Ageing yellowtail (*Trachurus novaezelandiae*) and blue mackerel (*Scomber australasicus*) in New South Wales.

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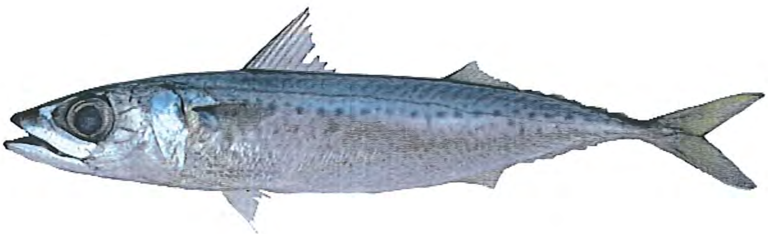

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Non-technical summary

95/151 Ageing Yellowtail (*Trachurus novaezelandiae*) and Blue Mackerel (*Scomber australasicus*) in New South Wales.

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OBJECTIVES:

(1) To provide estimates of the size and age composition of the commercial and recreational harvest of yellowtail and blue mackerel.

(2) To provide estimates of geographic differences in the age composition of commercial and recreational catches.

(3) To provide preliminary validations of age estimates in these species

NON TECHNICAL SUMMARY

Yellowtail (*Trachurus novaezelandiae*) and blue mackerel (*Scomber australasicus*) are two of the most important small pelagic baitfish in New South Wales. Both species are popular with commercial and recreational fishers for use as bait and support a growing commercial fishery for human consumption. Despite this there was no information on age and growth of these species or the size and age structure of harvests in New South Wales prior to the present study. This study determined the growth curves for these two species and quantifies the size and age compositions of catches of yellowtail and blue mackerel in New South Wales.

Examination of the commercial and recreational catches at three locations on the New South Wales coast: Wooli, Sydney/Wollongong and Bermagui/Eden, showed that both sectors harvested yellowtail and blue mackerel of the same sizes and ages. Similarly, the age compositions of fish in these catches showed little evidence of geographic variation. The majority of yellowtail captured at each location were 2 and 3 year olds with smaller numbers of fish up to 15 years. The majority of blue mackerel captured at each location were 1 year olds with smaller numbers of fish to 7 years.

Blue mackerel from Bermagui/Eden grew faster than those from more northern locations reaching 26 cm fork length after 1 year. Yellowtail from Sydney/Wollongong grew faster than those from either Wooli or Bermagui/Eden reaching 20 cm fork length after 2 years.

Estimates of age for both species were validated by marking the structures used to determine age (otoliths) with a stain and keeping the fish in aquaria for 1 year. The results showed that one annual mark is formed within the otoliths per year and that accurate estimates of age can be made by counting the number of annual marks within an otolith.

1. Introduction

1.1. Background

The NSW Fishing Industry Research Advisory Committee (FIRAC) identified the stock assessment of small pelagic baitfish species as a high priority for research in 1995. The present project was developed in response to a request from NSW FIRAC to provide preliminary age and growth information on two important small pelagic species: *Trachurus novaezelandiae* (yellowtail) and *Scomber australasicus* (blue, slimy or greasy mackerel). Information on size-at-age of these species at different locations will provide a starting point for future stock assessments of these species.

1.2. Need

Pilchards, yellowtail and blue mackerel are the most commonly harvested baitfishes in New South Wales. Pilchards are the subject of a large co-operative study presently being funded by FRDC (project No. 94/029), and have been studied extensively in NSW (Blackburn, 1949, 1950; Joseph, 1981). Relative to pilchards, little is known of the biology of either yellowtail or blue mackerel from NSW. Blue mackerel and yellowtail are caught in large numbers in NSW, both by commercial fishers and recreational anglers, particularly those taking them as bait for large pelagic fishes. Commercial landings of yellowtail have increased during recent years (Fig. 1.1) and the use of both species for human consumption is increasing. Validated estimates of age are available only for *Trachurus* species in New Zealand (Horn 1993). Horn estimated a maximum age of 28 years for *Trachurus novaezelandiae*, with an important proportion of the fishery made up of fish older than 10 years. This finding led to some concern in NSW because expectations were that age distributions of *Trachurus* would be more similar to those of pilchards, in that they would be dominated by relatively young fish (2-5 years, Fletcher 1991). These concerns highlighted the need for information on the age-structure of harvests of yellowtail and blue mackerel in New South Wales.

The validation used by Horn (1993) was based on the marginal increment approach, with additional support coming from following strong year classes through time. Prior to the present study there were no unequivocal validations of age estimates for these species and no estimates of age at all for yellowtail or blue mackerel in NSW. It appeared likely that both yellowtail and blue mackerel could be aged using conventional otolith techniques, but it was recognised that these age estimates would need to be properly validated before they could be used with confidence for fisheries management purposes.

1.3. Objectives

The objectives of this project were:

(1) To provide estimates of the size and age composition of the commercial and recreational harvest of yellowtail and blue mackerel

(2) To provide estimates of geographic differences in the age composition of commercial and recreational catches

(3) To provide preliminary validations of age estimates in these species.

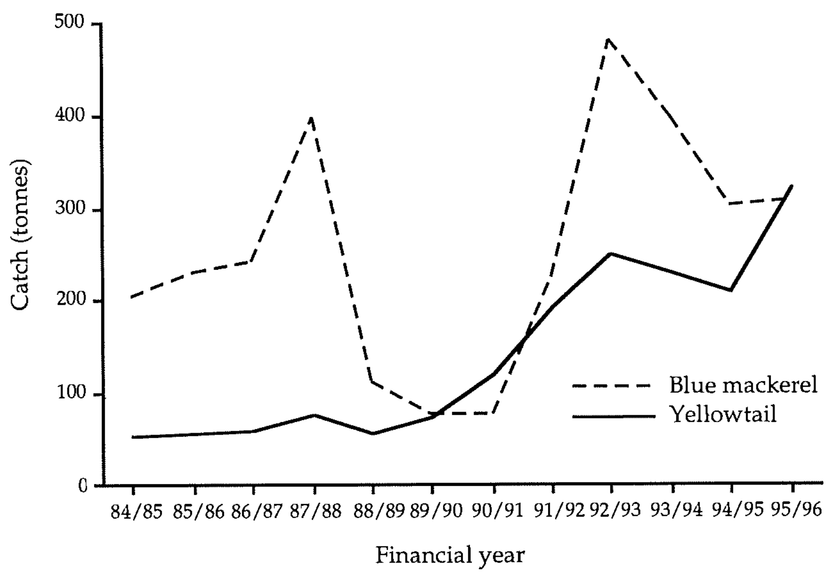

Figure 1.1. Annual commercial catches of yellowtail and blue mackerel in New South Wales. (Source: NSW Fisheries catch statistics)

2. Size and age composition of commercial and recreational catches.

The results in this chapter address objectives 1 and 2.

Objective 1. To provide estimates of the size and age composition of the commercial and recreational harvest of yellowtail and blue mackerel.

This chapter describes the size and age compositions of yellowtail and blue mackerel in commercial and recreational catches. 12,852 length measurements were made during the peak catching times for both species and surveys of three major gamefishing tournaments were done. These size compositions were combined with estimates of size-at-age to provide estimates of the age compositions of commercial and recreational catches.

Objective 2. To provide estimates of geographic differences in the age composition of commercial and recreational catches.

Estimates of the age compositions of yellowtail and blue mackerel in commercial and recreational catches were obtained for three locations off the New South Wales coast: Wooli, Sydney/Wollongong and Bermagui/Eden. Age compositions of fish in catches from these locations revealed little geographic variation. The majority of yellowtail captured at each location were 2 and 3 year olds, while the majority of blue mackerel captured at each location were 1 year olds.

2.1 Introduction

In Australia, yellowtail and blue mackerel are found around the south of the continent from southern Queensland to Western Australia (Kailola et al., 1993). Yellowtail are thought to mature at around 20 cm for females and 22 cm for males and reach a maximum length of 33 cm fork length (F.L.). Blue mackerel are thought to reach maturity at around 30 cm F.L. and grow to around

50 cm F.L. Both species are serial spawners during spring/summer, and are frequently captured together in large numbers in NSW by commercial and recreational fishers (Kailola et al. 1993).

Yellowtail and blue mackerel are utilised mainly as bait and increasingly for food. The recent increase in popularity of both species for human consumption has resulted in higher market prices and an increase in the commercial catch. Commercial landings of yellowtail in particular have steadily increased during recent years reaching a peak of 320 tonnes in 1995/96. Commercial landings of blue mackerel have historically been higher (averaging around 360 tonnes during the previous 12 years) but have been more variable (Fig. 1.1).

Most of the marketed commercial catch is taken by purse seining from Sydney southwards, although some fishers do target yellowtail and blue mackerel on the north coast of New South Wales. Landings are centred around a few ports, with most yellowtail being landed in Wollongong (55% of the catch between July 1984 and June 1996), and most blue mackerel being landed in Eden (45%), Wollongong (29%) and Bermagui (8.5%) during the same time period (source: NSW Fisheries Catch Statistics). Yellowtail and blue mackerel are also captured by commercial fishers for use as bait, but there are no estimates of the fish used this way.

The size of the recreational harvest of yellowtail and blue mackerel is unknown, but recreational fishers are potentially significant users of the resource. Yellowtail and blue mackerel are two of the most popular and readily available baitfish in NSW and are used as both live and dead baits when targeting a wide variety of species, including large pelagic gamefish. Both species feature significantly in recreational catches in estuaries such as Sydney Harbour (Henry, 1984) Botany Bay (Anon., 1981) and Jervis Bay (Anon., 1990). Baitfish are also captured from many headlands, bays and reef areas along the coast (see Glaister and Diplock 1993 for summary maps of the major baitfishing grounds in NSW).

Despite their increasing importance as a commercial fishery little is known of the biology of either yellowtail or blue mackerel from NSW. Validated estimates of age are available for *Trachurus* species in New Zealand (Horn 1993) which indicated a maximum age of 28 years for yellowtail and a significant proportion of the fishery made up of fish over 10 years old. The only published ageing study on blue mackerel in Australian waters (Stevens et al., 1984) suggests that blue mackerel in the Great Australian Bight grow rapidly and reach sexual maturity at around 30 cm fork length in about 3 years. Studies on other Scombrids around the world also suggest fast growth rates, with most fisheries being dependent mostly on fish aged between 1+ and 4+ (Jones, 1983; Kotlyar & Abramov, 1982; Chang & Chen, 1976).

