of the regions studied. When information on the location of capture was unavailable, but we knew it was somewhere within NSW, we were able to use these age estimates in our overall growth curve (chapter 3) and in calculating the age composition of catches along the NSW coast.

Otoliths from very large kingfish were also sourced from Lord Howe Island (31.5° S, 159.1° E), charter boat operators and recreational fishers. Fish smaller than those observed in commercial catches were collected by fisheries observers with permits to collect undersized kingfish whilst onboard commercial vessels. Age estimates from these very small and large kingfish were used in estimating growth rates.

Otoliths were removed by cutting away the top of the head at a level just above the eyes. The otoliths were removed using forceps and were cleaned and stored in small envelopes containing information on the sample. Whenever possible the sex of the fish was determined from a macroscopic examination of the gonads. Otolith weight has been related to age in other fast growing pelagic fish, and to examine this relationship for kingfish, we weighed all otoliths to the nearest 0.001g.

2.2.3 Determination of age

Gillanders *et al*., (1999a) found that whole otoliths were better for ageing kingfish than sectioned otoliths, and that in the latter it was difficult to discern any growth zones, especially in small fish. We believe that this was because the first growth increment of the otoliths in kingfish is difficult to establish and can be easily missed during the sectioning process. We also believe that sectioned otoliths may be more reliable than whole otoliths when estimating ages of large/older fish - which was a major objective of the present study. Initial trials were done to enhance the legibility of otolith sections using chemical stains and various planes (longitudinal, oblique and transverse), however we concluded that normal transverse sections provided the most legible samples when sectioned through the core of the otolith.

One sagittal otolith from each fish was embedded in clear resin and sectioned (approximately 0.25-0.30 mm) in a transverse plane using a low speed saw fitted with a single diamond blade. In order to ensure that we gained sections through the core of the otolith we took 3 consecutive sections through each otolith. Sections were polished on both sides using 9 μm lapping film and mounted on a standard glass slide under a coverslip. Otoliths were read (by D. J.) using a binocular microscope using reflected light against a black background. Estimates of ages were made by counting opaque bands, typically along the sulcal edge of the otolith.

To gain an estimate of the repeatability of our age estimates, 200 otoliths were read by different researchers (D. J. and B. vdW) and their estimates of ages compared. Percent agreement is often used as an index of precision, however this does not evaluate the degree of precision equally for all species (Beamish & Fournier, 1981). An index of precision which is dependent on age allows comparisons between species, and a coefficient of variation (cv) is often used to achieve this (Kimura & Lyons, 1991). We determined the cv for the two readings for each otolith and obtained an average across all otoliths after the method described in Kimura & Lyons (1991):

$$cv = \text{standard deviation}/\text{mean}$$

2.2.4 Age composition of landed catch

The age composition of the landed commercial catch of kingfish in each financial year was estimated using the weighted size composition for that financial year, and the estimates of size at age from kingfish sampled from commercial landings during that year. We estimated ages for 189 kingfish from the northern region, 241 from the central region, 318 from the southern region and 337 that were from unknown locations. Analyses of growth rates showed no differences in the growth of kingfish from these regions (see chapter 3) and we pooled estimates of age from each region to draw from when calculating the age compositions of landings for each financial year. We estimated ages for 68 kingfish during 1997/98, 509 kingfish during 1998/99 and 508 kingfish during 1999/00.

So that the size frequency distribution of fish used for estimating ages was the same as the size frequency distribution of landings during each year of the study, fish for ageing were drawn from each 5 cm size class in the same proportion as that size class occurred in the overall yearly size composition. Ages were drawn at random and without replacement from each size class. When there were insufficient ages in some of the larger size classes, ages were drawn randomly and alternatively from the size classes immediately above and below. The numbers of ages to be used each year were chosen to ensure that this rarely occurred.

To examine changes in the age composition of the landed catch, we used an age-length key (Kimura, 1977; Lai, 1993) using all of the ages determined during the present study. This age-length key was applied to the size composition for kingfish landed between 1985 and 1989 which were above the current minimum legal length (52 cm FL) and to the size composition of kingfish measured during the present study.

2.3. Results

2.3.1 Size composition of commercial landings

During this study we measured more than 47 tonnes of kingfish, which represented more than 16% of the total landed catch. The total reported landings of kingfish, the amount of landings measured and the sampling fractions from each region and yearly quarter sampled are given in Table 2.1. Sampling fractions varied from 0.17% of the landed catch up to 49.3% of the landed catch. Total landings were reported to be 44.9 tonnes during the 1st half of 1998, 86.8 tonnes in 1998/99 and 130.8 tonnes in 1999/00.

A total of 12,679 kingfish were measured from commercial landings during the study (Figs. 2.1, 2.2 & 2.3). Low catches and relatively small sampling fractions in some periods resulted in low numbers of kingfish being measured in some instances, particularly during 1998. These figures show that there was considerable spatial and temporal variation in the size composition of catches. Small fish tended to make up a large proportion of the catch in some sampling periods, however at other times they were either absent or the distribution contained several modes of size classes of fish.

Table 2.1. Reported landings (tonnes), measured length frequency sample (L/F - tonnes) and sampling percentage of kingfish from each region and period during the study.

Year/quarter	Northern region			Central region			Southern region			Total		
	catch (t)	L/F (t)	%	catch (t)	L/F (t)	%	catch (t)	L/F (t)	%	catch (t)	L/F (t)	%
1998/1st	4.1	0.02	0.49	6.80	0.12	1.76	14.70	0.52	3.54	25.60	0.65	2.54
1998/2nd	7.2	0.55	7.64	4.40	0.40	9.09	7.70	0.99	12.86	19.30	1.95	10.10
1998/3rd	5.2	0.17	3.27	6.00	1.62	27.00	9.60	1.69	17.60	20.80	3.48	16.73
1998/4th	4.3	0.30	6.98	5.50	1.97	35.82	16.50	3.43	20.79	26.30	5.69	21.63
1999/1st	4.4	1.06	24.09	2.50	0.80	32.00	13.70	6.55	47.81	20.60	8.41	40.83
1999/2nd	5.3	0.54	10.19	3.20	1.58	49.38	10.60	4.12	38.87	19.10	6.24	32.67
Total 1998/99	19.2	2.07	10.78	17.20	5.97	34.71	50.40	15.79	31.33	86.80	23.8	27.42
1999/3rd	3.3	0.13	3.94	4.00	1.01	25.25	13.20	2.82	21.36	20.50	3.95	19.27
1999/4th	3.4	0.18	5.29	2.00	0.52	26.00	29.30	3.32	11.33	34.70	4.02	11.59
2000/1st	2.7	0.44	16.30	3.60	1.31	36.39	31.20	4.27	13.69	37.50	6.02	16.05
2000/2nd	17.1	3.10	18.13	4.30	0.51	11.86	16.70	2.52	15.09	38.10	6.12	16.06
Total 1999/00	26.5	3.85	14.53	13.90	3.35	24.10	90.40	12.93	14.30	130.8	20.1	15.37
2000/3rd	5.90	0.01	0.17	1.50	0.21	14.00	12.50	0.55	4.40	19.90	0.77	3.87
Total study	**62.90**	**6.50**	**10.33**	**43.80**	**10.05**	**22.95**	**175.7**	**30.78**	**17.52**	**282.4**	**47.3**	**16.75**

The distribution of landings for each region and quarter sampled were calculated from the NSW Fisheries catch return database (Table 2.2). The relative contributions of landings from each region and yearly quarter sampled (Table 2.2) were used to determine the weighting from the lengths measured in Figs. 2.1, 2.2 and 2.3 to calculate the overall size distributions of kingfish landed in each region and for the entire state (Figs. 2.4 & 2.5). The weighted size frequency distributions for each of the financial years studied (Fig. 2.5) show that landings during 1998/99 contained a larger proportion of large (> 70 cm FL) kingfish. Very large (> 100 cm FL) kingfish were uncommon in the fishery during 1999/00.

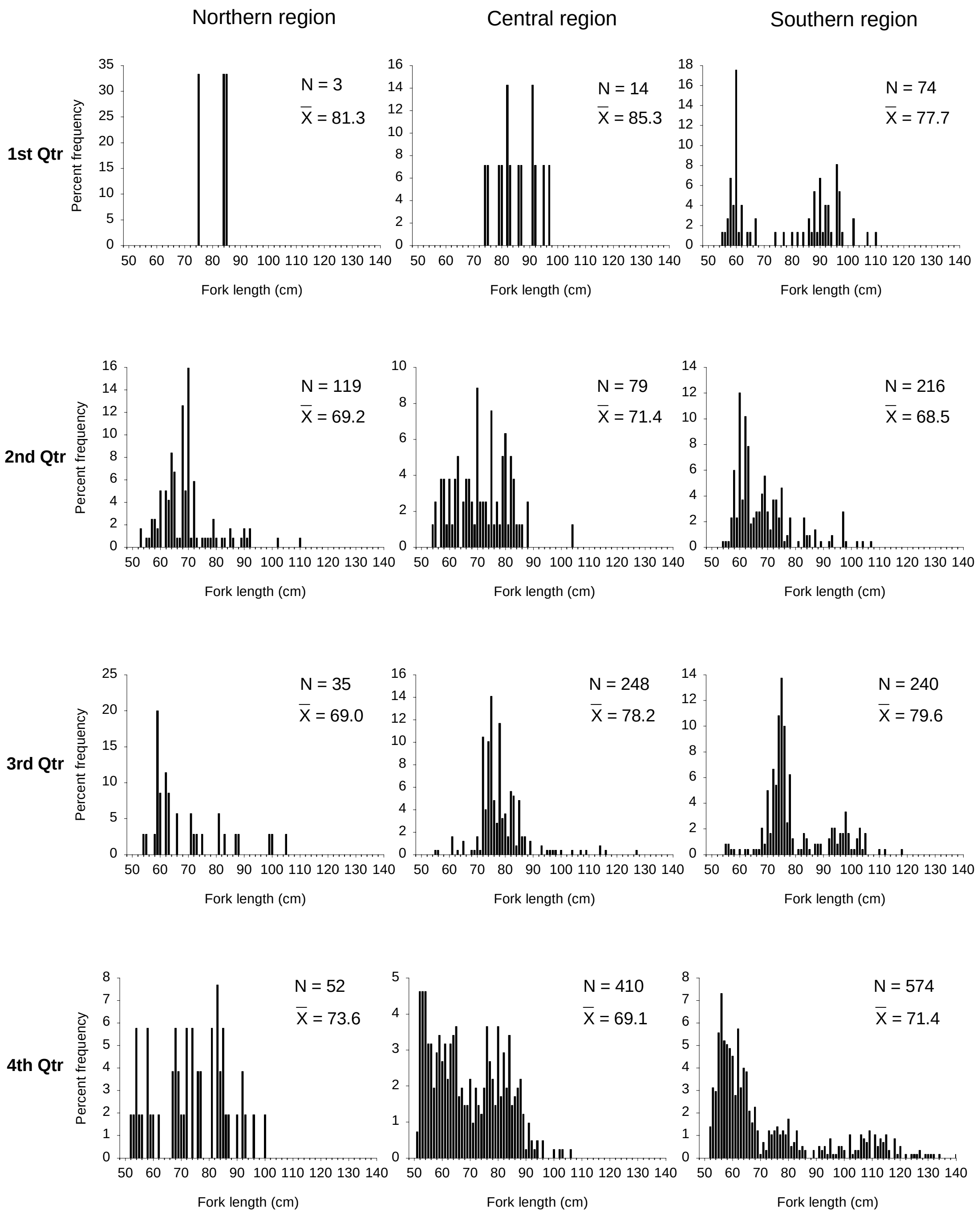


Figure 2.1. The size compositions of the commercial landings of kingfish from each region and calendar quarter sampled during 1998.

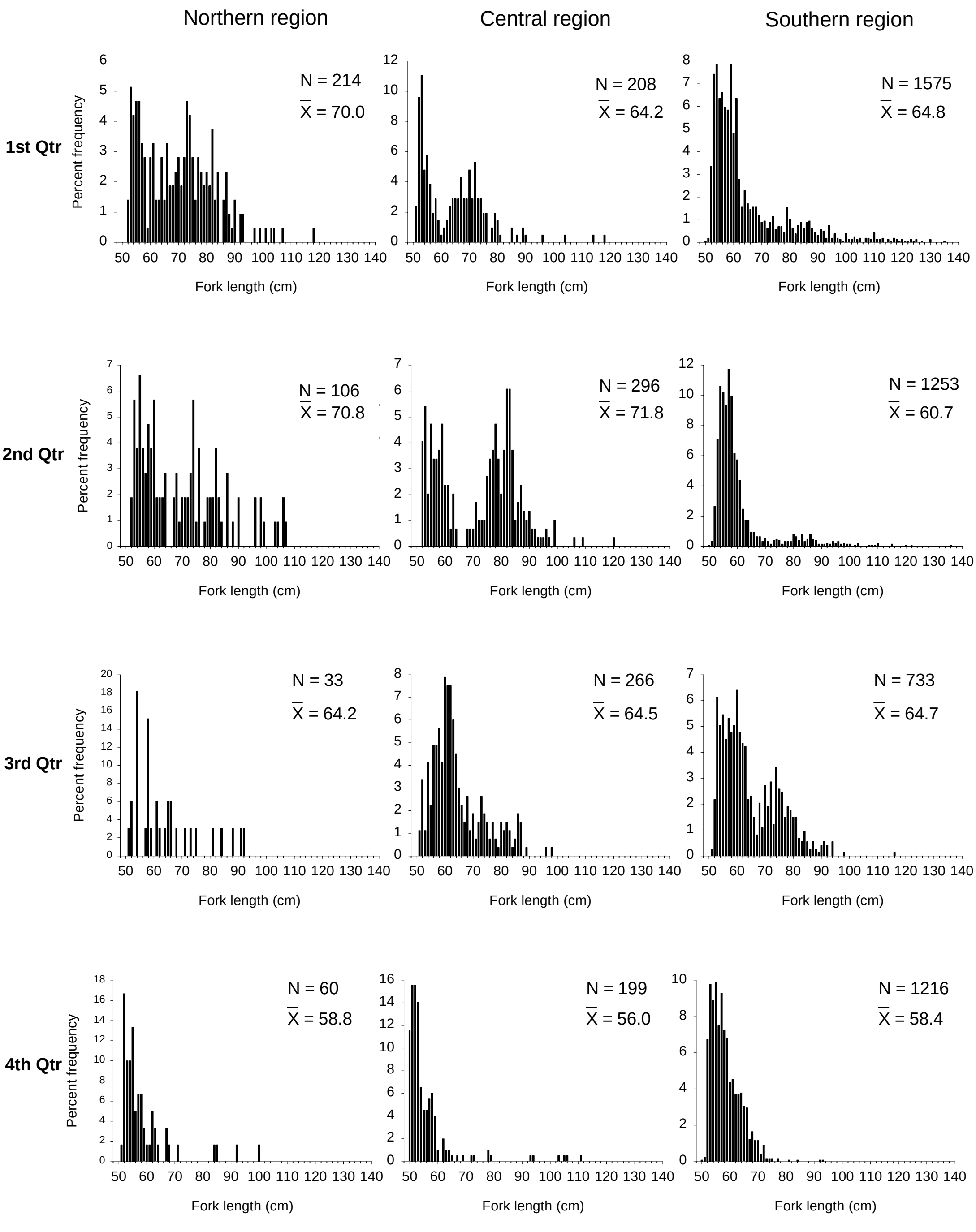


Figure 2.2. The size compositions of the commercial landings of kingfish from each region and calendar quarter sampled during 1999.