The findings of Horn (1993) led to concerns amongst fishers in NSW because of increasing fishing pressure on yellowtail and blue mackerel and previous expectations that the fishery would be comprised of mostly young fish. Increasing fishing pressure on known baitgrounds has also caused recreational gamefishers to be concerned about the future availability of bait and the effects that any overfishing of baitfish may have on their target large pelagic gamefish. These concerns highlighted the need for information on the age-structure of harvests of these species in New South Wales. In this chapter we quantify the age and size composition of these species in commercial and recreational catches. We use size at age data to provide estimated growth curves for both species at three locations along the coast. The information provided in this chapter will be used in future stock assessments of these species.

2.2 Materials and methods

2.2.1 *Size composition of the commercial harvest.*

Lengths of yellowtail and blue mackerel were measured to estimate the size composition of the commercial harvest. Most of the commercial harvest for these species comes from fishers using purse-seine nets out of the Sydney/Wollongong and Bermagui/Eden regions, with a few fishers targeting them on the north coast of NSW, mainly from Port Stephens and Wooli (Fig. 2.1). The targeting of yellowtail and blue mackerel by purse-seine fishers north of Sydney was minimal throughout the present study and consequently size distributions from commercial catches were not available north of Sydney. Both yellowtail and blue mackerel are landed from the Sydney/Wollongong region throughout the year and commercial catches were sampled during July/August, October and December 1996. Commercial fishers report that the fishery for both

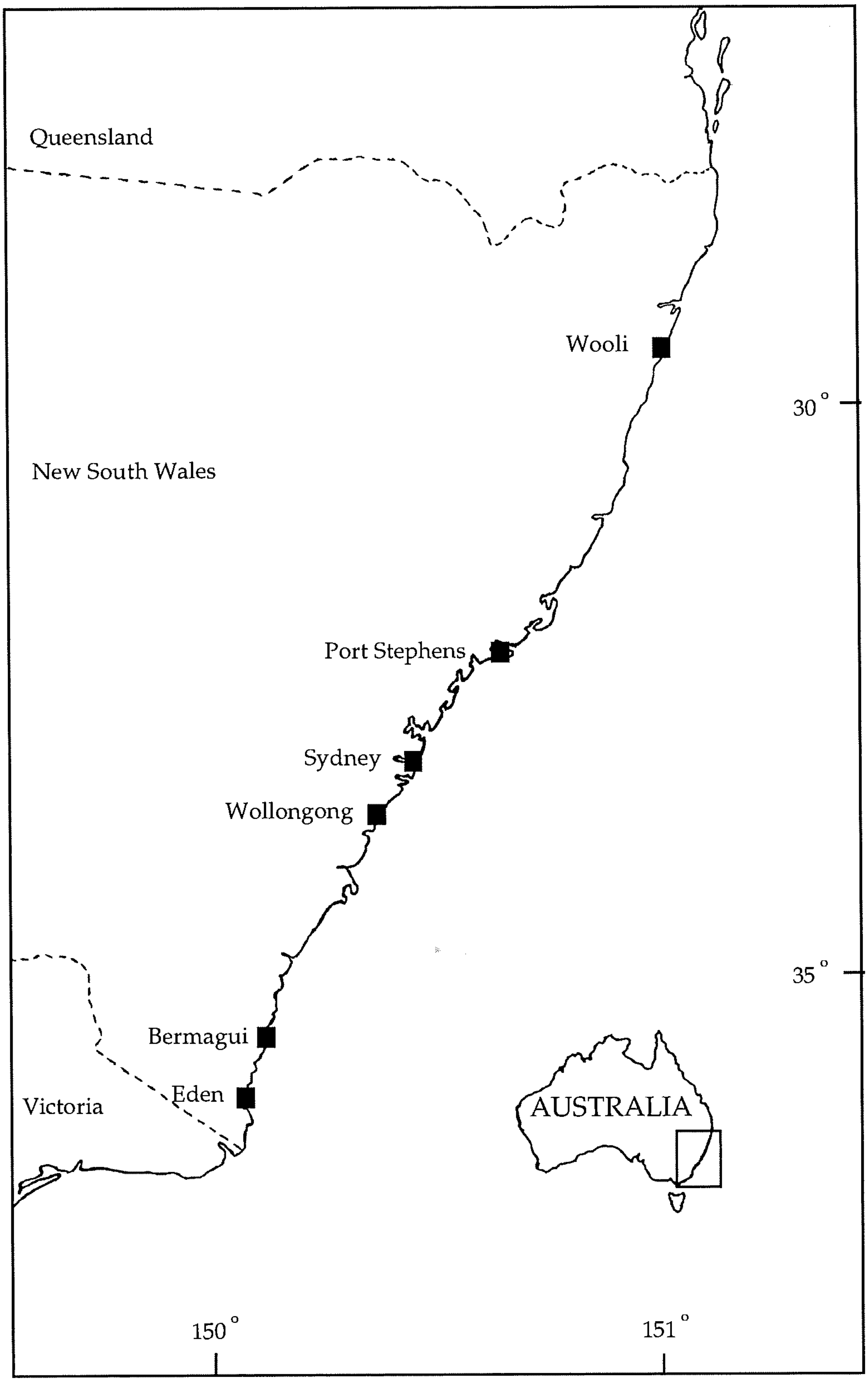

Figure 2.1. Location of study sites.

species in Bermagui/Eden is strongly correlated to water temperature, with fish tending to disappear during winter when the sea temperature falls below 13 °C (usually around June), and not returning in large numbers close to the coast until the water is approximately 17 °C (usually between November and January). Consequently commercial catches from the Bermagui/Eden region were sampled at the very end of the season during June 1996 and then again in January/February/March and April 1997.

Trips were done with commercial fishers out of each of the ports sampled to gain an understanding of the fishing methods and fish handling practices employed in the fishery. A working knowledge of the fishery at each location revealed when and under what circumstances the catch was sorted or graded and permitted representative subsampling of catches. To estimate the size composition of the commercial harvest we aimed to measure the catches from as many fisher days as possible for each species during each sampling period and to measure at least 100 individuals of each species from each catch. Catches of fish were either sampled directly at the point of landing prior to any sorting or grading, or unsorted boxes of fish from Bermagui and Eden were sent to the Sydney fish markets to be measured. Catches of yellowtail were measured from 30 fisher days from Sydney/Wollongong and from 11 fisher days from Bermagui/Eden. The catches of blue mackerel were measured from 28 fisher days from Sydney/Wollongong and from 15 fisher days from Bermagui/Eden. Lengths were measured as fork length and were recorded to the nearest 5 mm for each species. The weights of the fish measured and of the total catch for each trip were recorded in order to determine the contribution of the sampled catches to the total catch for the sampling period.

2.2.2 *Size composition of the recreational harvest.*

Representative sampling of recreational catches of yellowtail and blue mackerel is difficult because fishing activity is widespread and much of the catch is used at sea. Prior to the present study, observations at large gamefishing tournaments (e.g. tournaments at Mooloolabah, Lake Macquarie's "Big fish bonanza", Botany Bay's AIBT and the Port Stephens Billfish Classic) revealed that some gamefishers use large numbers of yellowtail and blue mackerel as bait (J. Pepperell pers. comm.). After consulting the peak recreational fishing bodies (including the New South Wales Gamefishing Association and the Port

Stephens, Bermagui, Canberra and Port Hacking Game Fishing clubs), catches of yellowtail and blue mackerel were sampled at the two largest game-fishing tournaments in New South Wales where the use of baitfish is common. The tournaments sampled were the 1996 and 1997 Port Stephens Interclub Gamefishing Tournament and the Canberra Game Fishing Club Yellowfin Tuna Tournament in Bermagui in May 1996.

To estimate the sizes and numbers of yellowtail and blue mackerel captured by gamefishers during these tournaments, gamefishers were surveyed at the end of each days fishing, either at weigh-stations, boat ramps or marinas. Fishers from each boat were asked how many of each species they had caught for bait that day, the baitground where they caught them, how many were used, released or kept for other purposes (e.g. dead-baits or burley), and any retained baits were measured. Prior to each tournament all participants were briefed as to the nature of our study and co-operation from all tournament organisers and participants was excellent.

Because the sizes of yellowtail and blue mackerel captured by recreational fishers were estimated by measuring baits retained at the end of each day, it was possible that a bias may have been encountered if a particular size of bait was preferred on any particular day (e.g. if only the smallest baits captured were retained at the end of a day). The magnitude of this possible bias was assessed at the 1996 and 1997 Port Stephens Interclub Gamefishing Tournaments. Baitfish were caught and measured independently alongside competitors at the major baitgrounds on each morning of the tournaments.

In addition to information on the sizes of yellowtail and blue mackerel used during gamefishing tournaments, estimates of the sizes of blue mackerel captured by recreational fishers were derived from the boat-ramp interview study done by NSW Fisheries (FRDC No. 94/053, Steffe et al. 1996). This study produced estimates of numbers and sizes of blue mackerel and yellowtail/jack mackerel combined landed by trailer boat fishers in New South Wales. The survey did not distinguish between the morphologically similar yellowtail (*Trachurus novaezelandiae*) and jack mackerel (*T. declivis*) and as such estimates of the sizes of yellowtail landed could not be reliably used in the present study.

2.2.3 *Age determination*

Yellowtail and blue mackerel were aged to (i) determine the age composition of commercial and recreational catches and (ii) to generate growth curves for each species at different locations. Estimates of age were made using sagittal otoliths of fish from 3 locations: Wooli, Sydney/Wollongong and Bermagui/Eden. Otoliths to be used for estimating age compositions were removed from fish which were either purchased from, or donated by, commercial fishers and were representative of the sizes of fish in the commercial catches at each location. Additional otoliths from smaller and larger fish than those typically in the commercial harvest were also used for estimating growth. These extra fish were obtained from the CSIRO research vessel "Southern Surveyor", charter boats, other commercial fishers and recreational fishers. The date, location of capture and length of each fish sampled was recorded, and each pair of otoliths cleaned and stored in small envelopes. Otolith weight has been associated with fish age in other small pelagic fish (e.g. Fletcher 1991) and we consequently weighed all otoliths to the nearest 0.001g.

For a structure to be of use in estimating age, it must grow throughout the life of the fish. To determine whether sagittal otoliths grow throughout the lives of yellowtail and blue mackerel, otolith radii and weights were plotted against fork length and age for each species. Otolith radius for yellowtail was measured as the distance from the core to the edge along the ventral edge of the sulcus in sectioned otoliths (Fig. 2.2). Otolith radius for blue mackerel was measured on whole otoliths as the distance from the core to the edge along the longest axis on the posterior part of the otolith (Fig. 2.3). Otolith weight for each fish sampled was the combined weights of the left and right otoliths.