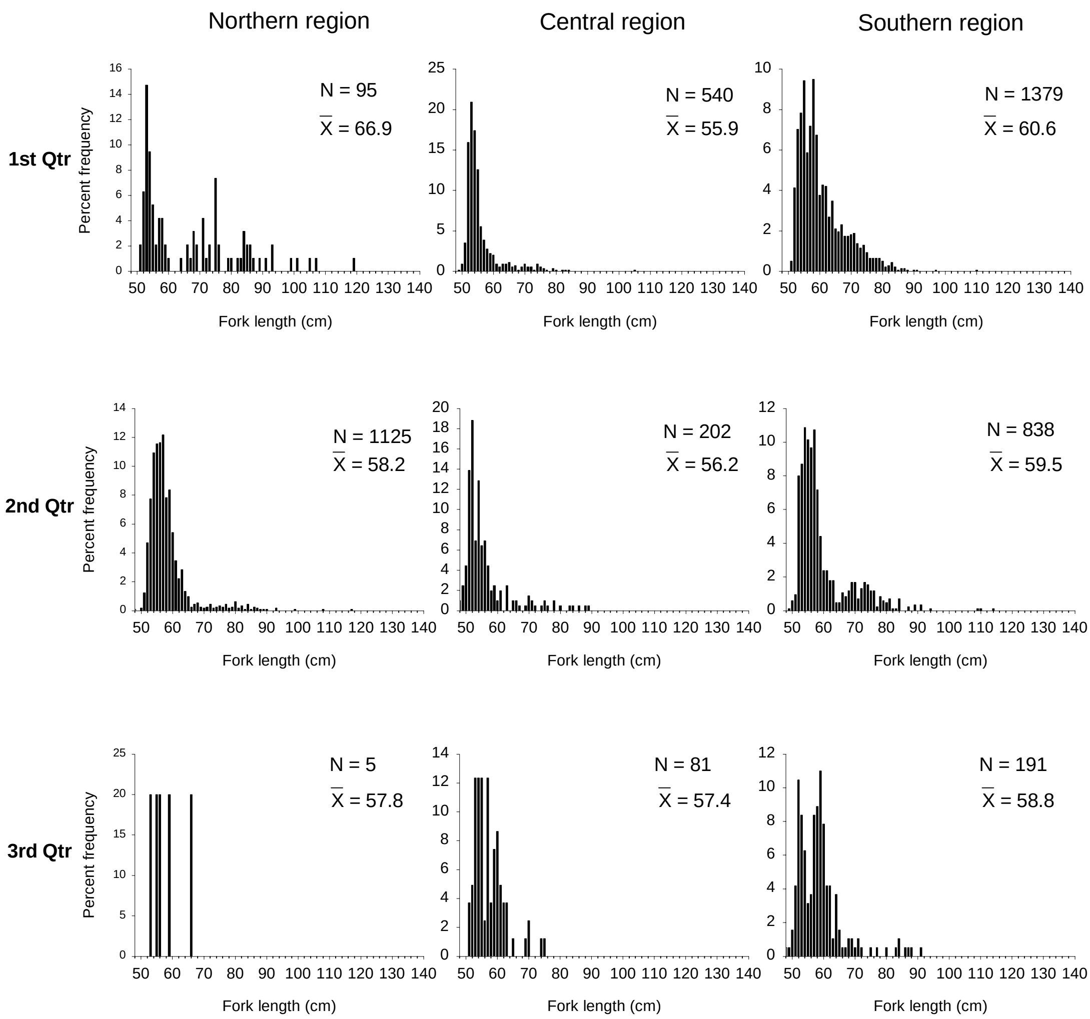


Figure 2.3. The size compositions of the commercial landings of kingfish from each region and calendar quarter sampled during 2000.

Table 2.2. The distribution of kingfish landings by year and region during the study (source: NSW Fisheries catch return data).

Year/quarter	Northern region % yearly landings	Central region % yearly landings	Southern region % yearly landings	**Total %**
1998/3rd	5.96	6.86	11.12	23.93
1998/4th	5.00	6.37	19.02	30.38
1999/1st	5.05	2.88	15.83	23.76
1999/2nd	6.06	3.68	12.19	21.92
Total for 1998/99	**22.06**	**19.78**	**58.16**	**100.00**
1999/3rd	2.56	3.04	10.09	15.69
1999/4th	2.63	1.55	22.35	26.54
2000/1st	2.07	2.78	23.79	28.64
2000/2nd	13.04	3.31	12.78	29.13
Total for 1999/00	**20.30**	**10.68**	**69.01**	**100.00**

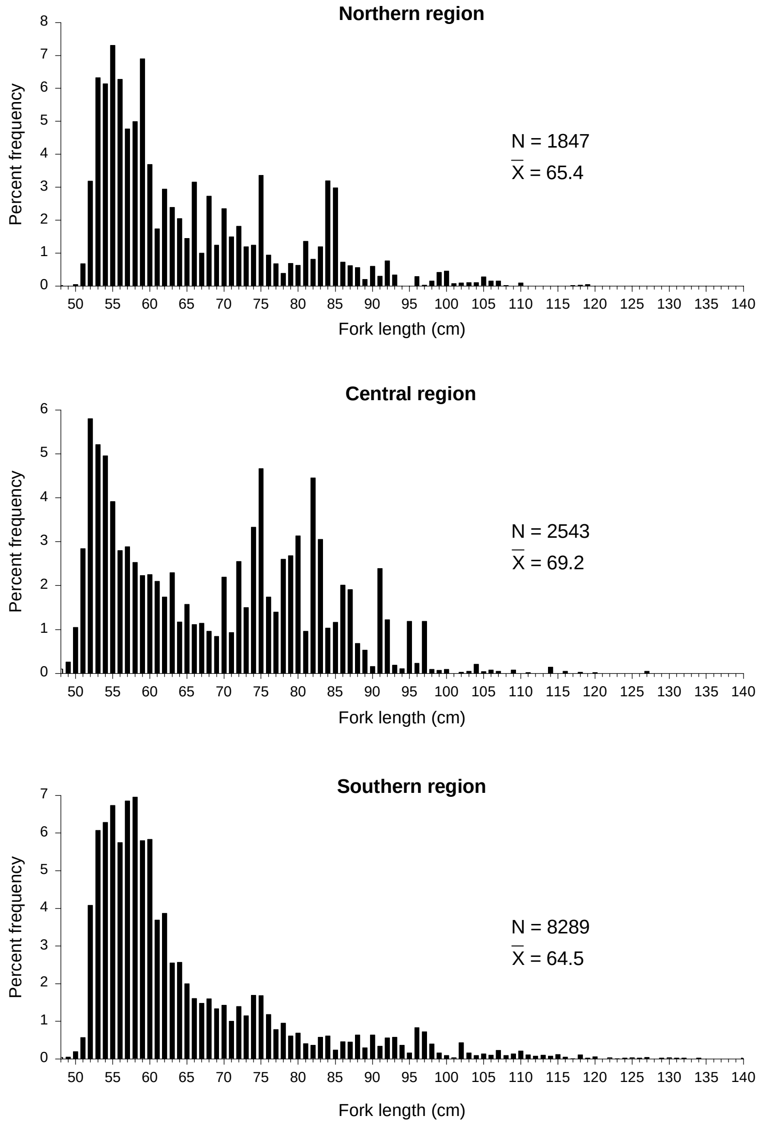


Figure 2.4. The size compositions for the commercial landings of kingfish for each region sampled during the present study (1998 to September 2000).

2.3.2 Age determination

We collected otoliths from 1416 kingfish from the 3 coastal regions sampled. Of these, we sectioned 1306 otoliths and assigned ages to 1085 fish. This rate of successfully being able to assign ages to otoliths (83%) reflects the difficulty in sectioning and interpreting kingfish otoliths reported by Gillanders et al. (1999a). The size distribution of fish for which we were able to estimate an age was similar to the size distribution of fish for which we were unable to assign an age (Fig 2.6), suggesting that any potential biases in our estimates of size at age were minimal. Pairwise comparisons between two readers for 200 otoliths indicated that 86.8% resulted in the same estimated age and that 13.2% differed by 1 year. The coefficient of variation (cv) was 0.03 which is around the level reported for many other species (Kimura & Lyons (1991).

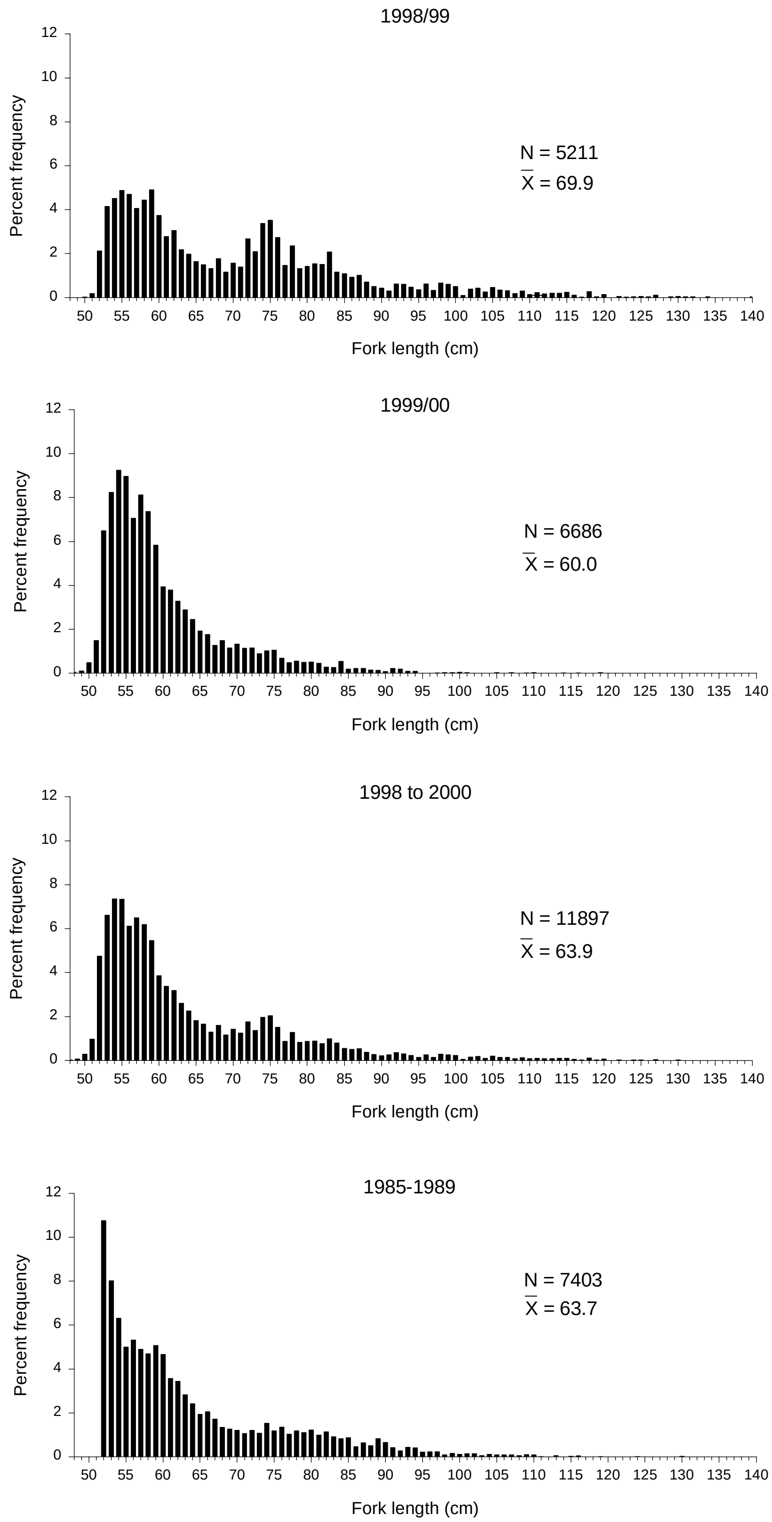


Figure 2.5. The size compositions of the commercial landings of kingfish for each year sampled from the present study and from historical measurements at the Sydney Fish Markets between 1985-1989. The data for 1985-1989 has been truncated at the current minimum legal length of 52.4 cm fork length.

Despite the difficulties in assigning ages to around 17% of kingfish sampled, many sections of otoliths showed what appeared to be clear opaque marks which were counted as being annual (Fig. 2.7). Counts were done along whichever axis displayed the clearest marks. Figs 2.7A and 2.7B show examples of the variation in growth zones of kingfish of similar sizes and the uncertainty associated with assigning ages.

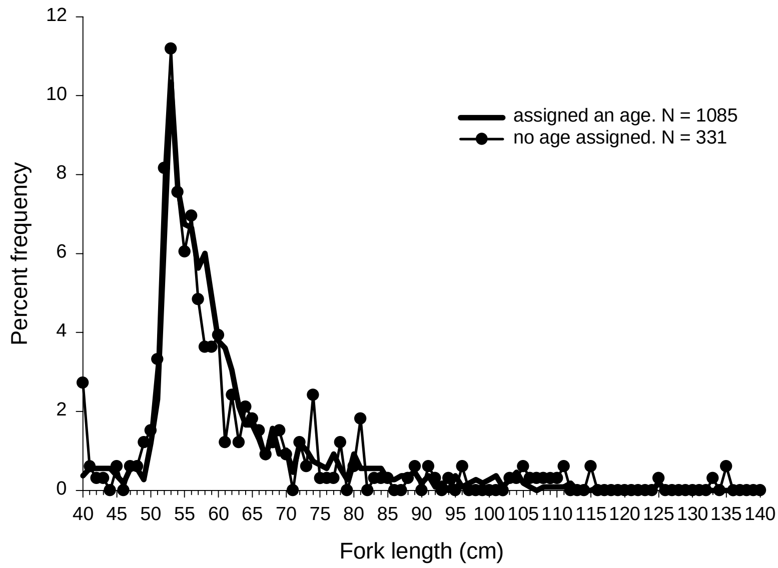


Figure 2.6. The size distributions of kingfish for which ages were unable to be assigned and for which ages were successfully assigned using sections through the core of the otolith. The 40 cm size class includes all kingfish smaller than 41 cm FL.

2.3.3 Age composition of landings

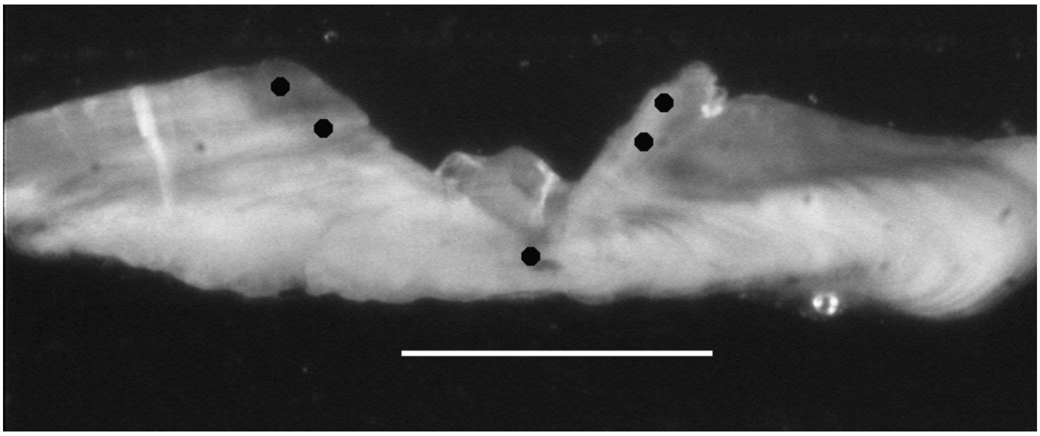
The length frequency distribution of kingfish sampled for age estimation (Fig. 2.8), when compared to the size distributions of commercial landings (Fig. 2.5), shows that we under-sampled fish greater than approximately 70 cm FL during 1998/99. The result was that we could only draw from 200 of the 509 otoliths sampled during that financial year to gain a representative age distribution (Fig. 2.9). The sizes of fish sampled for age estimation were similar to those measured from commercial landings during 1999/00 and we were able to draw from 250 of the 508 otoliths sampled during that financial year to estimate the age composition (Fig. 2.9).

Estimates of ages from sections of otoliths from commercially caught kingfish ranged from 1 up to 19 years in the present study. Catches were dominated by 2 and 3 year old fish in each year sampled, with these age classes comprising approximately 72% of landings in 1998/99 and 78% of landings in 1999/00 (Fig. 2.9). The pattern in the age structures of landings was similar to that shown by the size structures, with landings in 1998/99 containing a higher proportion of older fish than in 1999/00.

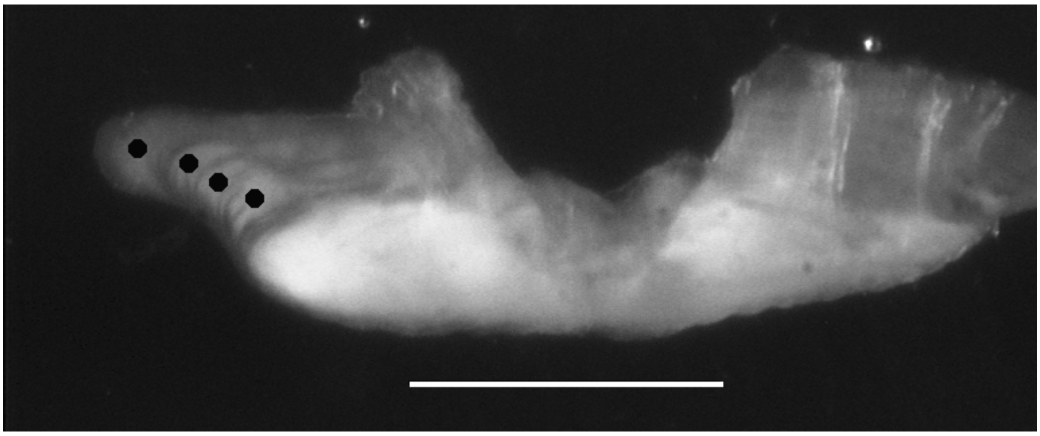
The age-length key for all of the kingfish which we could estimate ages for (1085 from the NSW coast and 130 from Lord Howe Island) is in Table 2.3.

Table 2.3. Age-length key for kingfish collected during the present study (1998 to 2000) from the east coast of NSW and Lord Howe Island. Ages were estimated by counting opaque bands in sections of otoliths.

	Age (years)																					
Length class (cm FL)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**Total**
35-39	4																					4
40-44	16	11	1																			28
45-49	7	29	1																			37
50-54	21	204	102	8	1																	336
55-59	9	180	108	19	2																	318
60-64	2	65	76	7		1																151
65-69		33	13	11	4	4		1														66
70-74		11	19	9	7	2	4															52
75-79		9	6	6	8	5	4	3														41
80-84		1	3	8	3	7	6	5	1	1												35
85-89			1	2	3		3	7	2	2												20
90-94			1	1	2		2	3	2	1		1			1							14
95-99						3	4		5	3	4											19
100-104					1	3	5	3	4	2	4	4			2							28
105-109							1	3	3	5	3	2	2		2							21
110-114								4		1	3	1	1	1	1							12
115-119											1	3	2	1		2						9
120-124										2	1	2	1	1		2		2	1			12
125-129										1				1				1				3
130-134										1	1								1	1		4
135-139											1										1	2
140-144																	1	1	1			3
N	**59**	**543**	**331**	**71**	**31**	**25**	**29**	**29**	**17**	**19**	**18**	**13**	**6**	**4**	**6**	**4**	**1**	**4**	**3**	**1**	**1**	**1215**



A.



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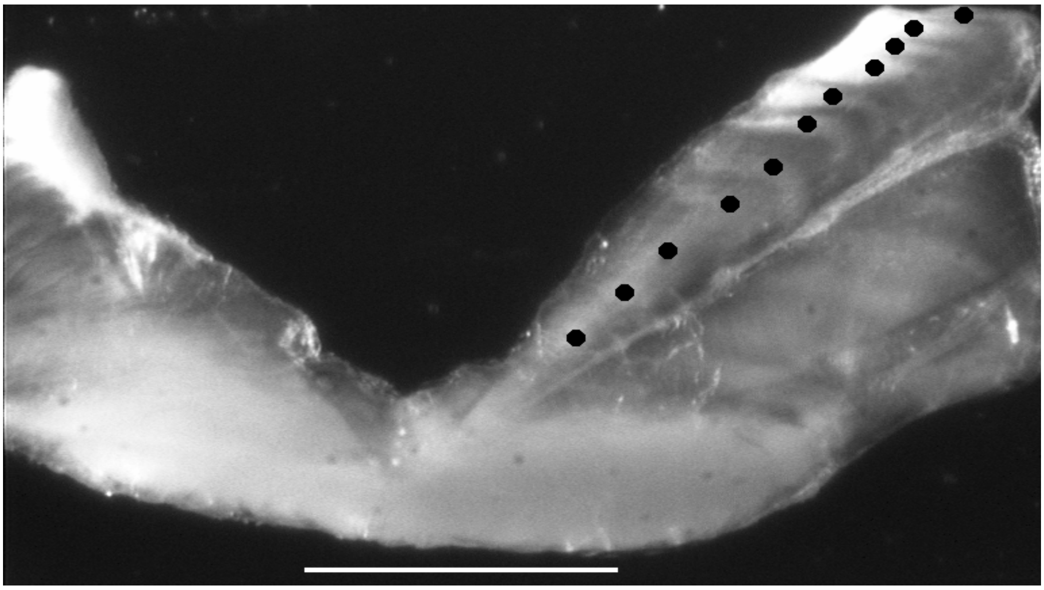


C.

Figure 2.7. Sections of kingfish otoliths, viewed under reflected light against a black background, showing the positions of counted opaque marks. **A.** 55 cm FL aged 2+. **B.** 52.5 cm FL aged 4+. **C.** 113 cm FL aged 11+. Scale bars are 1mm.

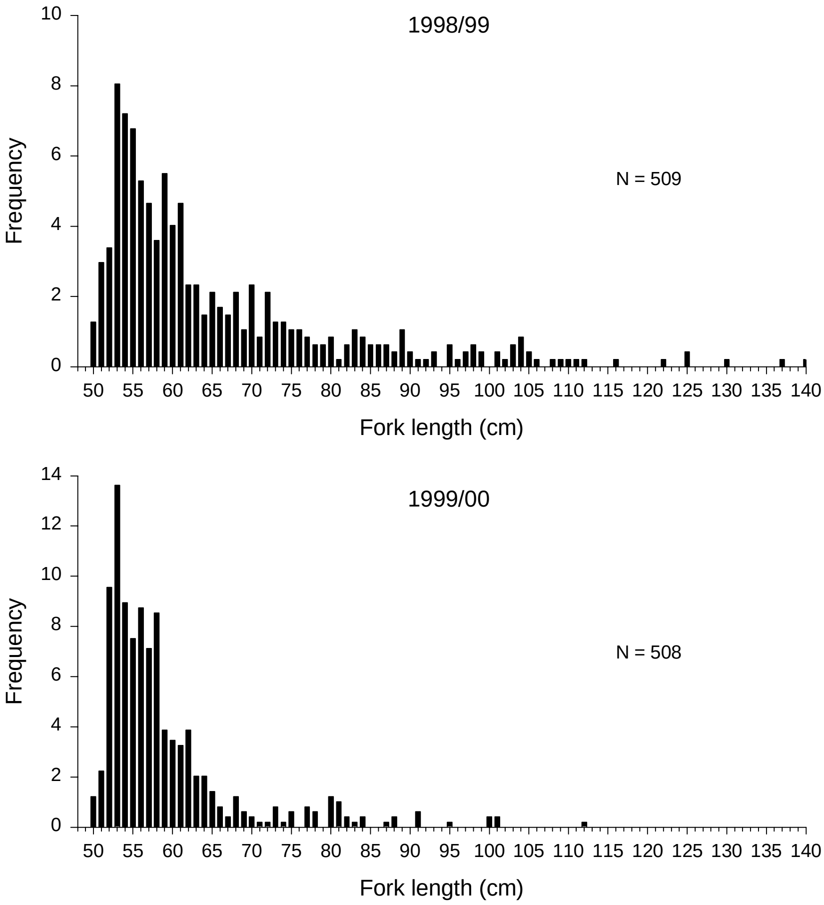


Figure 2.8. The size composition of kingfish sampled for age determination from commercial landings along the NSW coast.

The sex of 1,113 kingfish collected for ageing was determined from macroscopic examination of the gonads. The ratio of males to females did not differ from 1:1 (chi squared = 0.11, P>0.5) and we observed 546 males, 557 females and 10 which had gonads too small to assign a sex. The size frequency distribution of the fish collected for ageing (Fig. 2.8) was similar to that observed being landed in the fishery (Fig. 2.5) and it is therefore likely that the ratio of males to females in commercial landings is approximately 1:1.

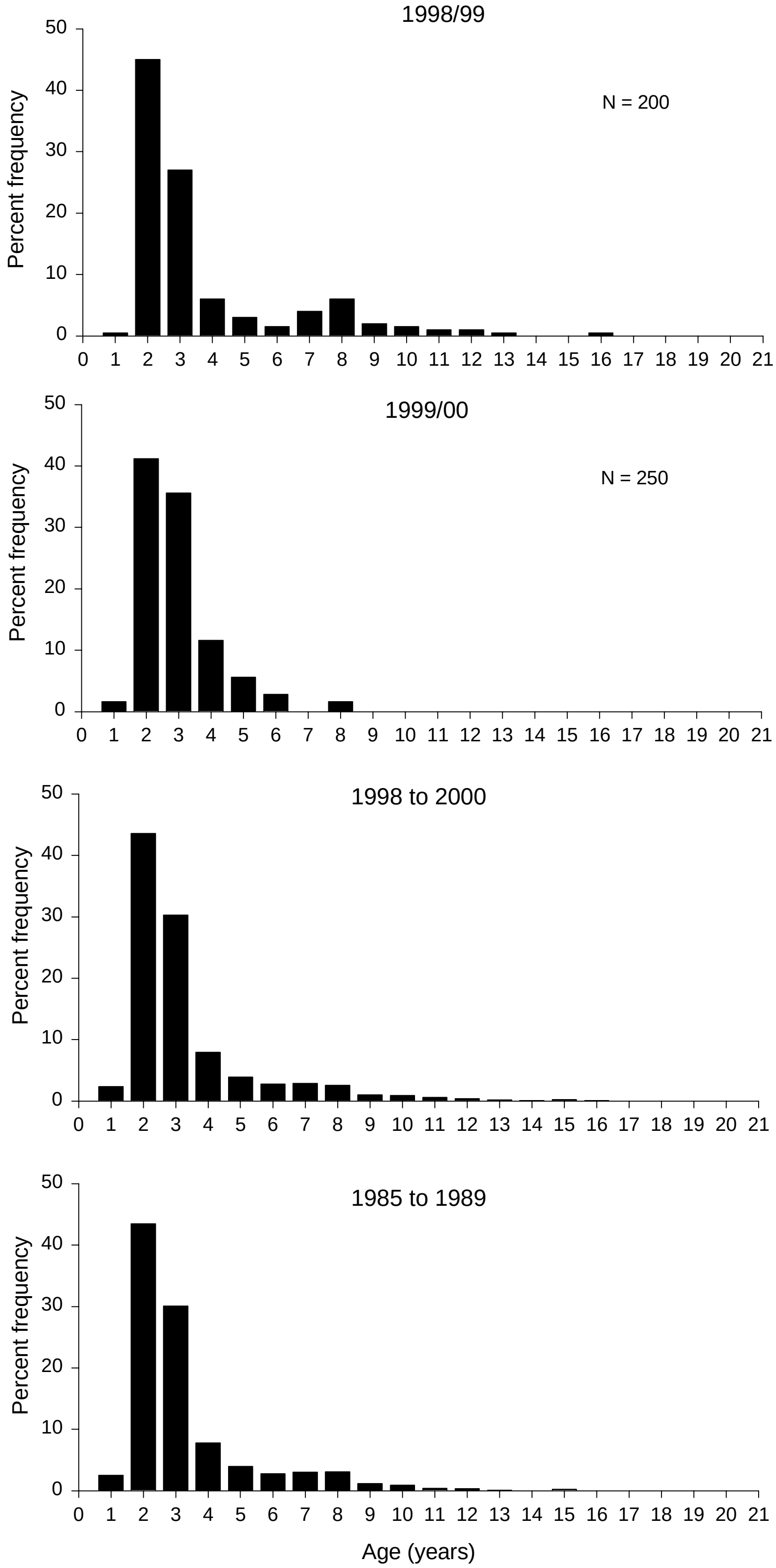


Figure 2.9. The estimated age compositions of kingfish sampled from commercial landings. Ages for 1998/99 and 1999/00 were drawn from kingfish sampled during those years. Ages for 1998 to 2000 and 1985 to 1989 were calculated from the age-length key in Table 2.3.