Estimates of ages for yellowtail were made from sections of otoliths. Each otolith was embedded in resin, sectioned transversely through its centre, mounted on a glass slide and viewed under a compound microscope using reflected light against a black background. Opaque bands were evident in sections of otoliths viewed this way and were scored as annual marks (Fig. 2.2). Measurements were made, using an image processor, from the core of the sectioned otolith to the centre of each successive opaque band and to the otolith edge along the ventral edge of the sulcus. Otoliths were read twice with a break of one month between the 1st and 2nd readings. Where the 2 readings differed, otoliths were read a third time and given a final score. An arbitrary birthday of 1 January was used for assigning ages from counts of annuli, ie. a fish with 2 annuli sampled in March would be 2 years and 3 months old. This date was selected because it has been used for yellowtail in New Zealand and it has some biological meaning because yellowtail in New Zealand (Horn, 1993) and New South Wales (pers. obs.) appear to spawn throughout late spring and summer.

Sectioned otoliths of blue mackerel were uninterpretable. When whole otoliths were viewed immersed in lavender oil using a stereo microscope and reflected light against a black background, alternating opaque and translucent zones became visible (Fig. 2.3). Opaque bands were best viewed on the outer or anti-sulcul surface at the posterior end of the otolith. Measurements were made using an image processor from the core to the centre of each opaque band and to the otolith edge along the longest axis on the posterior part of the otolith. Otoliths were assigned an age using the number of opaque bands visible and based on an arbitrary birthday of 1 January. All otoliths were read twice and three times if the 1st and 2nd readings differed.

2.2.4 *Age compositions of catches*

The age compositions of commercial catches were estimated using the size compositions and estimates of age from each region. Fish used in the estimated age distribution were drawn at random from 1 cm size intervals. The number drawn from each size interval was in the same proportion to that size interval's contribution to the pooled length distribution from each region.

The age composition of the recreational catch of blue mackerel was estimated by applying the age data to the sizes of fish measured during gamefishing tournaments and from boat ramp interviews with anglers. The age composition was generated in the same way as the age composition of the commercial catch. Small numbers of measurements of yellowtail from recreational fishers precluded calculating an age frequency distribution but the observed sizes of fish gave an indication of the age composition.

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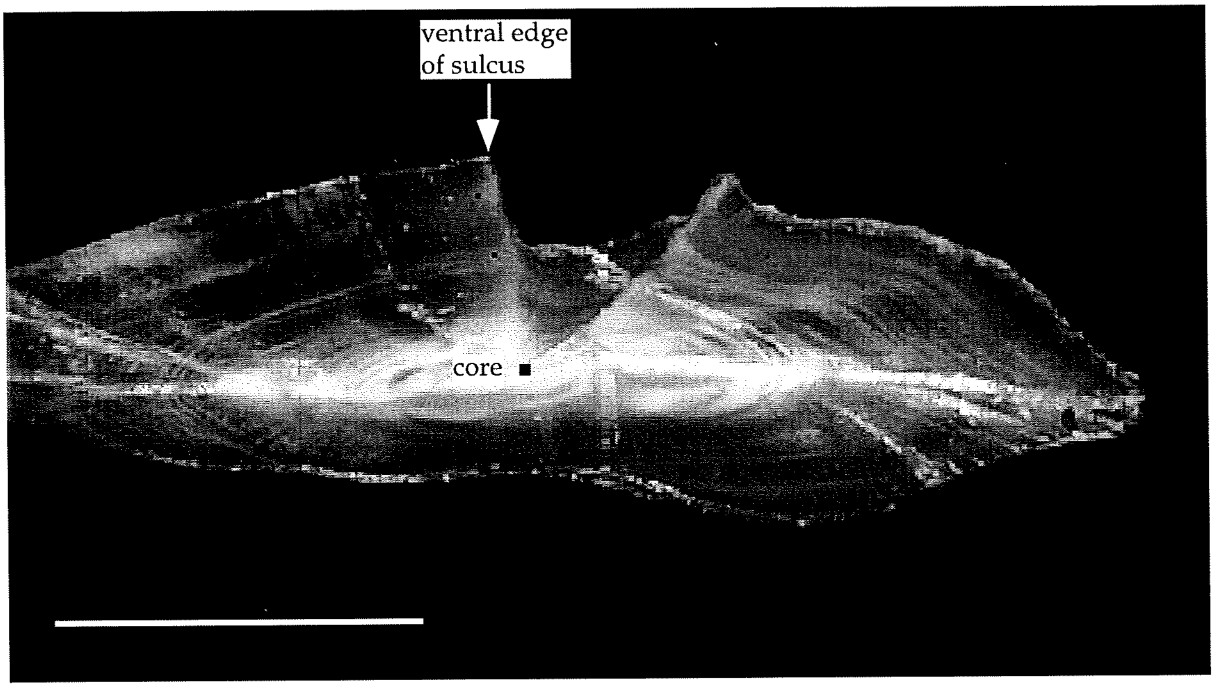

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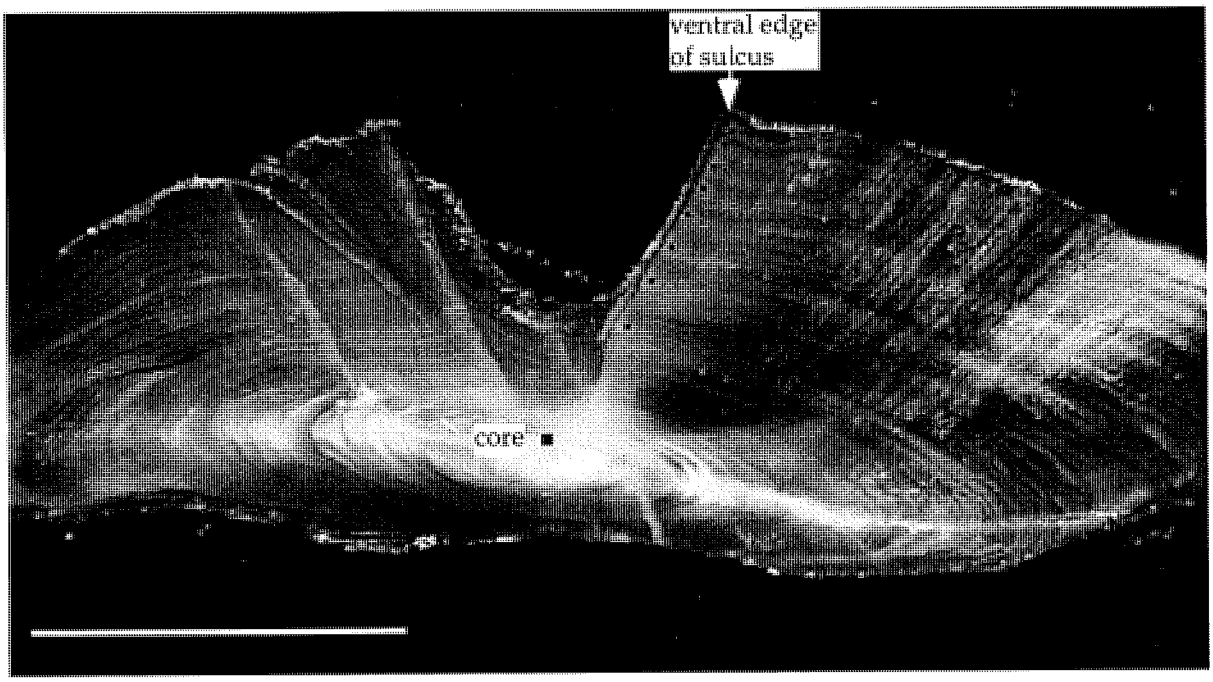
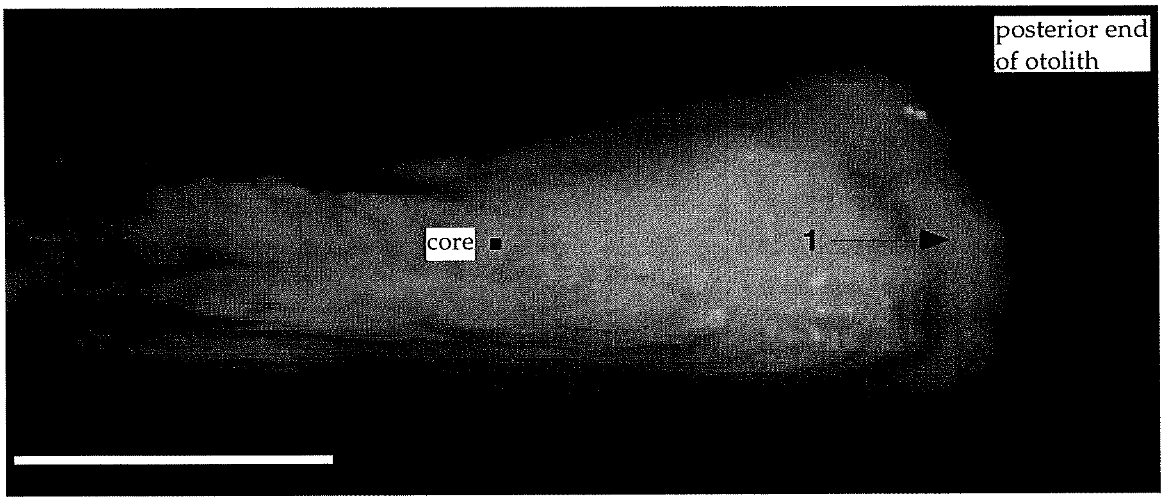


Figure 2.2. Sections of yellowtail otoliths viewed under reflected light against a black background showing position of annuli. **A.** 222mm F.L. aged 2+. **B.** 286mm F.L. aged 8+. Scale bars are 1mm.

A.