2.4. Discussion

The commercial fishery for kingfish in NSW was variable during the 2 financial years studied. Landings during 1998/99 contained a much greater proportion of large (70 to 100 cm FL), and correspondingly older, fish than during 1999/00. This difference can be attributed largely to 1 commercial fisher from the central region who landed significant catches of large kingfish during 1998/99, but did not target kingfish to the same extent during 1999/00. Generally, the fishery is dominated by fish smaller than 65 cm FL (Fig. 2.5) and consists mostly of 2 and 3 year old fish (Fig. 2.9). Most of the commercial catch is within 10 cm of the minimum legal length (60 cm total length and approximately 52.4 cm FL), although we did observe fish up to 145 cm FL in landings. We are confident that measuring kingfish at various ports of landing, and measuring all kingfish landed on any sampling day, has provided unbiased estimates of the sizes of kingfish landed and has revealed regional, seasonal and annual variations in the compositions of catches. Figs. 2.1, 2.2 and 2.3 show patterns in seasonal landings from each region and, when combined with Table 2.2, show that during times of very large catches that they tended to be dominated by small fish. There were no obvious differences in the overall size compositions of landings from different regions, however the compositions of landings varied between regions during some sampling quarters. The considerable variation in mean size of kingfish landed between regions and quarters suggests that the population structure varies at these scales. This has important implications for future monitoring of the fishery, which will have to incorporate this level of variation.

Total landings of kingfish in NSW increased during the second year of the study (87 tonnes in 1998/99 to 130.8 tonnes in 1999/00), largely due to an abundance of smaller fish during 1999/00. The observed decline in the proportion of large fish in landings (Fig. 2.5) may have been due to differences in targetting practices between years. Fishers tend to preferentially target the smaller kingfish when they are present in large numbers, however when the small fish are absent fishers will specifically target large kingfish on fishing grounds that are known to produce large fish. Consequently, the abundance of small fish during 1999/00 may have resulted in less targetting of larger kingfish. This situation should be monitored carefully, as the decline in proportion of large fish in landings may alternatively reflect overfishing of larger kingfish.

Despite large declines in the quantities of kingfish being landed by commercial fishers in NSW since the 1980’s (ie. 500 to 600 tonnes during the 1980’s to around 80 tonnes in 1997), there appears to have been little change in the size composition of kingfish larger than the current MLL available to the fishery. This is apparent when the sizes of kingfish which were measured at the Sydney Fish Markets between 1985 and 1989 are truncated at the minimum legal length of 60 cm total length (approximately 52.4 cm FL) and are compared to those measured during the present study during 1998 and 2000 (Fig. 2.5). This suggests that the imposed management changes (i.e. the introduction of a 60 cm TL minimum legal length in 1990 and the banning of pelagic kingfish traps in 1996) have had little effect on the sizes of kingfish greater than the current MLL available to the fishery off NSW. This constancy in the size compositions of landings (Fig. 2.5), the fishery being dominated by 2 and 3 year old fish (Fig. 2.9), and relatively low annual landings all suggest that small kingfish protected by these management changes do not grow through to become part of the fishery at much larger sizes. Rather, these fish seem most likely to be captured shortly after they reach the minimum legal length (see also discussion in Chapter 4).

Coefficient of variation (cv) is an index of precision of age estimates which takes into account the absolute age of the fish and is therefore useful for comparing among species of varying ages. Estimates of cv in the present study (cv = 0.03) were similar to values reported for many other species (Kimura & Lyons, 1991), but less than that reported by Gillanders et al. (1996) of 0.12

using whole otoliths, and less than the cv of 0.15 reported for the closely related Greater Amberjack (*Seriola dumerili*) (Thompson et al., 1999). However, our estimated cv did not include those otoliths for which we were unable to assign an age and therefore may be misleading. Having 17% of kingfish otoliths which were unable to be interpreted indicates considerable difficulty in estimating age from these structures. Thompson et al. (1991) reported 7.5% of otoliths to be unreadable, but had a higher cv of 0.15 for Greater Amberjack. Despite the relatively high proportion of kingfish otoliths considered as unreadable, we consider that sectioned otoliths represent the best method for estimating age. The cost-effectiveness of collecting otolith samples when 17% of them may be unusable is questionable in terms of ongoing monitoring of the kingfish fishery.

The similarity in size distribution of fish having readable and unreadable otoliths (Fig. 2.6) initially suggests no bias resulting from the problem of having a large proportion of otoliths being uninterpretable. Many kingfish otoliths were easy to interpret and were assigned ages with a high degree of confidence. However, it may be that otoliths that were unreadable were from either very fast or very slow growing kingfish, in which case our estimates of growth rates (discussed in chapter 3) may be biased.

There is yet to be a fully validated ageing technique for kingfish or closely related species. Gillanders et al. (1999a) used marginal increment analyses to validate that annual growth zones were deposited in the otoliths of kingfish aged between 2 and 4 years when viewing whole otoliths. Thompson et al. (1999) used a mark recapture study using tetracycline to mark otoliths of Greater Amberjack (*Seriola dumerili*), and validated that marks in sectioned otoliths of 2 and 3 year old fish were formed annually. We were unable to use marginal increment analyses as a validation of our techniques in the present study because of the difficulty in determining the state of the otolith edge. This problem was also reported by Thompson et al. (1999) as precluding marginal increment analyses on sectioned otoliths of Greater Amberjack. All evidence suggests that the opaque bands observed in sectioned kingfish otoliths are deposited annually and can therefore be used to estimate age. However, there has been no validation of the timing of formation of the first observed annual mark and this needs to be resolved before the growth rates estimated from age based data can be refined.

3. GROWTH OF YELLOWTAIL KINGFISH OFF NSW

This chapter addresses objective 2 of the study.

Objective 2. To refine existing estimates of kingfish growth with new information on size at age, with a focus on large fish.

Growth rates of kingfish were determined using age estimates derived from sectioned otoliths. The results suggested that previous studies using whole otoliths may have under-estimated the age of older kingfish. Kingfish reached an average size of around 50 cm fork length after 1 year and around 72 cm fork length after 5 years. We found no differences in the growth rates of kingfish along the NSW coast, off Lord Howe Island, or between males and females.

3.1. Introduction

Despite being one of the most popular and important recreationally and commercially caught species in NSW, until recently we have had little knowledge about the growth rate of kingfish. This lack of information on growth rates probably stems from the fact that all members of the genus *Seriola* are notoriously difficult to age from hard part analysis. Gillanders et al. (1999a) demonstrated that kingfish off NSW could be aged reliably using otoliths, scales and vertebrae, but did not provide any strong validation for their techniques. The growth rates estimated from their age-based models compared favourably to estimates of growth made from tagging data and from cohort analyses made on historical catch information, which provided some confidence in the accuracy of their results. The results from Gillanders et al. (1999a) indicated that kingfish off the NSW coast were a fast growing species, reaching around 50 cm FL after age 1 year and around 80 cm FL after age 5 years.

Kingfish are reported to grow to at least 190 cm total length and can weigh up to 70 kg (Kailola et al., 1993). Despite the potential to grow to such sizes, kingfish greater than 100 cm FL are rarely seen off the coast of NSW and represent a very small proportion in commercial landings (see Chapter 2). The study of Gillanders et al. (1999a) was designed to compare different bony structures to estimate age in kingfish and not to provide definitive growth curves for this species. Gillanders et al. (1999a) aged very few fish greater than 90 cm FL when estimating growth curves for kingfish and observed a maximum age of 9 years when using whole otoliths. Gillanders et al. (1999a) recommended that more work be done on estimating the ages of young fish (where interpretation of the first years growth band is difficult) and of larger/older fish (> 100 cm FL - which were not sampled during the study) in order to refine their initial growth models. They also suggested that sections of otoliths may be more reliable when estimating the age of older kingfish.

We have very little information on spatial variation in size at age of kingfish. Kingfish are a highly mobile, pelagic species and are thought to comprise a single unit stock off the coast of NSW, which suggests that regional differences in growth rates are unlikely. However, the results of tagging studies have demonstrated that small kingfish tend not to move far (Gillanders et al., 2001) and hence the potential for regional growth variation does exist. Unexpected significant differences in growth rates have been demonstrated for another highly mobile, pelagic fish species thought to consist of a single unit stock off the coast of NSW, the yellowtail scad (*Trachurus novaezelandiae*) (Stewart & Ferrell, 2001).

A major objective of the present study is to consider the appropriateness of the current minimum legal length of 60 cm total length for kingfish. This will be done using yield per recruit analyses and estimates of the growth rates of kingfish around the minimum legal length. It is important that we have reliable estimates of the growth rates of kingfish in order to provide confidence in our assessments of the impacts of any changes in minimum legal length regulations on landings and the kingfish stock.

3.2. Materials and methods

3.2.1 Growth rates

Estimates of growth rates were based on size at age data. Estimates of age were made from sectioned otoliths as described in chapter 2.

Growth curves describing size at age of kingfish were derived using procedures outlined in Schnute (1981). Schnute's model relates size to age by four parameters: y_1, y_2, *a*, and *b*. The parameters y_1 and y_2 are the mean sizes at ages τ_1 and τ_2 respectively, where the value of τ_1 and τ_2 are specified. In the present study τ_1 and τ_2 were chosen to be 1 and 5 years for kingfish from all locations (northern, central and southern regions and Lord Howe Island). τ_1 and τ_2 were chosen to be 1 and 5 years to allow comparisons with the results of Gillanders et al. (1999a) and to allow mean sizes at age to be formally compared between regions. The parameters *a* and *b* combine to describe the shape of the curve (Schnute 1981). These parameters were used to provide estimates of the traditional von Bertalanffy parameters t_0, *k* and L_∞ for comparison with previous studies using the methods outlined in Schnute (1981).

All models were fitted using additive error models because variation in size at age was similar for fish of all ages. Initially, a two parameter model (y_1 and y_2) was fitted to the data. Two types of 3 parameter models (a, y_1, y_2, and b, y_1, y_2) and a 4 parameter model (a, b, y_1 and y_2) were then fitted. To determine whether the addition of extra parameters significantly improved the fit of the model, significance tests based on the *F*-distribution were used (Schnute 1981). When comparing the two 3-parameter models the model with the lowest sum of squares was selected as the better fit.

3.2.2 Length/Weight relationship

Knowledge of the length/weight relationship for any fish is important when using size based data in estimates of yield. We measured (as FL to the nearest ½ cm rounding down) and weighed (to the nearest 0.1 kg) 636 whole kingfish at the Sydney Fish Markets to estimate this relationship. Where sufficient data were collected we were able to examine seasonal variation in the length/weight relationship.

3.3. Results

3.3.1 Growth rates

Table 3.1 shows the parameters describing growth curves for kingfish estimated using Schnute's growth model. There were no significant differences in the mean sizes of kingfish aged 1 and 5 years from either the northern, central or southern regions (Table 3.1). Kingfish from Lord Howe Island were slightly smaller at age 1 (44.1 cm FL) and slightly larger at age 5 (76.1 cm FL) than those from the coastal fishery. When plotted together, the estimates of size at age from Lord Howe Island appeared similar to those from the coastal fishery. The slight differences in mean size at age for kingfish from Lord Howe Island are likely to have resulted from the large numbers of very large (> 100 cm FL) and old kingfish sampled from this region. The parameters y_1 and y_2 in Schnute's model are the mean sizes at ages τ_1 and τ_2 respectively, with τ_1 and τ_2 chosen to span the range of the data. While choosing these ages to be 1 and 5 encompassed the majority of ages estimated from the coastal fishery, a large proportion of ages estimated from Lord Howe Island were greater than 10 years and these old fish are likely to have influenced the shape of that growth curve.

Table 3.1. Parameters (with standard errors) describing growth curves for kingfish. Parameters were estimated using Schnute's (1981) growth model. Units are in cm, N is the sample size, y_1 and y_2 are the mean sizes (Fork length) at ages 1 and 5, *a* and *b* are constants.

Parameter	Northern region	Central region	Southern region	Lord Howe Island	Pooled males	Pooled females	Pooled kingfish
N	189	241	318	130	435	445	880
y_1	49.6 (1.1)	50.0 (0.6)	49.6 (0.7)	44.1 (2.1)	51.3 (0.4)	50.4 (0.6)	49.2 (0.5)
y_2	71.3 (1.1)	70.3 (0.8)	72.4 (1.0)	76.1 (1.3)	69.0 (0.5)	71.3 (0.7)	72.4 (0.6)
a	0.09 (0.03)	1.2 (1.2)	0.4 (0.3)	0.18 (0.02)	0	0.07 (0.01)	0.36 (0.07)
b	0	-14.8(14.0)	-3.7 (3.2)	0	0	0	-3.4 (1.0)

There was little difference in the estimated growth of male and female kingfish with estimated mean sizes (with standard errors) at age 1 being 51.3 (0.4) and 50.4 (0.6) cm FL respectively and at age 5 being 69.0 (0.5) and 71.3 (0.7) cm FL respectively.

We considered that there were no significant differences in the growth rates of kingfish between any of the regions sampled and pooled all size at age data to generate an overall growth curve for kingfish. The general growth curve for kingfish was best described by the 4 parameter model with estimated mean sizes of 49.2 cm FL at age 1 and 72.4 cm FL at age 5 (Table 3.1, Fig. 3.1). Estimates of the von Bertalanffy growth function parameters were t_o = -4.4, k = 0.054 and L_∞ = 184 cm FL.

A comparison of the growth curves for kingfish from Gillanders et al. (1999a) from ages based on whole otoliths, and from cohort analysis using historical length composition data, with the growth determined using sectioned otoliths in the present study is shown in Fig. 3.2. Estimates of size at age are different between the methods used. Estimates of mean size at age from sectioned otoliths were smaller than those determined from whole otoliths (Gillanders et al., 1999a). The maximum age of 9 years determined by Gillanders et al. (1999a) was much younger than many of the fish sampled during the present study (see Fig. 3.1), and their growth curve does not take growth rates of these older fish into account.

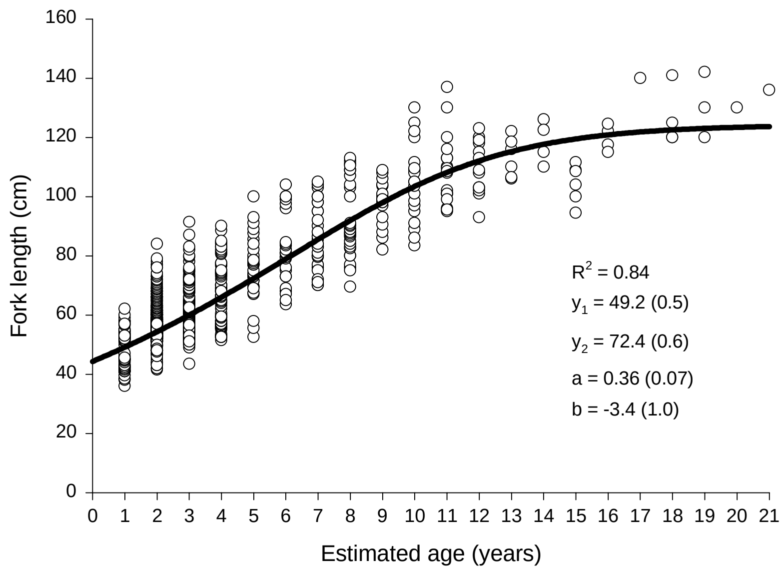


Figure 3.1. General growth curve for kingfish off NSW from size at age data estimated from sectioned otoliths during the present study. The curve was estimated using Schnute's (1981) growth model. Parameters y1 and y2 are the estimated mean sizes of kingfish at ages 1 and 5 respectively. Standard errors are in parentheses. Other parameters are described in the text.

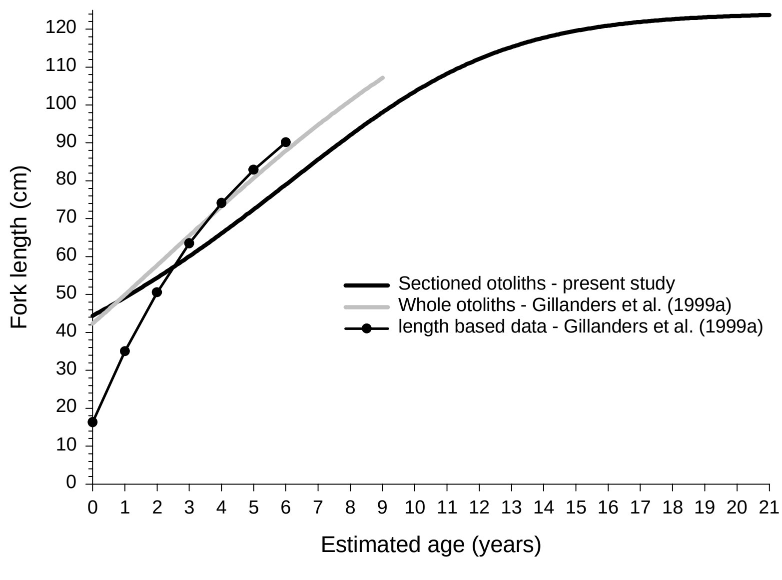


Figure 3.2. A comparison of the growth curves estimated for kingfish using whole otoliths and cohort analysis (from Gillanders et al.,1999a) with the growth curve estimated from sectioned otoliths in the present study.

3.3.2 Length/Weight relationship

We measured the lengths and weights of 636 kingfish during the study, ranging from 27.8 cm to 142 cm FL and 0.3 kg to 35kg. The relationship between weight (kg) and fork length (cm) was described by the equation $W = 1.28x10^{-5}$ x $FL^{3.0}$, $R^2 = 0.98$ (Fig. 3.3). The relationship showed considerable variation in weight for any given length, with kingfish from the southern region having significant differences in their length/weight relationships between summer and winter (Fig. 3.4). Kingfish caught during winter were much heavier than fish of equivalent lengths caught during the summer months.

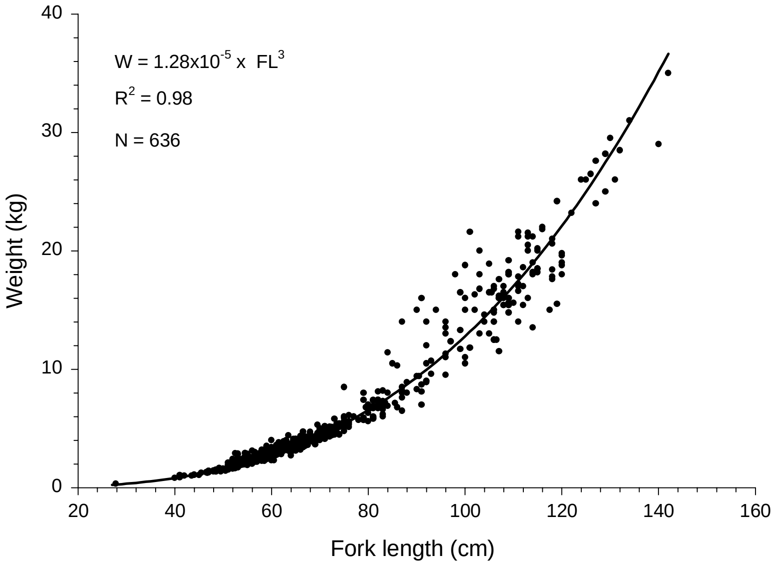


Figure 3.3. Fork length (cm) to weight (kg) relationship for kingfish during the present study.

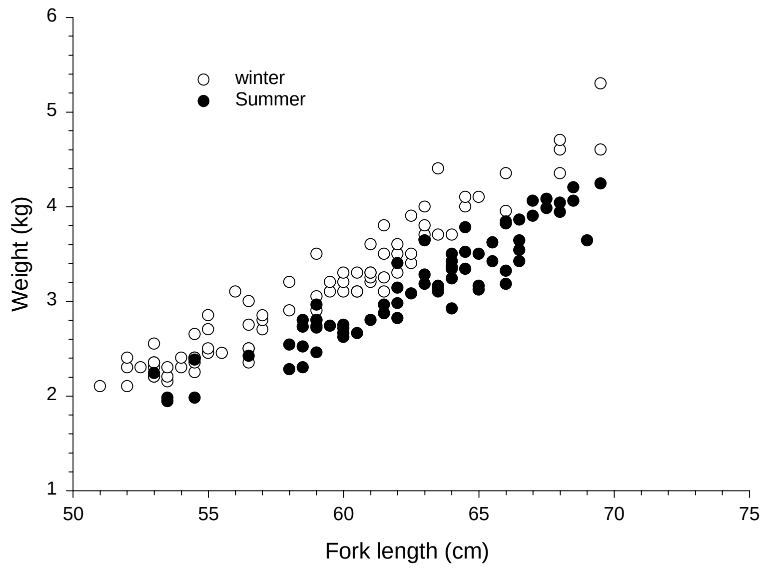


Figure 3.4. Fork length (cm) to weight (kg) relationships for kingfish from the southern region during the summer and winter months.

3.4. Discussion

The growth curve for kingfish off NSW shows that while growth can be highly variable, on average it is nearly linear for the first 11 years before slowing down (Fig. 3.1). Growth of young fish is rapid with fish reaching their legal minimum length (60 cm TL or approximately 52.4 cm FL) at around 2 years of age. The maximum age recorded in this study was 21 years and the fish measured 136 cm FL. Our estimates of the von Bertalanffy growth function parameters (t_o = -4.4, k = 0.054 and L_∞ = 184 cm FL) appear to be more realistic than those reported by Gillanders et al. (1999a) and estimated from cohort analysis (t_o = -0.7, k = 0.189 and L_∞ = 125.2 cm FL). Our estimated maximum size (L_∞ = 184 cm FL) is close to the maximum reported for the species of 190 cm (Kailola et al., 1993).

There were no differences in the growth rates of kingfish between regions or between males and females. Given the highly mobile, pelagic nature of kingfish, and the apparent single unit stock off NSW, it is not surprising that we found no regional differences in growth rates. Conversely, the widely differing weights of kingfish at different times of the year (Fig. 3.3), together with the fact that small fish have been shown not to move long distances (Gillanders et al., 2001), suggested that regional differences in growth rates of small fish may have been a possibility. Thompson et al. (1999) found no differences in the growth rates of males and females for the closely related *Seriola dumerili* from the Gulf of Mexico, but did report sex related differences in their maximum sizes. Males were rarely found to be older than 7 years, whereas females were found up to 15 years old. This is hypothesized to be the result of age related differential mortality, with males dying at younger ages than females. There is no evidence of age related differential mortality of kingfish, with males and females appearing in similar numbers at all sizes in commercial landings (see chapter 2). However, we still have limited data for older (> 10 years) kingfish and the question of age related differences in mortality between sexes is an interesting one which warrants further study.

Growth rates determined using ages based on sections of otoliths in the present study compared favourably to those determined by Gillanders et al. (1999a) using whole otoliths only for the younger age classes (Fig. 3.2). Our estimates of the mean size of kingfish (cm FL with standard errors) at age 1 year of 49.2 (0.5) was similar to that of Gillanders et al. (1999a) of 49.9 (0.5). However, our estimates of the mean size at age 5 years of 72.4 (0.6) was considerably smaller than the 80.7 (0.8) estimated from whole otoliths. This is likely to have resulted from Gillanders et al. (1999a) under-estimating the age of larger fish and therefore over-estimating growth rates. This potential bias was flagged by Gillanders et al. (1999a) as a well reported problem when using whole otoliths to estimate ages in older fish. In older fish, the asymmetric growth of otoliths results in material being deposited to thicken the otolith, rather than in the anteroposterior plane, making recently formed growth zones difficult to observe (Beamish, 1979).

The growth curve for kingfish estimated from length based data (Gillanders et al., 1999a) did not compare well with our estimates of growth for young (less than 2 years) fish. The growth of young fish may be better described using the results of Gillanders et al. (1999a) based on cohort analysis because we are not confident of our age estimates for very small fish. Despite sampling fish as small as 28 cm FL (and 11 fish smaller than 40 cm FL), we did not estimate any as being in their first year. It is likely that many of the 17% of fish to which we could not assign an age were in their first year (see Fig. 2.6). Gillanders et al. (1999a) reported fish around 40 cm FL to be in their first year from examination of whole otoliths, and were able to validate that one growth zone was deposited each year between August-September in fish aged 2-4 years using marginal increment analysis. Other studies have reported the difficulty in determining the location of the first annual mark in *Seriola spp*. Thompson et al. (1999) used sections of otoliths to estimate age in *Seriola dumerili* and concluded that the first annual mark was actually formed during the fish's second year when actually aged 15 to 21 months old. Kingfish are reported to spawn off the NSW coast during summer (Gillanders et al. (1999b). Opaque annual marks form between August-September in kingfish (Gillanders et al., 1999a) and the first mark will therefore be deposited when the fish are a little more than 6 months old. The core region of otoliths tends to be opaque and this first mark may be difficult to identify. The annual mark formed during the fish's second year may be the first mark identified in sections of kingfish otoliths and the growth curve determined in the present study may have to be shifted to the right by around 6 months. Despite this, our estimate of a mean size of 49 cm FL at age 1 year is similar to the growth rates reported for kingfish kept under aquaculture conditions in South Australia. Kingfish have been reported to reach 1.5 kg after 1 year in captivity which, from our length/weight relationship, is reached at around 49 cm FL. This similarity in estimated sizes at age 1 year provides confidence in our data, however the timing of formation of the first annual mark in kingfish otoliths needs to be further studied.

The seasonal variation in weight for fish of similar lengths from the southern region (Fig. 3.3) was not surprising to commercial fishers in this region. While such seasonal variation may be expected to be related to spawning condition, most of these fish would have been immature (the estimated size at 50% maturity being 83.4 cm FL for females – Gillanders et al., 1999b), and kingfish are thought to have a summer spawning period off NSW (Gillanders et al., 1999b). Fishers think that these smallish kingfish tend to move southwards during summer to areas of more food where they put on weight and return northwards during the winter months. Despite this seasonal variation, it is probably best to use the overall length weight relationship determined during this study ($W = 1.28 \times 10^{-5} \times FL^{3.0}$) when estimating yields.

4. YIELD PER RECRUIT ANALYSES

This chapter addresses objective 3 of the study.

Objective 3. To examine the suitability of the current minimum legal length with yield models, utilising the improved information on kingfish growth and information on kingfish size and age composition.

This chapter estimates mortality rates for kingfish and models the yield per recruit for a range of fishing and natural mortality rates. Our best estimates of mortality rates were a natural mortality rate of M = 0.12 and a fishing mortality rate of between F = 0.31 and 0.67. Yield estimates suggest that kingfish are currently growth overfished. Removing the minimum legal length may result in decreased yields and potential increases in effort. Increasing the minimum legal length may increase yields, however the availability of larger fish to the fishery is unknown. Introducing a maximum legal size limit may help to protect the spawning population while having minimal impact on the commercial harvest of kingfish.

4.1. Introduction

Despite kingfish being one of the most important commercially and recreationally targeted fish off the NSW coast, we have little knowledge of their mortality rates or optimal harvest size. The debate about the appropriateness of the current minimum legal length (60 cm TL) requires information on how the stock may be impacted by any changes in MLL. Gillanders et al. (1999) estimated natural mortality to be 0.13 based on the rate of decay of tag returns from a co-operative tagging programme. They advised caution in using this estimate as it assumed that there was no tag loss and that fishing effort was constant, both of which were unlikely. Apart from the estimates of growth described in Chapter 3 there are no other estimates of life-history parameters available for kingfish.