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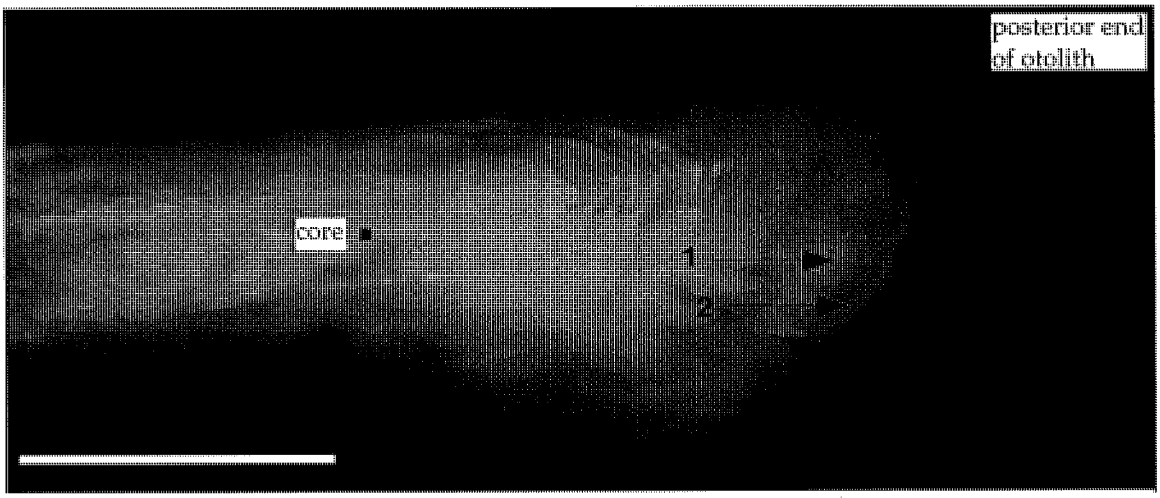


C.

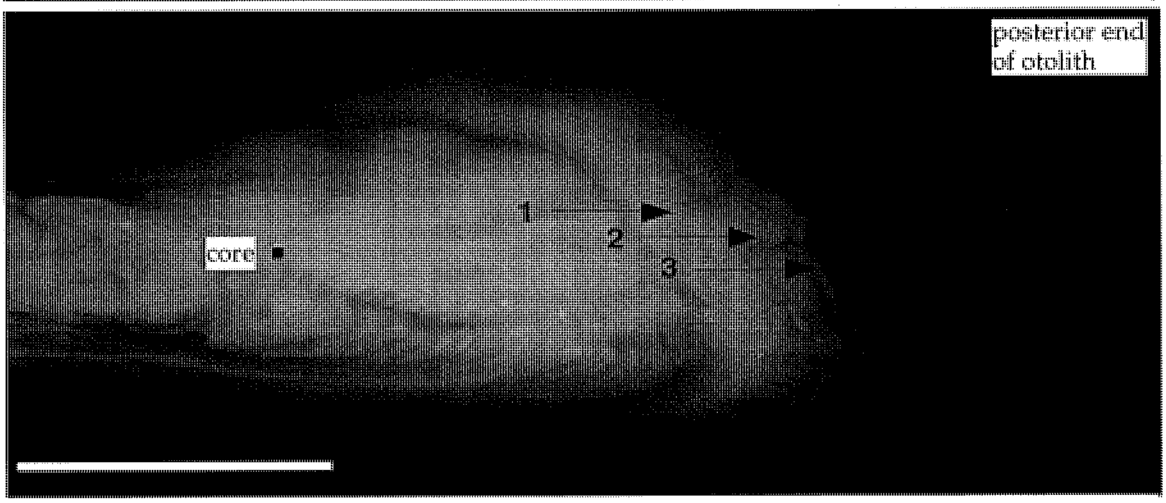


Figure 2.3. Whole blue mackerel otoliths immersed in lavender oil and viewed under reflected light against a black background. Arrows show position of the opaque marks scored as annuli on the posterior part of the otolith. **A.** 257mm F.L. aged 1+. **B.** 259mm F.L. aged 2+. **C.** 309mm F.L. aged 3+. Scale bars are 1mm.

2.2.5 *Estimating growth*

Growth curves describing size at age of yellowtail and blue mackerel pooled from all locations and from Eden/Bermagui, Sydney/Wollongong and Wooli were derived using procedures outlined in Schnute (1981). Schnute's model relates size to age by 4 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 which are chosen to be near the upper and lower ends of the range of ages in the data. In the present study τ_1 and τ_2 were chosen to be 2 and 8 years for yellowtail and 1 and 3 years for blue mackerel for all locations. Choosing τ_1 and τ_2 to be constant across locations allowed mean sizes at age to be formally compared among locations. The 2 parameters a and b combine to describe the shape of the curve. 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 2 parameter model (y1 and y2) 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 three-parameter models the model with the lowest sum of squares was selected as the better fit.

2.3 Results

2.3.1 *Size composition of commercial catches.*

A total of 7,148 yellowtail and 5,704 blue mackerel were measured from catches of commercial fishers. The sizes of yellowtail landed by commercial fishers differed between the Sydney/Wollongong and Bermagui/Eden regions (Fig. 2.4), with those from Sydney/Wollongong (mean size 23.0 cm F.L.) being generally larger than those from Bermagui/Eden (mean size 20.3 cm F.L.). Half of the catch from Sydney/Wollongong was made up of fish larger than 23 cm F.L. in contrast to only 2% from Bermagui/Eden.

The sizes of blue mackerel landed by commercial fishers ranged from 16 cm to 39.8 cm F.L. (Fig 2.5). The mean sizes of fish measured were 29.0 cm F.L. from Sydney/Wollongong and 27.8 cm F.L. from Bermagui/Eden. The mean size of blue mackerel from Bermagui/Eden was influenced by a few large catches of very small fish.

2.3.2 *Size composition of recreational catches.*

Surveys on bait usage at major gamefishing tournaments revealed that fishers in these tournaments can use large numbers of yellowtail and blue mackerel for bait (Table 2.1). Interviews with a large proportion of competing boats at each tournament showed that the mean sizes of retained yellowtail was similar at each tournament. The mean sizes of retained blue mackerel varied between years at the Port Stephens Interclub and were largest at the Canberra Game Fishing Clubs Yellowfin Tuna Tournament at Bermagui.

Interviews at boat ramps with anglers competing in the Canberra Game Fishing Club Yellowfin Tuna Tournament, at Bermagui on the 18th and 19th of May 1996, revealed that bait catching was done almost exclusively off Horseshoe Bay. 83% of interviewed boats captured bait (Table 2.1) and most retained blue mackerel were between 27 and 31 cm F.L. and most yellowtail between 16.5 and 24 cm F.L. (Fig. 2.6).

The 1996 and 1997 Port Stephens Interclub tournaments were extremely popular events and the surveys showed that bait usage varied considerably between years (Table 2.1). The most popular baitgrounds used by competitors during both years were at Cabbage Tree Island and Tomaree headland, although bait was also captured at many other locations including Fingal Bay, Yacaaba Headland, Broughton Island, Boondelbah Island, Little Beach and Shoal Bay. The most common method of capturing bait was by burleying and using small baited hooks or bait jigs. Blue mackerel were a much more popular bait than yellowtail at these tournaments. The sizes of blue mackerel retained by competitors were larger during 1996 than 1997 (Fig. 2.7). Only 24 and 27 yellowtail were measured from competitors at the 1996 and 1997 tournaments respectively. These fish were of a similar size each year and ranged between 16 and 24.5 cm F.L. (Table 2.1).

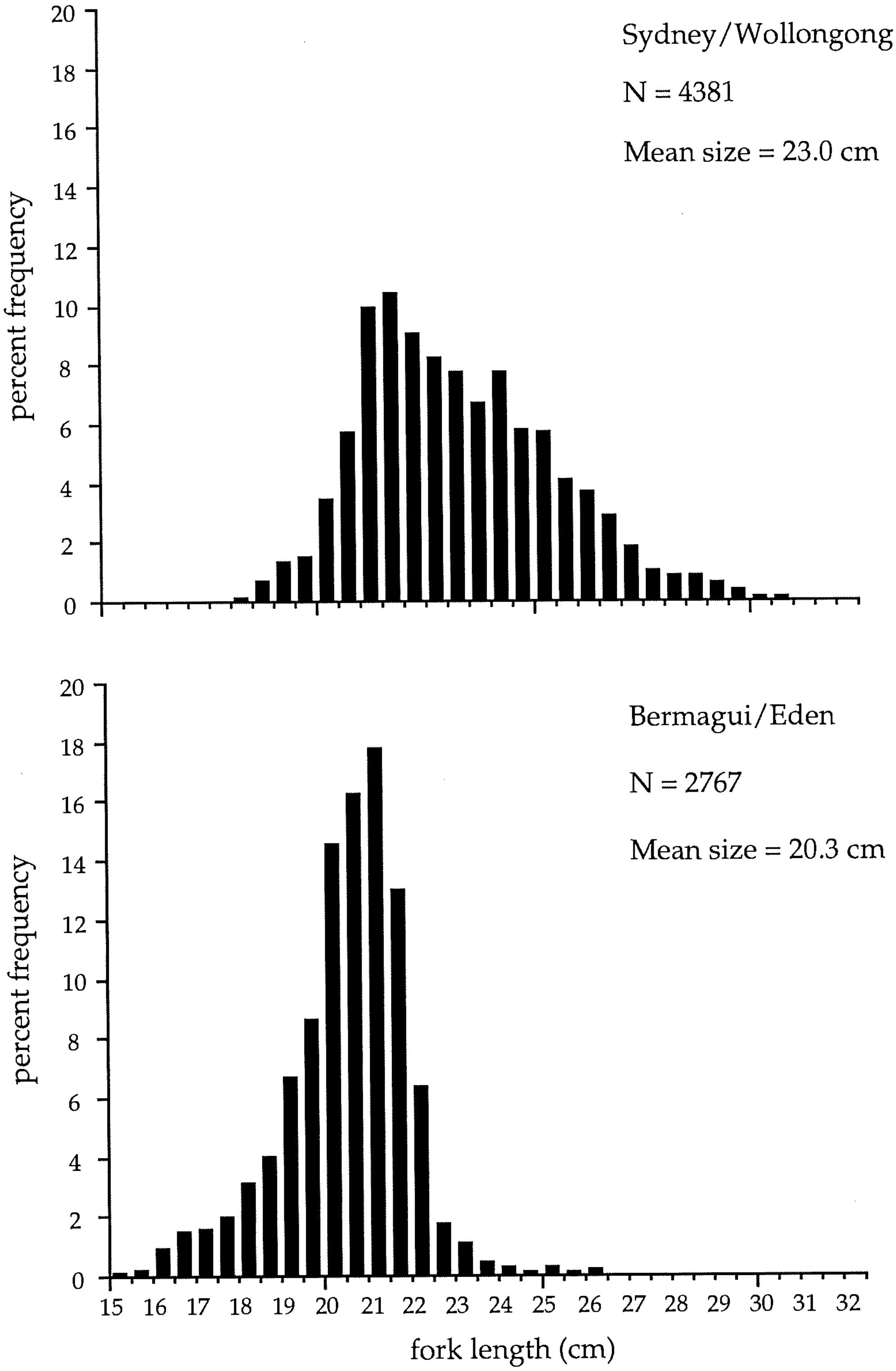


Figure 2.4. Size composition of the commercial landings of yellowtail from the Sydney/Wollongong and Bermagui/Eden regions during 1996/97.

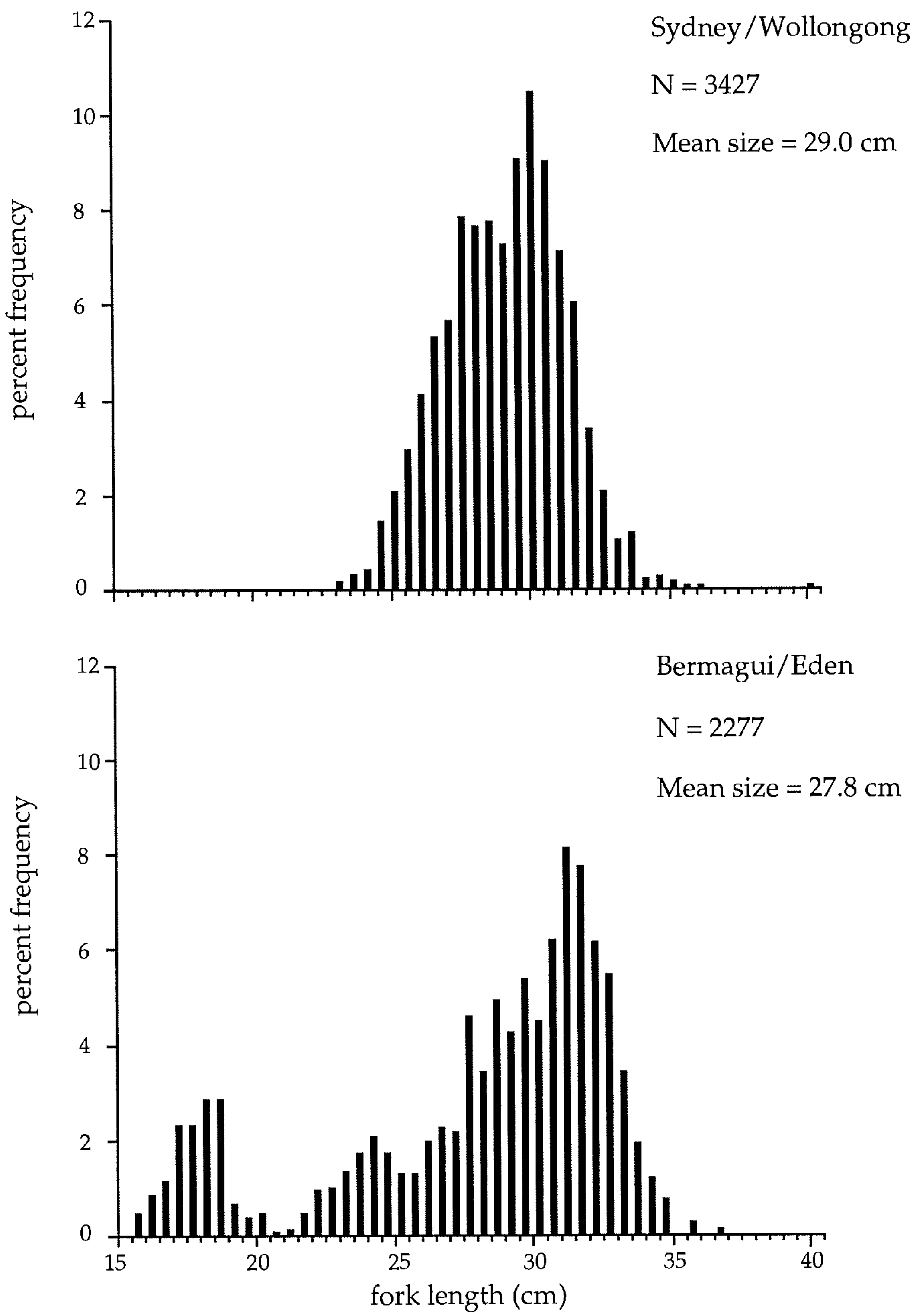


Figure 2.5. Size compositions of the commercial landings of blue mackerel from the Sydney/Wollongong and Bermagui/Eden regions during 1996/97.

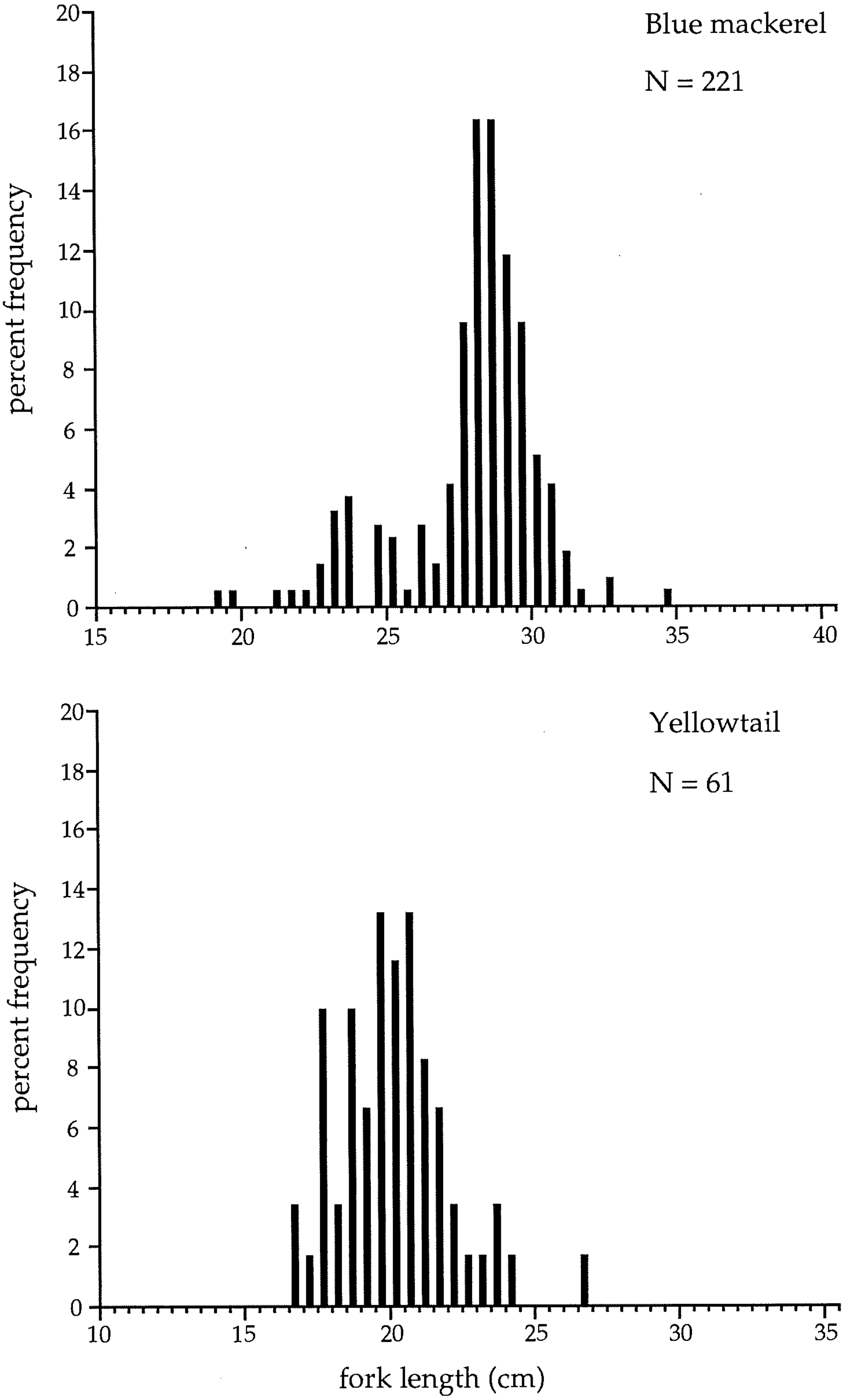


Figure 2.6. Size composition of retained blue mackerel and yellowtail used as bait during the Canberra G. F. C. yellowfin tournament at Bermagui, May 1996.