A natural progression in the stock assessment of kingfish is to use the improved estimates of growth, determined in Chapter 3, with estimates of mortality in yield per recruit analyses. Such analyses use estimates of growth rates, mortality rates and age at first capture to examine the trade-off between capturing a large number of small fish when they are young, and capturing smaller numbers of larger fish when they are older. Yield per recruit analyses can be used to estimate suitable minimum legal size limits, however there are many assumptions that are often violated and they should be used with caution. The physical yield of fish is a product of the yield per recruit and the number of recruits produced in the stock.

In this chapter we present estimates of mortality rates and yield per recruit for kingfish off the NSW coast. These estimates are discussed in terms of changes to the minimum legal length of kingfish and exploitation rates within the fishery.

4.2. Materials and methods

4.2.1 Estimation of mortality rates

Estimates of total mortality (Z) were made from the slope of the descending limb of the catch curve i.e. by regressing the natural logarithm of age frequency against age for all fully recruited age classes, for each financial year sampled (see Chapter 2). We chose age 3 as being fully recruited to the fishery. This method is based on "pseudo-cohorts" because age classes are compared within each year sampled. The method therefore assumes constant recruitment and survival for all cohorts.

Natural mortality rate (M) was estimated after the method of Hoenig (1983) and Annala et al., 1999 (MAF unpublished data), for exploited populations where:

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

T_{max} was set at 25 years.

An independent estimate of Natural mortality rate (M) was also made using the method of Pauly (1980). Pauly's formula is based on the von Bertalanffy growth parameters L_∞, K and the environmental temperature T:

$$\text{Log } M = -0.0.066 - 0.279\log L_\infty + 0.6543\log K + 0.4634\log T$$

We used the von Bertalanffy growth parameters described in chapter 3 (L_∞ = 184 cm, K = 0.054) and a mean water temperature of 18° C.

An estimate of fishing mortality (F) was made by subtracting the estimated natural mortality (M) from the estimated total mortality (Z).

Mortality rates were converted to percentages using the equation:

$$\text{Mortality (\%)} = 100 \times (1-\exp[\text{mortality rate}])$$

4.2.2 Yield per recruit analyses

Yield per recruit calculations were done based on the method of Beverton and Holt (1957). Their model considers the trade off between capturing large numbers of young fish or smaller numbers of older fish when they are larger. The model considers the dependence of yield on age at first capture, growth and fishing mortality.

Assumptions of the model are: (i) natural mortality (M) is constant for all ages after recruitment; (ii) fishing mortality (F) is constant after the age at first capture; (iii) gear selection is knife-edged, ie. after the mean age at first capture all fish coming into contact with fishing gear have an equal probability of capture; (iv) recruitment is constant; and (v) the fish are a closed population.

The standard assumption of knife-edged selectivity based on an age of first recruitment was modified in our calculations to include knife-edged selectivity based on fish length (Quinn & Deriso, 1999). The modification provides a probability of selection at a given age based on the mean size from the growth model and estimates of variation in size at age from the data.

Growth estimates used in the yield per recruit calculations were made using a hybrid growth model. The early growth estimates used were from the cohort analysis of Gillanders et al. (1999a) (up to age three) and the growth estimates for all older ages is described in Chapter 3 (Fig. 3.2). The two curves gave nearly identical estimates at age three. The reason for using the cohort-derived growth estimates for young fish was that the selectivity in the fishery arising from the current minimum legal size limit, and our relative lack of material from small individuals, meant that the otolith based growth estimates in this study may have over-estimated early growth (see discussion in Gillanders et al., 1999a). Mean weight at age was predicted from the von Bertalanffy growth function (Chapter 3 - L_∞ = 184 cm FL, K = 0.054, t_o = -4.4) and the length/weight relationship (Chapter 3 – W(kg) = 1.28×10^{-5} x FL(mm)$^{3.0}$).

Changes in yields per recruit resulting from changes to the minimum legal length were estimated by changing the size at first capture in the model. Size at first capture was varied between 35 cm TL (which is extremely small and is referred to as having no MLL) and 80 cm TL (the approximate size at sexual maturity – Gillanders et al., 1999b).

4.3. Results

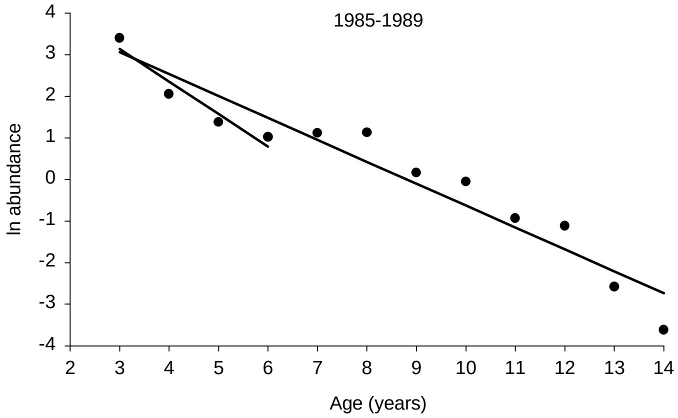
4.3.1 Mortality rates

Instantaneous total mortality rates were determined from catch curves for kingfish for 1985-1989 and for 1998-2000 assuming fish of age 3 to be fully recruited to the fishery. Total mortality rates do not appear to have changed during this period (Table 4.1). Total mortality rates for fish aged 3 to 6 were 0.78 for 1985-1989 and 0.79 for 1998-2000 (Fig. 4.1). Age 6 was also chosen because of the hypothesis that larger/older kingfish move offshore and are not always available to the fishery, therefore violating the assumptions of constant fishing mortality after the age at first capture and that the fishery is a closed population. Using a catch curve only between the ages of 3 and 6 may have over-estimated total mortality and we also estimated total mortality rates between the ages of 3 and 14 years. Total mortality rates between ages 3 and 14 ranged from 0.53 for 1985-1989 to 0.43 for 1998-2000 (Fig. 4.1). Instantaneous total mortality rates of between 0.43 and 0.79 equate to between 35% and 55% annual mortality.

Total mortality must include mortality from both fishing (F) and natural causes (M). Gillanders et al. (2001) estimated natural mortality to be 0.13 based on the rate of decay of tag returns in a co-operative tagging study. The method of Pauly (1980) provided an estimate of natural mortality (M) of 0.12. The method of Hoenig (1983) provided an estimate of M = 0.12. Our best estimates of mortality rates were determined from the average of values obtained and our only estimate of fishing mortality estimated by subtracting natural mortality from the total mortality. Estimated fishing mortality ranged between 0.31 and 0.67, which equates to between 27% and 49% annual mortality due to fishing.

Table 4.1. Estimates of natural and total mortality rates for kingfish.

	Instantaneous Mortality Estimates		
Estimation source	**Fishing (F)**	**Natural (M)**	**Total (Z=F+M)**
Catch curve 1985-1989			0.53 - 0.78
Catch curve 1998-2000			0.43 - 0.79
Pauly (1980)		0.12	
Gillanders et al. (2001)		0.13	
Hoenig et al. (1983)		0.12	
Range of estimates	**0.31 - 0.67**	**0.12**	**0.43 - 0.79**



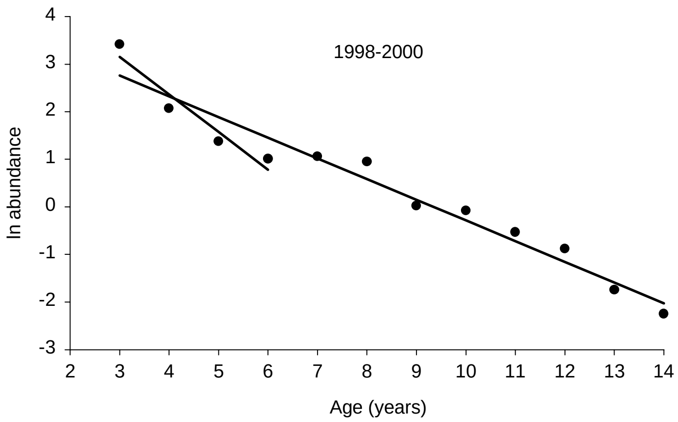


Figure 4.1. Linear regressions fitted to the natural logarithms of age composition data for kingfish landed in commercial catches during 1985-1989 and 1998-2000. Curves were fitted between ages 3 (fully recruited) and both 6 and 14 years.

4.3.2 Yield per recruit analyses

The results of the yield per recruit analyses show that the estimate of natural mortality (M) has a major effect on the yield for any given size at first capture and fishing mortality (F) (Fig. 4.2). For lower values of M, delaying the age/size at first capture significantly increases yields, whereas at estimates of M = 0.3 there is very little change in yield at different fishing mortality values. Our best estimates of mortality rates (Table 4.1) suggest that they are in the order of M = 0.12 and F = 0.31 to 0.67.

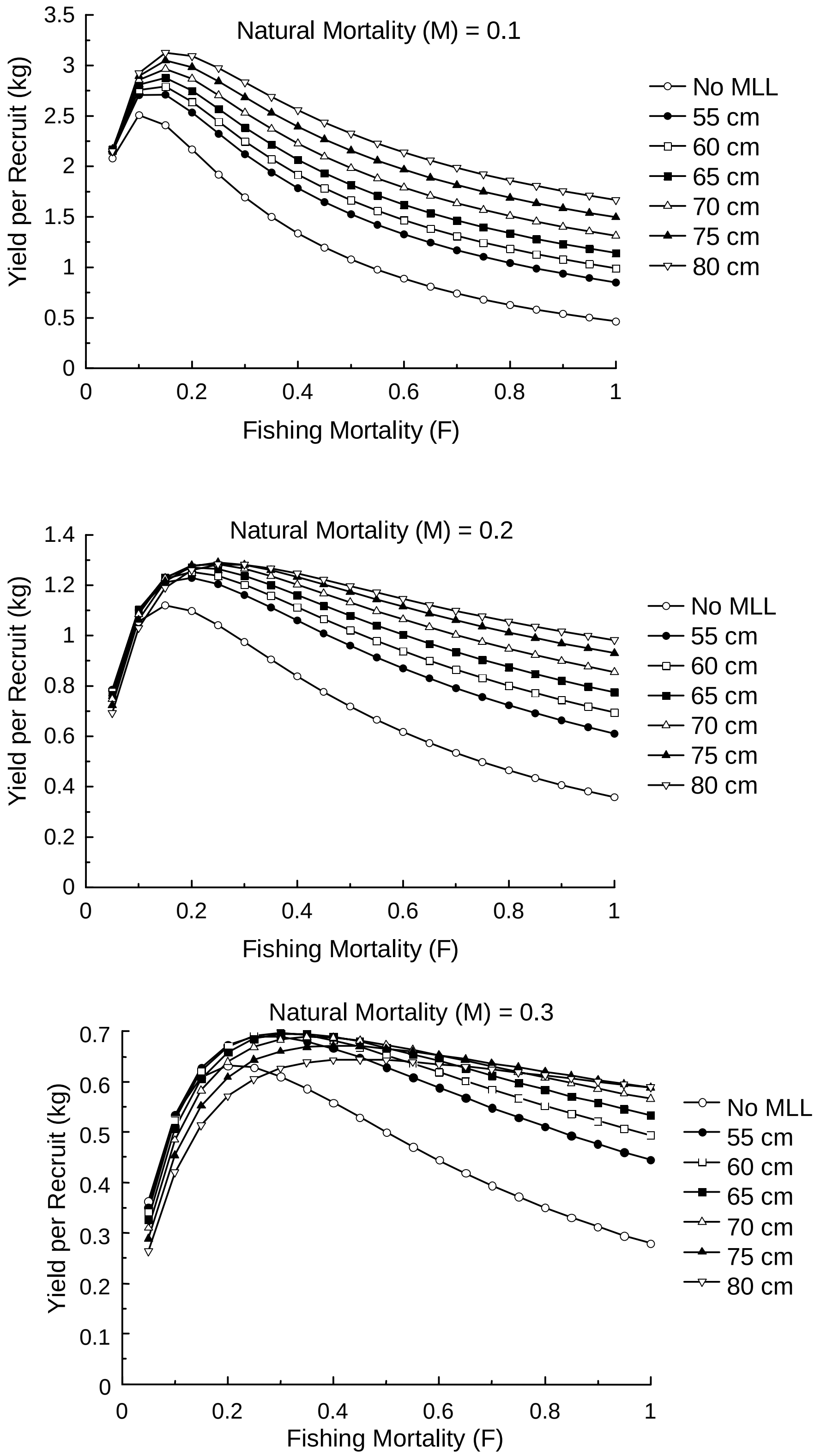


Figure 4.2. Changes in yield per recruit of kingfish at a range of different minimum legal lengths (TL), fishing and natural mortality rates.

4.4. Discussion

4.4.1 Mortality rates and yield per recruit

The mortality rates estimated in this chapter suggest that a large proportion of kingfish die each year. Estimates of total mortality calculated from the catch curves ranged from 0.43 to 0.79. These mortality rates equate to between 35% and 55% of kingfish dying each year. These estimates are similar to those determined for the closely related Greater Amberjack (*Seriola dumerili*) from the Gulf of Mexico, which have been reported to be around 0.7 based on catch curves (Manooch & Potts (1997). Ignoring age classes greater than 6 in the catch curve analysis in the present study may have resulted in overestimates of Z, however this approach is precautionary and is preferable to under-estimating Z. This highlights problems with estimating Z from catch curves for kingfish. There is anecdotal evidence that kingfish may move offshore after a few years and become less available to the fishery, therefore violating the assumption of constant vulnerability to fishing gear. We consider that basing estimates of total mortality only on the age classes which make up the bulk of the fishery will give better estimates of mortality (both natural and fishing) operating within the fishery. During 1999/00 more than 98% of the fishery was based on fish younger than 7 years. Choosing the first year class that is fully recruited to the fishery is also difficult and is often chosen as the size class with the greatest abundance (King, 1995). The growth curve (Fig. 3.1) shows that most fish estimated as being 3 years old were greater than the MLL of approximately 52.4 cm FL and that almost 100% of this age class is recruited to the fishery.