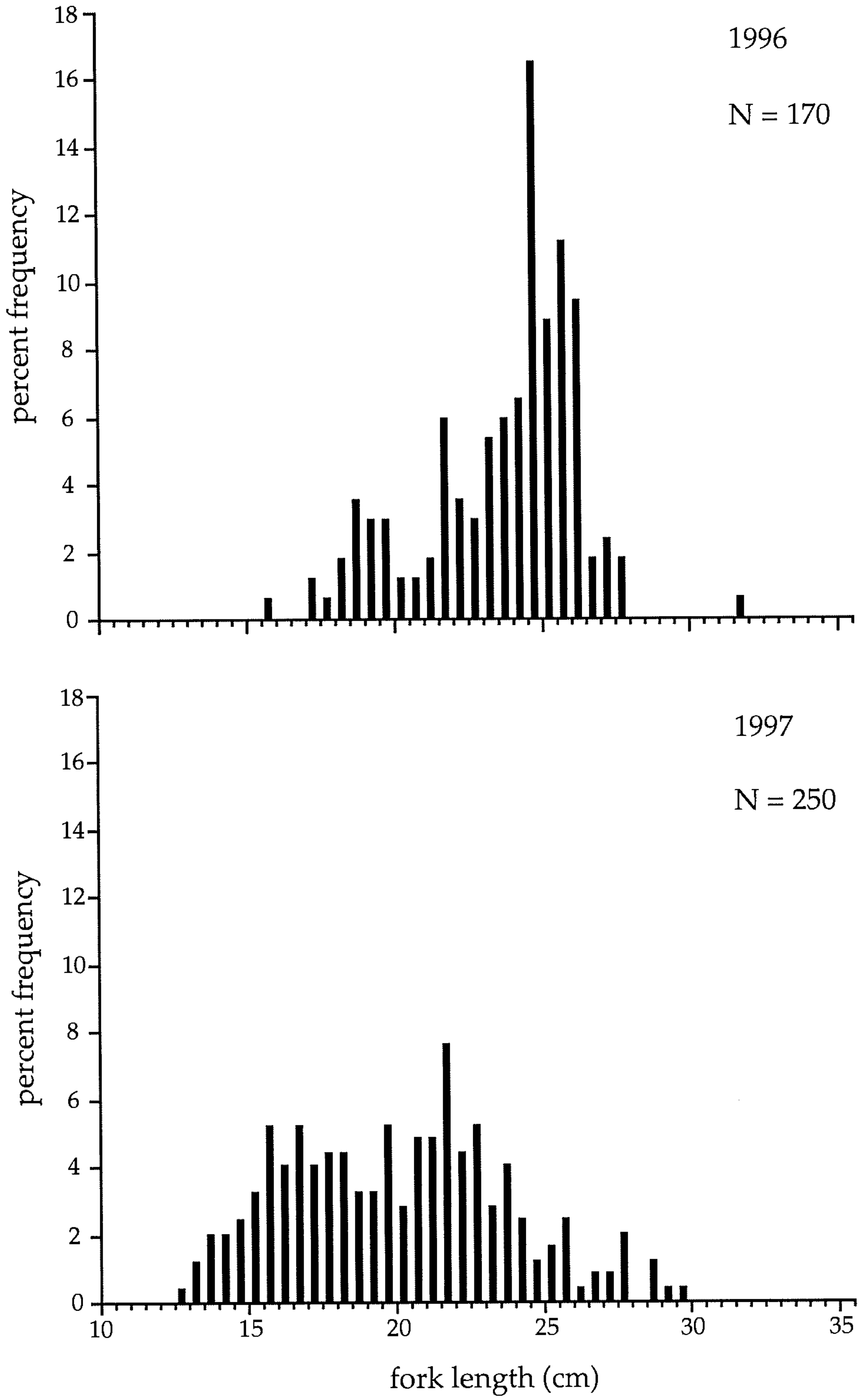


Figure 2.7. Size composition of retained blue mackerel measured from competitors during the 1996 and 1997 Port Stephens Interclub gamefishing tournaments.

The sizes of blue mackerel captured independently during the 1996 and 1997 tournaments were similar each year (Fig. 2.8). The sizes of retained blue mackerel measured from gamefishers were very similar to those captured independently during the 1996 tournament but were significantly smaller during the 1997 tournament.

The sizes of blue mackerel measured from trailer-boat fishers (Steffe et al. 1996) were similar from Sydney/Wollongong and Bermagui/Eden but tended to be smaller on the north coast (Fig. 2.9). Catches consisted of similar sized fish to those captured by commercial fishers (Fig. 2.5) but included some larger individuals.

Table 2.1. Summary of the usage of blue mackerel and yellowtail for bait at major gamefishing tournaments. Boat-days fished is the sum of the number of boats fished per day during the tournaments. Mean sizes of baits retained at the end of fishing are fork lengths (with standard errors) and approximate weights were derived from length weight relationships (Appendix A).

Tournament	boat-days fished	no. boats interviewed (% of total)	% capturing bait	no. baitfish captured by interviewed boats		mean sizes of retained baitfish F.L. and approx. weight	
				blue mackerel	yellowtail	blue mackerel	yellowtail
1996 Port Stephens Interclub	790	492 (62%)	32%	2,700	202	23.5 cm (0.2) (Approx. 260 g)	19.5 cm (0.4) (Approx. 100 g)
1997 Port Stephens Interclub	875	467 (53%)	69%	5,638	1,282	19.8 cm (0.2) (Approx. 220 g)	19.8 cm (0.5) (Approx. 105 g)
1996 Canberra G.F.C. yellowfin tuna	282	76 (27%)	83%	916	289	27.8 cm (0.15) (Approx. 310 g)	19.9 cm (0.25) (Approx. 105 g)

2.3.3 *Age determination*

Otoliths were removed from 264 yellowtail and 342 blue mackerel from Bermagui/Eden, 357 yellowtail and 305 blue mackerel from Sydney/Wollongong and 135 yellowtail and 157 blue mackerel from Wooli. Otolith weights and lengths increased with fish size and age for blue mackerel (Fig. 2.10) and yellowtail (Fig. 2.11), suggesting that they continue to grow throughout the lives of the fish and are therefore suitable structures for estimating ages of all size/age

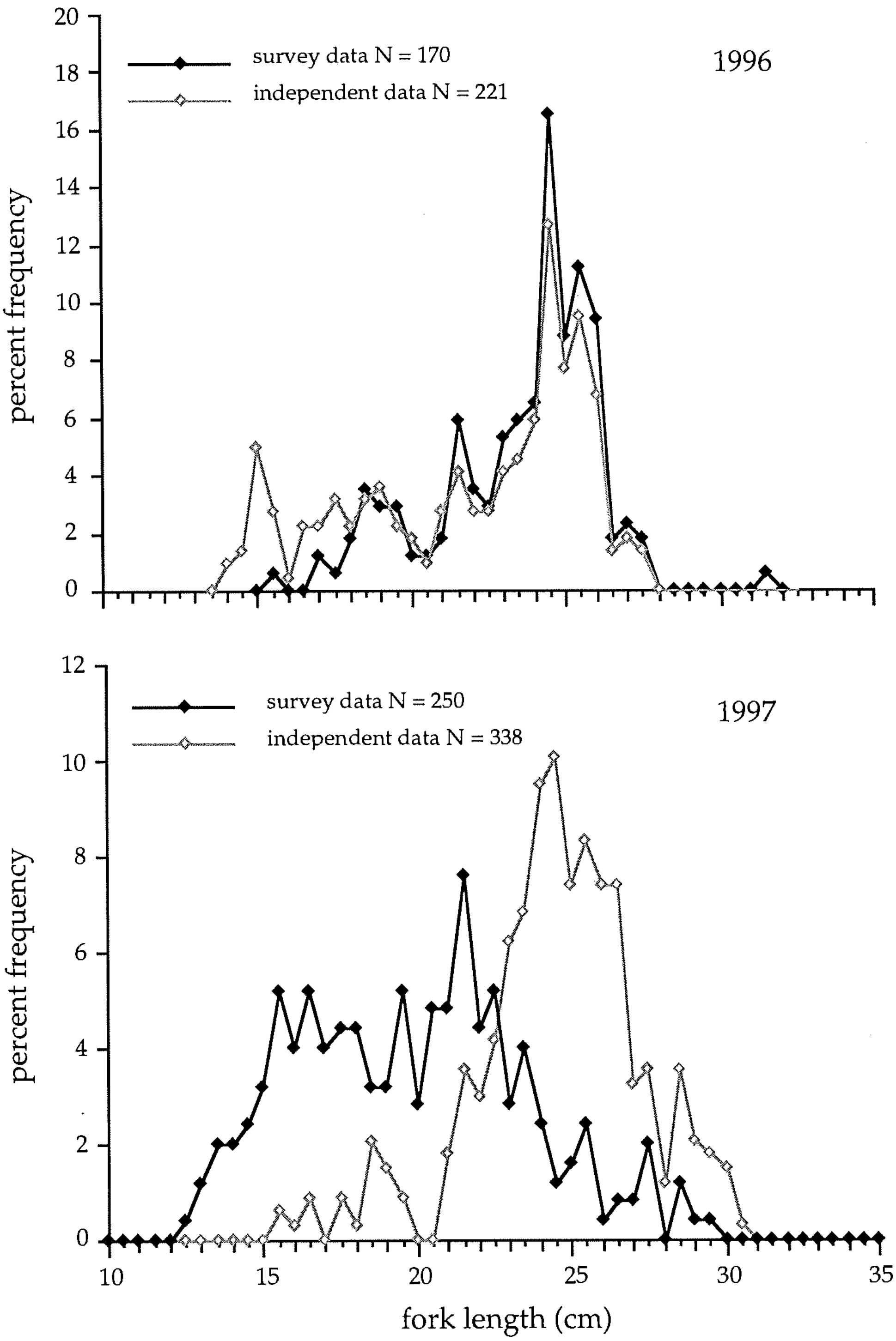


Figure 2.8. Overlapping distributions of size compositions of retained blue mackerel measured from gamefishermen at the end of each days fishing and from fish independently captured on local baitgrounds during the 1996 and 1997 Port Stephens Interclub tournaments.

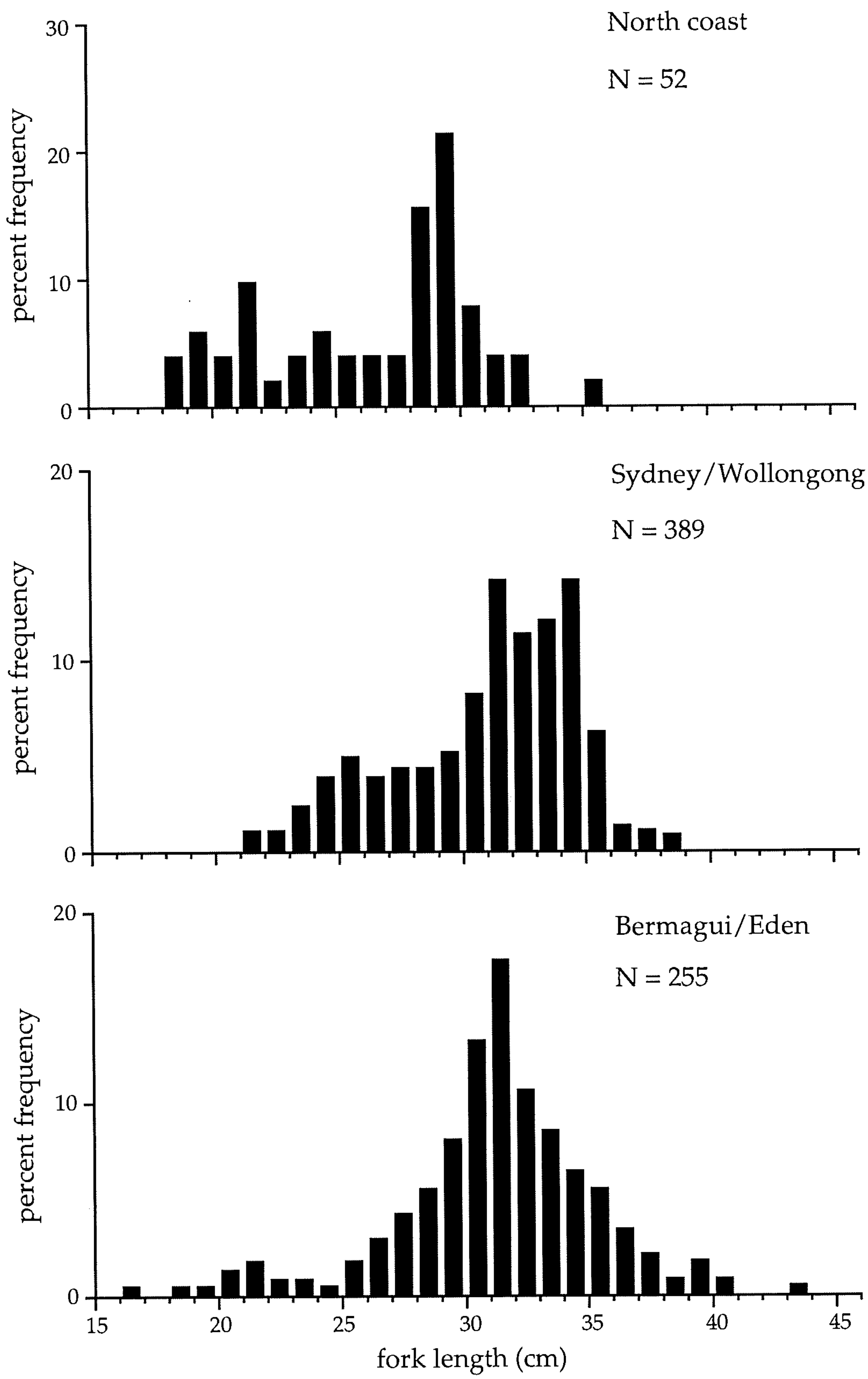


Figure 2.9. Length composition of blue mackerel measured at boat-ramp interviews with recreational fishers from 3 regions along the NSW coast, September 1993 to August 1995 (Steffe et al., 1996).