Our fishery independent estimates of natural mortality of 0.12 (from Pauly 1980) and 0.12 (from Hoenig 1983) compared well with the estimate of Gillanders et al. (1999a) of M = 0.13 based on the rate of return of tagged fish. This provides support for our estimates of natural mortality and the estimates of fishing mortality made by subtracting the natural mortality rate from the total mortality rate. The resulting estimated range of F = 0.31 to 0.67 (which equates to between 27% and 49% of kingfish dying annually from fishing mortality) is high, but not unreasonable given the high catchability of kingfish. This fishing mortality includes the mortality of discarded under-sized fish and catches from the recreational sector. The only estimates we have for landings by the recreational sector are from creel surveys during 1993/94 and 1994/95 (Steffe et al., 1996) and were reported to be 15% and 12% of the commercial catch respectively. These estimates were based on trailer-boat fishers and did not include kingfish captured by charter boats, from fixed mooring vessels or from the shore. The National Angling Survey currently being done should provide better estimates of the recreational catch of kingfish.

Estimates of optimal fishing mortality are often taken as the point where the slope of the yield per recruit curve is 0.1 of the value of the slope at low levels of fishing mortality, and is referred to as $F_{0.1}$. While we did not formally calculate $F_{0.1}$ in this study, the shape of the yield per recruit curves in Fig. 4.2 show that the present estimates of fishing mortality (between 0.31 and 0.67) are larger than $F_{0.1}$ which would be around 0.1 to 0.2. This suggests that at the current levels of fishing mortality that kingfish may be growth overfished.

We stress the uncertainties surrounding the yield per recruit estimates determined in this study as: (i) our estimates of growth for young kingfish remain uncertain and; (ii) our estimates of total and fishing mortality rates are based on models where the underlying assumptions have almost certainly been violated. Consequently the estimates of yield per recruit should be used with caution.

4.4.2 Discussion of the appropriateness of the current minimum legal length

The appropriateness of the current MLL of 60 cm TL for kingfish has been debated since its introduction in 1990. A MLL was introduced to satisfy public opinion that it was wrong for commercial fishers to be landing small kingfish. The size was set at 60 cm TL because it was decided (between commercial fishers and NSW Fisheries) that the length of a fish box (60 cm) was a reasonable size and because 60 cm TL was slightly smaller than many of the fish being landed at the time (C. Judd pers. Comm.). The debate about the appropriateness of the current MLL includes: (i) fishers wanting the size limit removed because it was not based on biological reasons; (ii) commercial and recreational fishers claiming the current MLL creates a by-catch problem as schools of kingfish are often encountered which straddle 60 cm TL; and (iii) the introduction of a maximum legal size to protect the spawning population. Information on the dynamics of the fishery, growth and mortality rates determined in the present study, along with information on the size at sexual maturity (Gillanders et al., 1999b) can now be used to promote discussion regarding the MLL for kingfish in NSW. Kingfish are managed in various ways in the different states of Australia. Queensland has a MLL of 50 cm TL, South Australia has a MLL of 60 cm TL, and Victoria and Western Australia have no MLL for kingfish.

The yield per recruit analyses indicate that, in the range of plausible fishing mortalities (approx. 0.3 to 1) and with natural mortality of around 0.12, that removing the MLL on kingfish would decrease the yield per recruit by around one third. The fast growth rates of kingfish at a young age, with a relatively low natural mortality rate, indicate that it is better to harvest them at a later age. It may be perceived by the general community as poor management to remove a size limit for any species. In addition, many of the major commercial fishers of kingfish are happy with the current MLL and claim that the Sashimi market does not pay the best prices for smaller fish. Another factor to consider is the potential increase in effort if the MLL was removed. At certain times, large schools of small kingfish occur off the NSW coast and removing the MLL would cause these fish to become available to opportunistic fishers who do not regularly target kingfish at the moment. The result would be an over-supply of small kingfish to the markets with a corresponding decrease in market price. There appear to be no sound reasons for removing the MLL on kingfish.

The issue of changing the current MLL because of the perceived high levels of by-catch of undersized kingfish at certain times largely depends upon the mortality of discarded fish. We have now quantified the level of by-catch of undersized kingfish at some times and places through the voluntary logbook completed during this study (see Chapter 5). The results showed that at times the ratio of discarded to retained catch was up to 30:1. While there is likely to be some mortality of discarded kingfish, they are a robust fish and recapture rates from a co-operative tagging programme suggest good survival rates. Gillanders et al. (2001) reported an overall recapture rate of 8% of kingfish tagged by recreational anglers. The recapture rate of kingfish tagged by experienced taggers (i.e. those having tagged more than 50 fish) was up to 20%, suggesting that fish handling may effect survival. It is likely that commercial fishers, who are experienced in handling fish and do not traumatize them via tagging, release undersized fish in good condition. For the reasons discussed above, any change in MLL designed to reduce the problem of by-catch resulting from schools of kingfish which straddle the current MLL, would need to be an increase rather than a decrease in MLL.

The current MLL of 60 cm TL is well below the estimated size at sexual maturity of females of around 70 cm FL (approximately 80 cm TL) (Gillanders et al., 1999b). One argument for setting MLL's is to allow all individuals the chance to spawn once before being recruited into the fishery. The yield per recruit analyses suggest that yields may be increased by around one third if changing the MLL from 60 cm to 80 cm TL. While setting the MLL at the size at sexual maturity would increase yield and egg production, 80 cm TL may be inappropriate in this fishery. Apart from the fact that up to 90% of the commercial catch of kingfish were smaller than 80 cm TL during the present study, there is evidence that fish of this size may not be fully available to the fishery. The wide ranging pelagic nature of these large kingfish (Gillanders et al. 2001), together with the size composition of commercial landings (Chapter 2), suggest that setting a size limit based on the size at sexual maturity (80 cm TL, approximately 4.5 kg) may make kingfish generally unavailable to both commercial and recreational fishers.

Despite the inappropriateness of using the size at sexual maturity of female kingfish as the basis for a MLL, there remains an argument to increase it from 60 cm TL. Our estimate of fishing mortality suggests that kingfish are currently growth overfished. An increase to either 65 cm or 70 cm TL may result in increased yields under our best estimates of mortality and growth rates (but see uncertainties surrounding these estimates discussed above). These increases may also reduce the potential for the fishery to collapse due to poor recruitment in any year. While increases in the MLL to either of these sizes would reduce the problem of high discard rates from schools of fish straddling the current 60 cm TL MLL, they would have initial negative impacts on both commercial and recreational catches. Approximately 50% of kingfish in commercial landings were less than 65cm TL during 1999/00 and approximately 71% were less than 70 cm TL. These fish would weigh around 2.4 kg and 3.0 kg respectively and are the size preferred by the Sashimi markets in Sydney. Our estimates of growth rates suggest that it would take, on average, 9 months to grow from 60 to 65 cm TL and 18 months to grow from 60 to 70 cm TL.

The results of this study have shown that commercial fishers catch very few large (sexually mature) kingfish. Anecdotal evidence suggests that these large fish may not be available to the inshore fishery for much of the time. Alternatively, the lack of large fish may be the result of high fishing mortality as indicated by the catch curves between ages 3 and 6 (Fig. 4.1). Introducing a maximum legal size limit may be an astute management decision, which would have almost no impact on the commercial fishery.

5. MONITORING THE COMMERCIAL FISHERY FOR YELLOWTAIL KINGFISH OFF NSW

This chapter addresses objective 4 of the study.

Objective 4. To examine the possibility of using age-structured modelling in future assessments of yellowtail kingfish.

Results in this chapter suggest that the most cost-effective way to monitor the kingfish fishery off NSW is by using size-based assessments from fisher logbooks. Any benefits in using age-based assessments to model annual recruitment are countered by the costs and uncertainties surrounding estimating ages. Logbooks recording daily numbers of discarded and retained kingfish produced similar estimates of the mean sizes of fish landed from the dedicated fishery sampling described in Chapter 2. Logbooks may provide a relatively cheap method for assessing recruitment in terms of the abundance of undersized kingfish and any changes in the mean size of fish landed.

5.1. Introduction

As the principal agency responsible for aquatic resource conservation and management in NSW, NSW Fisheries has an obligation to monitor the status of fish stocks. Kingfish are one of the most highly prized species captured by recreational and commercial fishers in NSW, however monitoring of the state of the fishery has been rudimentary until now. A lack of information on the recreational catch has meant that the only information by which to assess the status of the kingfish stock has come from commercial landings. Since the 1980’s, kingfish have been assessed by examining trends in reported annual commercial landings. These trends have shown landings declining from 600 tonnes during the 1980’s down to less than 100 tonnes during the mid 1990’s. Commercial landings may vary for many reasons unrelated to the status of the stock (such as changes in fishing effort or management restrictions) and without information on the size and/or age composition of landings, cannot be used to reliably predict stock responses to exploitation.

Most important finfish species in NSW are monitored in terms of the size and age compositions of landings (eg. snapper, sea mullet, yellowfin bream, dusky flathead, sand whiting etc.). The results can be used in size and age based models to estimate stock biomass and to predict the way stocks will respond to being exploited. However, monitoring commercial landings provides no information on the abundance of undersized fish which are captured and subsequently discarded at sea. Information on these discards may be used to assess recruitment strength each year. The appropriateness of the current minimum legal length for kingfish may be assessed using information on the level of by-catch of undersized kingfish. This information can only be obtained by observations onboard commercial vessels, and the costs of sending trained fisheries observers onboard boats to document the discarded catch is prohibitive.

In this chapter we examine the utility of a daily fisher logbook as a method of monitoring the commercial kingfish fishery off NSW. A fisher log can detail the composition of both retained and discarded catches and, once initiated, may be a cheap alternative to the labour intensive assessments based on sizes and/or ages. A similar logbook is being used successfully to monitor catches of undersized eastern rock lobsters in NSW.

5.2. Materials and methods

We designed a daily log to be completed by fishers on days when they targeted kingfish (Fig. 5.1). The log recorded the date, the number of kingfish discarded, the number retained and the weight of the landed catch. This enabled calculation of discard rates and of the average size of kingfish landed on any day. Fishers willing to participate in completing a logbook on a voluntary basis were identified through port meetings.

We were able to check on the accuracy of the logbooks for days where both the logbook was completed by the fisher, and for which we had sampled as a part of the sampling of commercial landings detailed in Chapter 2. Variation in the size composition of kingfish on any fisher day was examined to assess the suitability of using mean size as an index of catch composition.

5.3. Results

Nine commercial fishers who targeted kingfish (of 15 who we approached) volunteered to trial the logbook for us. Logs were kept for varying periods between May 1999 and November 2000. We received details from 396 fisher days targetting kingfish.

A summary of the data provided is presented in Table 5.1 and shows that different fishers reported very different ratios of discarded to retained catch. Overall, individual ratios ranged between 0.4 and 3.2 undersized kingfish discarded for each legal sized kingfish retained. On a daily basis this ratio ranged between zero and 30 discarded fish for each one retained. The number of discarded fish per day was related to the mean sizes of kingfish being landed, with days of large amounts of discarding occurring when the mean size of landed fish was small Fig. 5.2.

Table 5.1. Summary of the data returned by the 9 fishers who completed voluntary logbooks.

Fisher	Number of days	Number discarded	Number retained	Ratio disc:retain	Landed weight kg	Mean weight per fish (kg)
Fisher 1	34	273	273	1.0:1	1101	4.03
Fisher 2	29	1608	unknown	N/A	2942	N/A
Fisher 3	15	112	68	1.6:1	377	5.54
Fisher 4	87	6658	2187	3.0:1	6727	3.07
Fisher 5	137	2491	7028	0.4:1	24856	3.53
Fisher 6	4	117	45	2.6:1	134	2.98
Fisher 7	21	423	133	3.2:1	280	2.11
Fisher 8	53	847	2172	0.4:1	6422	2.96
Fisher 9	16	194	106	1.8:1	301	2.84

DISCARDED KINGFISH LOGSHEET

NAME:_________________ PORT: _________________

* RECORD THE NUMBER OF UNDERSIZE KINGFISH DISCARDED, THE NUMBER OF KINGFISH KEPT (ABOVE 60 CM) AND THE APPROXIMATE AMOUNT OF KINGFISH WEIGHED IN EVERY DAY. IF YOUR CATCH IS LARGE, GOOD APPROXIMATIONS ARE SUFFICIENT.

DAY	DATE	NUMBER DISCARDED	NUMBER KEPT	APPROX. AMOUNT WEIGHED IN (KG)	COMMENTS
MON					
TUES					
WED					
THURS					
FRI					
SAT					
SUN					
MON					
TUES					
WED					
THURS					
FRI					
SAT					
SUN					
MON					
TUES					
WED					
THURS					
FRI					
SAT					
SUN					
MON					
TUES					
WED					
THURS					
FRI					
SAT					
SUN					

Figure 5.1. The voluntary logbook completed by selected fishers during the study.

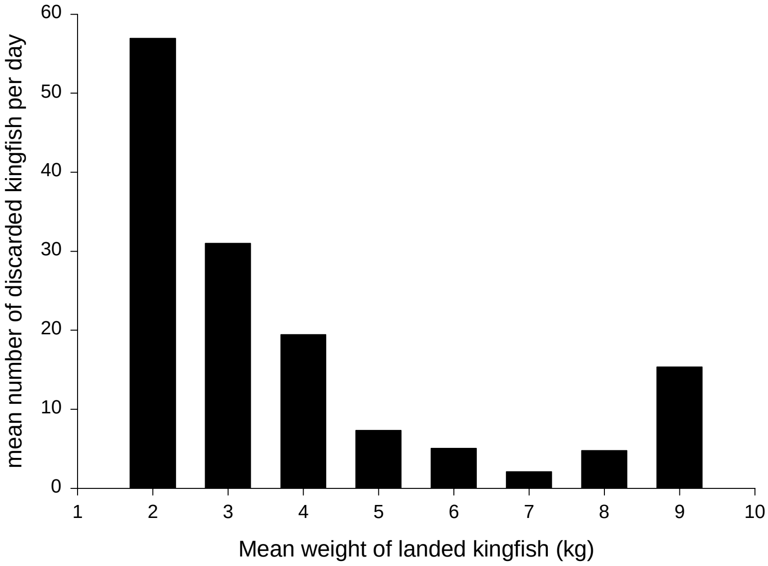


Figure 5.2. Mean numbers of discarded undersized kingfish per day with the mean size of landed kingfish reported in the voluntary logbook.