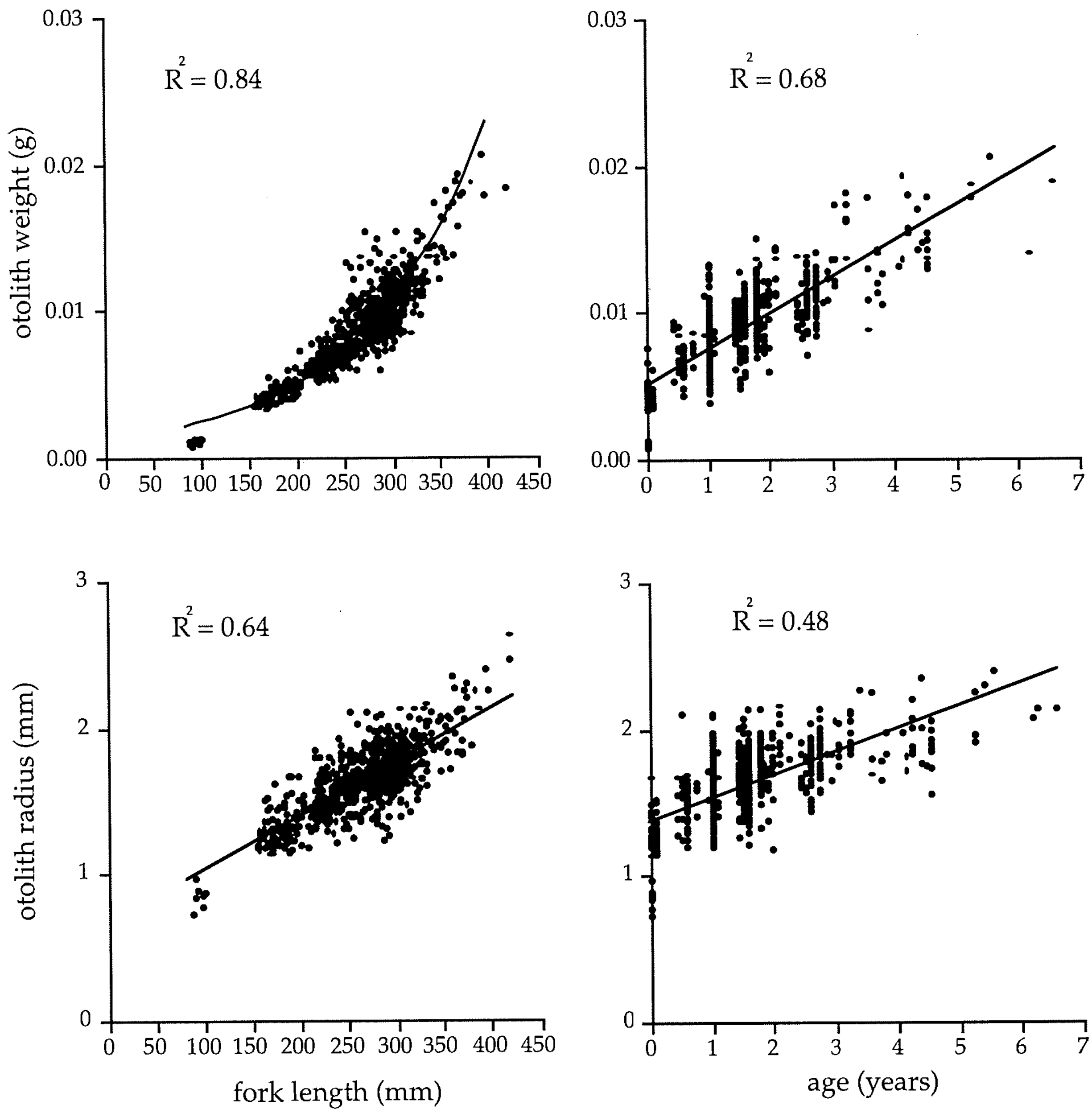


Figure 2.10. Relationships between otolith sizes (weights and radii) and fish lengths and ages for blue mackerel. Lines of best fit are shown.

classes. The relationships between otolith weight and fork length for yellowtail and blue mackerel, and between otolith radius and fork length for yellowtail were best described by exponential equations. All other relationships were best described by linear equations.

Percent agreement between readings and coefficient of variation values indicate that our interpretations of otolith age were repeatable. Reading all otoliths twice revealed 67.9% agreement and 96.4% agreement ± 1 year for yellowtail, and 84.3% agreement and 98.8% agreement ± 1 year for blue mackerel. Our estimates of mean coefficients of variation averaged over all ages were 0.12 for yellowtail and 0.11 for blue mackerel and are within the ranges described for many other species (Kimura & Lyons, 1990).

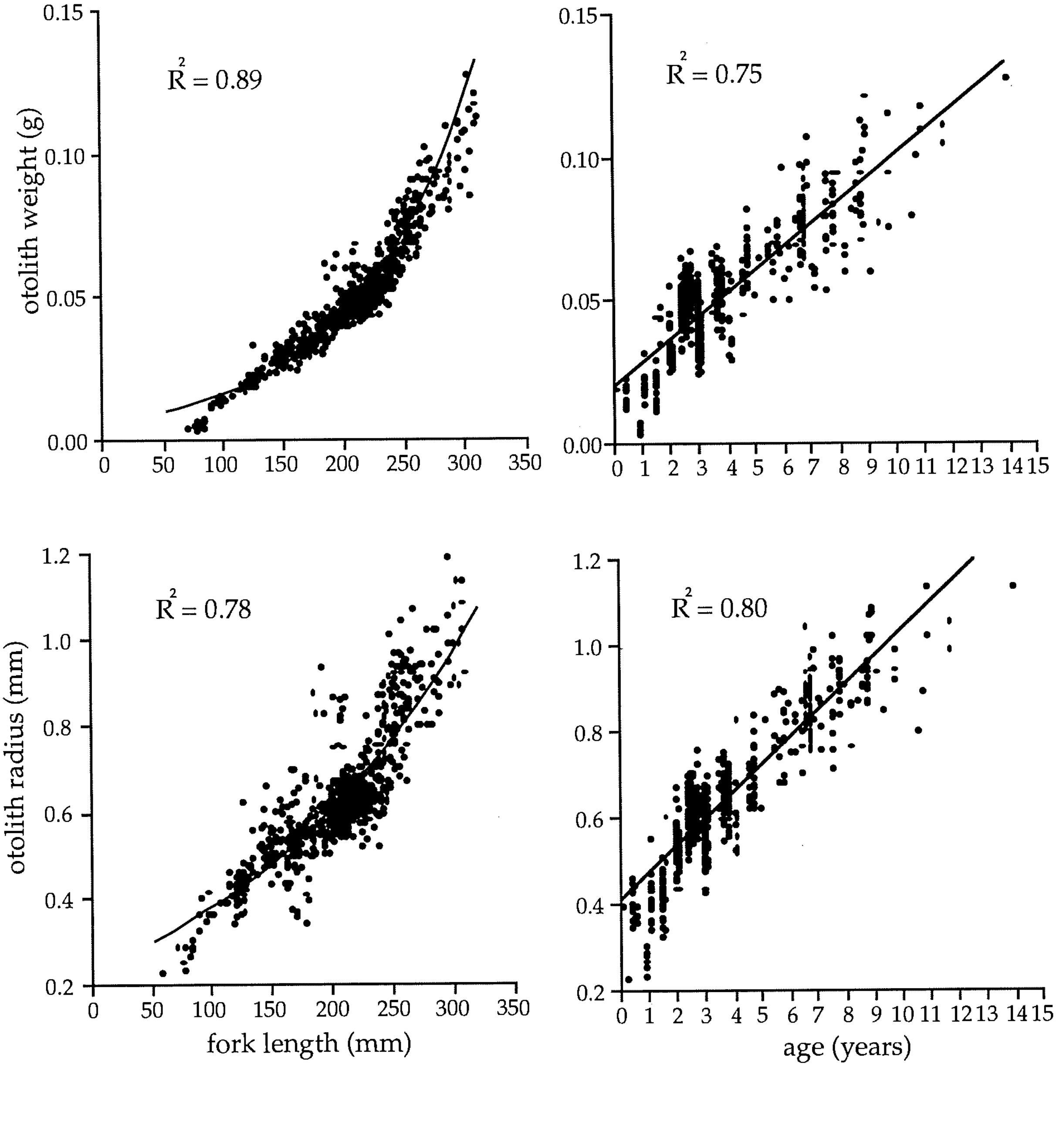


Figure 2.11. Relationships between otolith sizes (weights and radii) and fish lengths and ages for yellowtail. Lines of best fit are shown.

2.3.4 *Age composition of commercial and recreational catches.*

The commercial fishery for yellowtail from the Sydney/Wollongong region comprised mostly 2 and 3 year old fish but with significant numbers of fish up to 11 years old and a strong presence of 6 year olds (Fig. 2.12). The fishery for yellowtail from the Bermagui/Eden region comprised almost exclusively 2 and 3 year old fish with small numbers of older fish up to 8 years.