Comparing the data reported in the logbook with the sizes of kingfish measured from those fisher days as part of the sampling of commercial landings (Table 5.2), showed that the number of kingfish reported each day was similar to the number sampled. Differences were probably the result of either: (i) fishers estimating numbers incorrectly, or; (ii) fishers not sending their entire catch to market on that day. The estimated mean weights of kingfish landed on any fisher day were similar for both logbook and sampling data, with estimates of 3.14kg per fish from the logbook and 2.97kg per fish from fishery sampling.

Estimates of the standard error of the mean size of kingfish landed can be used as an index of how well mean size represents the size structure of the landed catch. Table 5.2 shows that for most catches measured the standard error of the mean size was small (generally less than 1 cm). This suggests that the mean size of the landed catch on any fisher day will generally be a good estimator of the size structure of the catch. However, when the standard error of the mean size is relatively large (e.g. Fisher 1 day 2 in Table 5.2), the mean size is not likely to reflect accurately the size composition of the catch. Data from the logbook gives no indication of the variance around the mean size.

Table 5.2. Comparisons between the data returned from 3 fishers who completed voluntary logbooks for the 24 days which we also sampled as part of the sampling of commercial landings. The mean weights per fish from fisher 3 were estimated from the mean size measured and the length/weight relationship described in Chapter 3.

	Logbook data			Sampling data						
Fisher	No. retained	Weight landed kg	Mean weight per fish kg	No. sampled	Weight sampled kg	Mean length (cm FL)	S. D. length	SE length	Mean weight per fish kg	Difference in mean weight kg
Fisher 1	24	70	2.92	23	70.5	58.9	7.7	1.61	3.07	-0.1
Fisher 1	5	27	5.40	8	36.5	64.5	15.2	5.37	4.56	0.8
Fisher 2	27	68	2.52	27	68	57.02	5.37	1.03	2.52	0.0
Fisher 2	46	150	3.26	45	150	63.35	4.6	0.69	3.33	-0.1
Fisher 2	119	420	3.53	134	420	63.16	5.2	0.45	3.13	0.4
Fisher 2	15	49	3.27	21	49	56.04	4.4	0.96	2.33	0.9
Fisher 2	4	11	2.75	5	11	54.3	1.68	0.75	2.20	0.6
Fisher 2	78	222	2.85	86	238	57.8	4.8	0.52	2.77	0.1
Fisher 2	10	25	2.50	11	25	56.27	3.8	1.15	2.27	0.2
Fisher 2	155	686	4.43	108	411	65.8	7.7	0.74	3.81	0.6
Fisher 2	15	67	4.47	15	67	68.2	8.46	2.18	4.47	0.0
Fisher 2	54	253	4.69	54	259	69.78	8.58	1.17	4.80	-0.1
Fisher 2	283	705	2.49	270	705	55.34	2.82	0.17	2.61	-0.1
Fisher 2	229	568	2.48	222	568	55.87	3.7	0.25	2.56	-0.1
Fisher 2	33	153	4.64	33	150	68.9	11.3	1.97	4.55	0.1
Fisher 3	27	76	2.81	23	74	61.37	4.85	1.01	3.22	-0.4
Fisher 3	23	76	3.30	23	unknown	56.65	3.59	0.75	2.33	1.0
Fisher 3	16	57	3.56	16	unknown	56.2	2.1	0.53	2.27	1.3
Fisher 3	17	57	3.35	10	unknown	58.4	2.5	0.79	2.55	0.8
Fisher 3	52	128	2.46	24	unknown	55.83	3.1	0.63	2.23	0.2
Fisher 3	97	304	3.13	94	unknown	58.83	3.6	0.37	2.61	0.5
Fisher 3	70	217	3.10	68	unknown	61	3.2	0.39	2.91	0.2
Fisher 3	40	130	3.25	46	unknown	62	3.3	0.49	3.05	0.2
Fisher 3	37	110	2.97	13	unknown	61.5	5.5	1.53	2.98	0.0
TOTAL	**1476**	**4629**	**3.14**	**1376**	**4092**				**2.97**	**0.17**

5.4. Discussion

It does not appear to be either cost-effective or reliable to use age-based models to monitor the kingfish fishery. The present study required a full-time fisheries technician plus a part-time scientist and various casual assistants to obtain an estimate of the age structure of commercial landings. For a fishery worth less than $1 million per year, it is difficult to justify these dedicated salaries each year to continue monitoring the fishery to this degree. In addition, the uncertainties surrounding estimating age for kingfish (see Chapter 3) and the fact that around 17% of otoliths collected during the present study were unable to be aged, suggests that the results from any age-based models may be unreliable and would need to be treated with considerable caution. The fishery is based on 2 and 3 year old fish and changes in the fishery are likely to be identifiable using size-structured monitoring.

Landings of commercially caught kingfish were dominated by fish close to the minimum legal length of 60 cm TL (approx. 52 cm FL). The results in Chapter 2 showed that approximately 75% of the landed catch during 1999/00 was within 10 cm of the MLL and 50% was within 5 cm of the MLL. These fish are mostly 2 and 3 year olds. The dedicated sampling of commercial landings during this study (Chapter 2 and also Table 5.2) showed that on any fisher day, all kingfish landed tended to be of a similar size. This was not always the case if fishers specifically targeted large kingfish for part of a day and small fish during another part of the day, but this was not common. Using the mean size of fish landed on a fisher day from logbook data would allow an estimation of the size composition of the catch based on the variance around the mean size observed during the present study.

The results of Chapter 4 showed that estimates of fishing mortality were high (F = 0.31 to 0.67) indicating that a large proportion of kingfish are captured each year. The most obvious threats to the fishery are: (i) poor years of recruitment and; (ii) fishers targetting the larger spawning stock which appears to be wide-ranging and unavailable to the inshore fishery much of the time. A daily fisher logbook could identify both of these occurrences. An increase in the mean size of landed fish may indicate: (i) targeting of larger fish, or; (ii) lower recruitment of barely legal sized fish. Lower landings may indicate poor recruitment if the mean sizes landed and the ratios of discarded to retained fish remain similar. Significant changes in landings, discarded to retained ratios or mean sizes identified by a logbook would indicate more in-depth sampling of the fishery was required to assess the reasons for the changes. Some low-level random sampling of the sizes of kingfish landed would be required to ensure the validity of the logbook data. It is likely that monitoring the kingfish fishery using daily fisher logbooks would be welcomed by commercial fishers as a cheap alternative to full-time, dedicated fishery sampling.

Information on the abundance of undersized kingfish from a daily fisher logbook would provide the first quantitative evidence of changes in the stock. Each year since pelagic kingfish traps were banned in 1996, fisheries managers, politicians and recreational fishers have been keen to see positive results in terms of increases in the abundance of kingfish. There has been no strong evidence of any change in the kingfish stock since pelagic traps were banned. Every year there are anecdotal claims from recreational fishers of increasing numbers of undersized kingfish, however these have not become evident in commercial landings (landings have decreased since 1996). A logbook detailing the discarding of undersized kingfish in the commercial fishery would provide reliable data on the relative abundance of recruiting year classes of kingfish. It should be noted, however, that we have no validation of the accuracy of the information on the number of discards reported. Fisheries observers onboard commercial vessels could be used to provide a check on this. Finally, the logbook would provide a check on the accuracy of the catch return data provided by fishers to NSW Fisheries.

6. RECOMMENDATIONS AND IMPLICATIONS

6.1 Benefits

Benefits from this study will flow to both the commercial and recreational users of the kingfish resource. The knowledge gained from sampling commercial catches will allow for future cost-effective monitoring of the fishery. Information on the fishery and on growth and mortality rates will benefit fisheries managers when assessing the appropriateness of the current minimum legal length for kingfish in NSW.

The refined ageing techniques using sectioned otoliths will benefit researchers studying similar species around the world.

6.2 Further Development

The information provided in this report should be used in discussions concerning the minimum legal length for kingfish in NSW. These discussions should include both the commercial and recreational fishing sectors.

The harvest of kingfish by recreational fishers needs to be described. This should include estimates of the quantity of kingfish caught and the size/age composition of catches.

The timing of formation of the first opaque mark in kingfish otoliths needs to be resolved. This information would enable estimates of growth rates to be refined for small kingfish.

Continued monitoring of the status of the kingfish stock is highly recommended.

6.3 Conclusion

Dedicated sampling of the commercial landings of kingfish in NSW has shown that the fishery is dominated by 2 and 3 year old fish between 52 and 65 cm fork length. The size composition of kingfish larger than the current MLL of 60 cm total length does not appear to have changed since the 1980’s, despite large declines in commercial landings. Refined estimates of growth rates based on estimates of ages from sectioned otoliths showed an average size of around 50 cm fork length after 1 year and around 72 cm fork length after 5 years. The maximum recorded age was 21 years. There were no differences in the growth rates of kingfish between regions studied, nor between males and females.

Estimates of mortality rates and yield per recruit suggest that kingfish are currently growth overfished. Total mortality estimates suggest that between 35% and 55% of kingfish may die each year due to both natural and fishing mortality. Removing the minimum legal length for kingfish may reduce the yield per recruit by around one third. Increasing the minimum legal length to the estimated size at sexual maturity (approximately 70 cm fork length) may increase the yield per recruit by around one third, but would not be appropriate in this fishery because of limited availability of these larger fish. The introduction of a maximum legal length may help to protect the spawning population of kingfish while having minimal impact on the commercial fishery.

Future monitoring of the status of the kingfish stock is essential. The most cost-effective method for monitoring the commercial fishery is by using a combination of yearly landings, low-level random sampling of the size composition of commercial catches and a fisher logbook documenting the mean sizes of fish landed.

7. REFERENCES

Annala, J.H., Sullivan, K.J. and O'Brien, C.J. (compilers) (1999) Report from the Fishery Assessment Plenary, April 1999: stock assessments and yield estimates. 430 pp Unpublished report held in NIWA Library, Wellington. MAF, New Zealand.

Beamish, R. J. (1979) Differences in the age of Pacific hake (*Merluccius productucs*) using whole otoliths and sections of otoliths. *Journal of the Fisheries Research Board of Canada* 36: 141-151.

Beamish, R. J. and Fournier, D. A. (1981) A method for comparing the precision of a set of age determinations. *Can. J. Fish. Aquat. Sci*. 38: 982-983.

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.

Gillanders, B. M., Ferrell, D. J. and Andrew, N. L. (1996) Determination of ageing in kingfish (*Seriola lalandi*) in New South Wales. Final report to the Fisheries Research and Development Corporation, project No. 95/128. NSW Fisheries, Cronulla.

Gillanders, B. M., Ferrell, D. J. and Andrew, N. L. (1999a) Aging methods for yellowtail kingfish, *Seriola lalandi*, and results from age- and size-based growth models. *Fishery Bulletin* 97: 812-827.

Gillanders, B. M., Ferrell, D. J. and Andrew, N. L. (1999b) Size at maturity and seasonal changes in gonad activity of yellowtail kingfish (*Seriola lalandi*; Carangidae) in New South Wales, Australia. *New Zealand Journal of Marine and Freshwater Research* 33: 457-468.

Gillanders, B. M., Ferrell, D. J. and Andrew, N. L. (2001) Estimates of movement and life-history parameters of yellowtail kingfish (*Seriola lalandi*): how useful are data from a cooperative tagging programme? *Marine and Freshwater Research* 52: 179-192.

Gray, C. A., Pease, B. C., Stringfellow, S. L., Raines, L. P., Rankin, B. K. and Walford, T. R. (2000) Sampling estuarine fish species for stock assessment. Final report to the Fisheries Research and Development Corporation, project No. 94/042. NSW Fisheries Final Report Series No. 18 ISSN 1440-3544.

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

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

Kimura, D. K. (1977) Statistical Assessment of the Age-length Key. *Journal of the Fisheries Research Board of Canada*. 34(3): 317-324.

Kimura, D. K. and Lyons, J. J. (1991) Between-reader bias and variability in the age determination process. *Fishery Bulletin* 89: 53-60.

King, M. (1995) Fisheries Biology, Assessment and Management. Fishing News Books, Oxford, 34pp.

Lai, Han-Lin (1993) Optimal sampling design for using the age-length key to estimate age composition of a fish population. *Fishery Bulletin* 92: 382-388.

Manooch, C. S. and Potts, C. P. (1997) Age, growth, and mortality of Greater Amberjack, *Seriola dumerili*, from the U. S. Gulf of Mexico headboat fishery. *Bulletin of Marine Science* 61(3): 671-683.

Pauly, D. (1980) On the interrelationships between natural mortality, growth parameters, and mean environmental temperature in 175 fish stocks. *J. Cons. Int. Explor. Mer*. 39(2): 175-192

Quinn, T. J. and Deriso, R. B. (1999) Quantitative Fish Dynamics. Oxford University Press, New York, 542pp.

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

Smith, A., Pepperell, K., Diplock, J., and Dixon, P. (1991) Study suggests NSW kingfish one stock. *Australian Fisheries* March, 34-36.

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

Stewart, J. and Ferrell, J. (2001) Age, growth, and commercial landings of yellowtail scad (*Trachurus novaezelandiae*) and blue mackerel (*Scomber australasicus*) off the coast of New South Wales, Australia. *New Zealand Journal of Marine and Freshwater Research*. 35(3): 539-549.

Thompson, B. A., Beasly, M. and Wilson, C. A. (1999) Age distribution and growth of greater amberjack, *Seriola dumerili*, from the north-central Gulf of Mexico. *Fishery Bulletin* 97: 362-371.

8. INTELLECTUAL PROPERTY

No patentable inventions or processes have been developed as part of this project. The work reported in this report will be published in scientific journals.

9. STAFF

Staff directly employed on this project with FRDC funds were:

Doug Ferrell	Principal Investigator
Dr Michael Lowry	Fisheries technician
Bryan van der Walt	Fisheries technician
Daniel Johnson	Fisheries technician
Glenn Cuthbert	Casual assistant
Michael Middleton	Casual assistant
Dean Hiscox	Casual assistant
Darrin Nobbs	Casual assistant

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

Dr John Stewart	Scientific Officer

Other titles in this series:

ISSN 1440-3544

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

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

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

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

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

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

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

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

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

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

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

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

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

No. 14 Fielder, D.S., Bardsley, W.J. and 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.

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

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

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

No. 18 Gray, C.A., Pease, B.C., Stringfellow, S.L., Raines, L.P. 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.

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.

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.

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.

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.

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 – main report, 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.

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.

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

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.

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).

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.).

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.

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

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.

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.

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.

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.