Commercial and recreational catches of blue mackerel comprised fish of similar age compositions regardless of location (Fig. 2.13). Approximately 70% of commercial catches of blue mackerel sampled from the Sydney/Wollongong and Bermagui/Eden regions were made up of 1+ fish, with the majority of the remainder being 0+ and 2+. Catches of blue mackerel by recreational fishers from the NSW coast also comprised mostly 0+, 1+ and 2+ fish with small numbers of older fish (Fig. 2.13).

2.3.5 *Estimating growth*

Growth curves describing size at age were best estimated by 3 parameter models for yellowtail and blue mackerel from all locations (cases 2 & 3 in Schnute, 1981) (Figs. 2.14 & 2.15). Growth curves for yellowtail and blue mackerel pooled from all locations were best estimated by 4 parameter models (Fig. 2.16). Yellowtail sampled from the Sydney/Wollongong region appeared to grow faster than those from the Bermagui/Eden and the Wooli areas (parameters y_1 and y_2 - mean sizes of yellowtail aged 2 and 8 years - Table 2.2). There were no differences between the mean sizes of 8 year old yellowtail from Bermagui/Eden and Wooli, but 2 year old yellowtail from Wooli were significantly smaller than those from the other two locations. Estimates of the von Bertalanffy growth function parameters varied widely between locations and may not be good descriptors of growth for some of our data sets. This was most obvious in Wooli, where our estimates of K (0.036) and L_∞ (576.1 mm F.L.) were unrealistic.

There were no significant differences in the expected growth of 1 year old blue mackerel between Bermagui/Eden and Sydney/Wollongong, but those from Wooli were significantly smaller (Table 2.2, Fig. 2.15). Three year old blue mackerel were largest from Bermagui/Eden (327 mm F.L.), were approximately

311 mm F.L. from Sydney/Wollongong and were smallest from Wooli (268 mm F.L.). Estimates of the von Bertalanffy growth function parameters produced similar estimates of K for each location, but the estimate of L_{∞} was larger at Bermagui/Eden than at Sydney/Wollongong which was larger than at Wooli (Table 2.2).

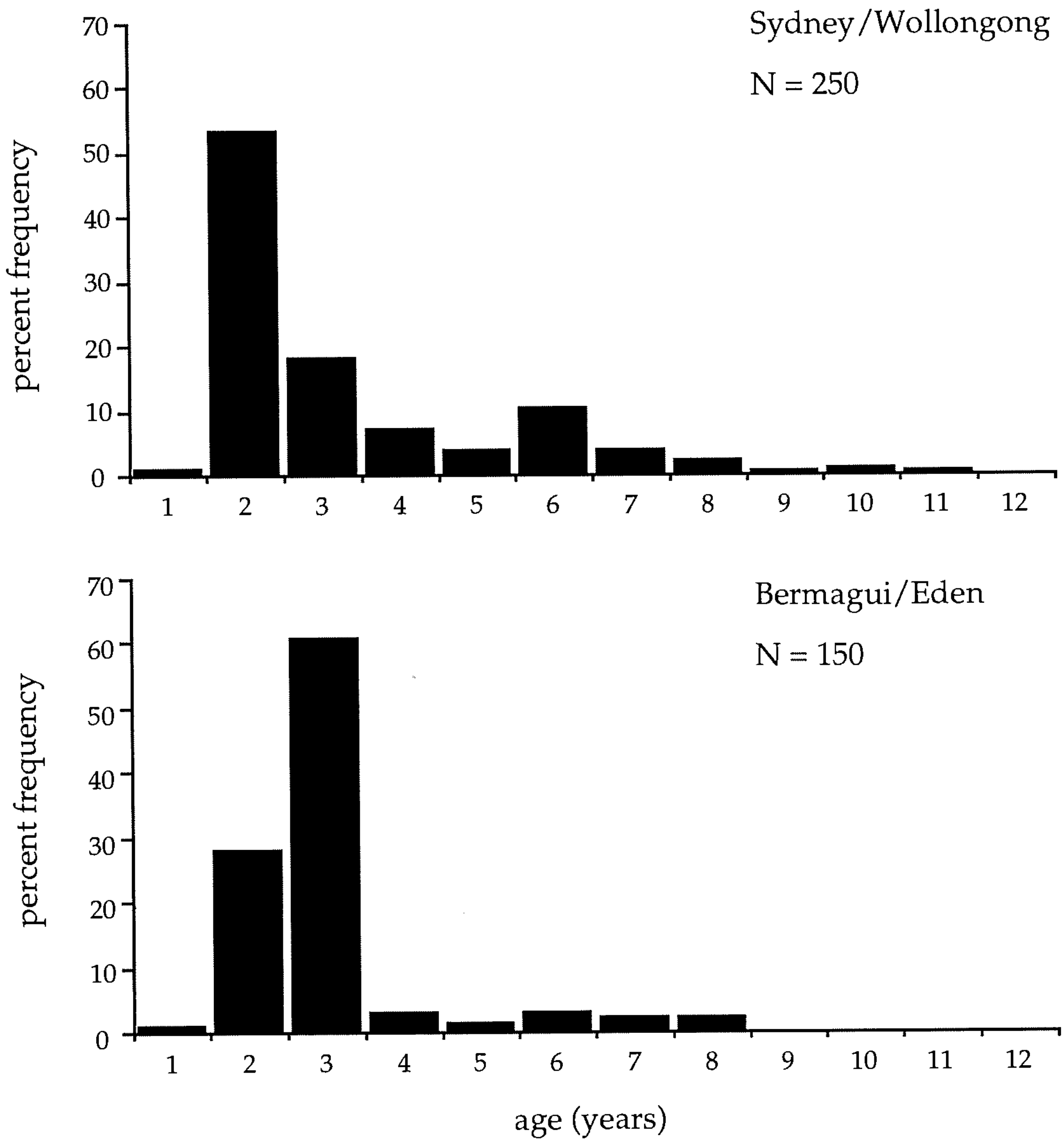


Figure 2.12. Age compositions of commercial catches of yellowtail from the Sydney/Wollongong and Bermagui/Eden regions.

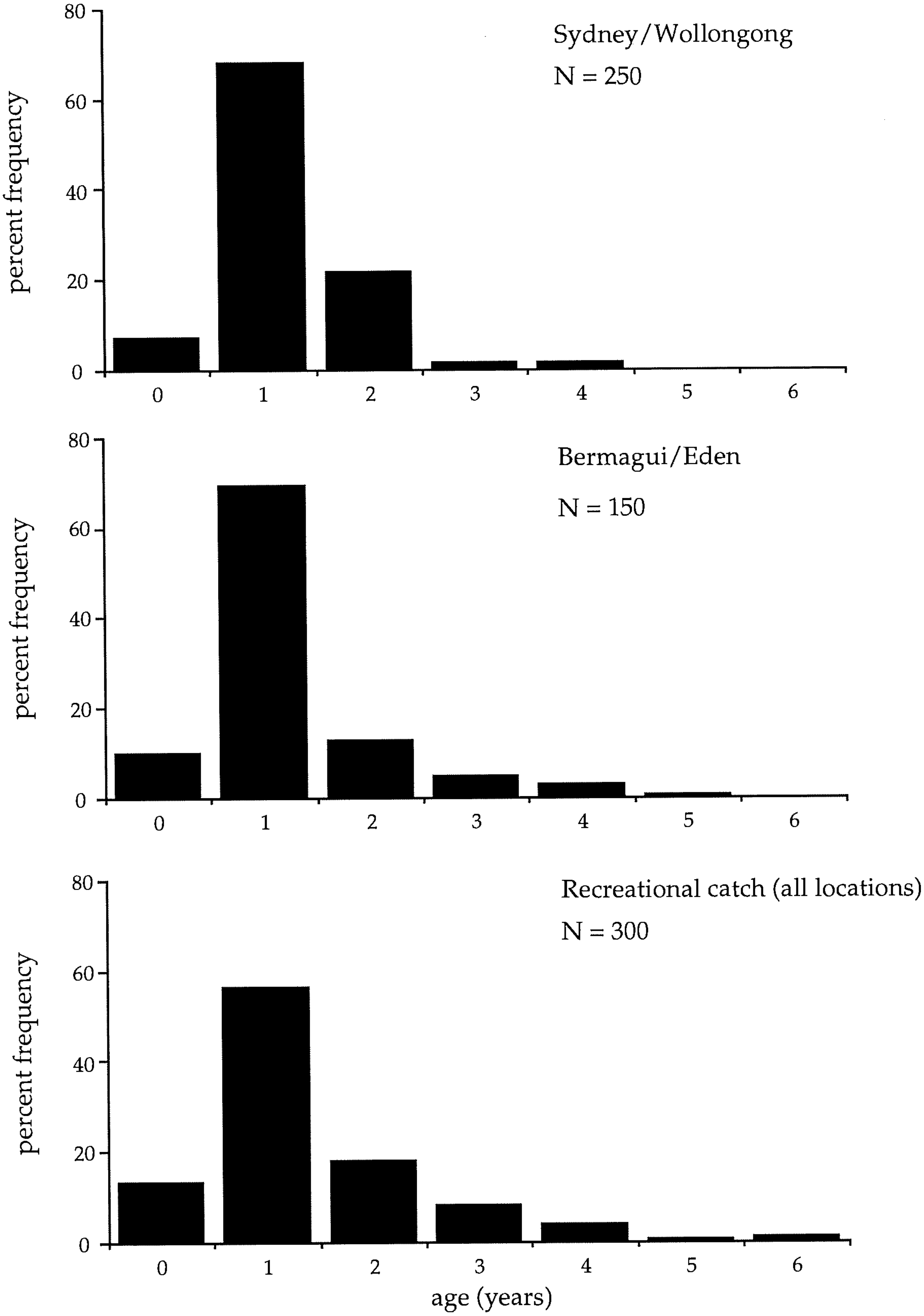


Figure 2.13. Age compositions of commercial catches of blue mackerel from Sydney/Wollongong and Bermagui/Eden and from all recreational catches.

Table 2.2. Parameters (with standard errors) describing growth curves for **A.** yellowtail and **B.** blue mackerel. Parameters were estimated using Schnute's growth model.

A. Yellowtail. Parameters y1 and y2 are the mean sizes (mm F.L.) at ages 2 and 8 respectively.

parameter	All locations	Bermagui/Eden	Sydney/Wollongong	Wooli
y1	175.9 (1.8)	188.8 (2.8)	203.8 (3.6)	140.8 (1.8)
y2	263.6 (2.7)	231.2 (5.6)	272.3 (2.2)	228.8 (5.4)
t_0	-0.9 (0.11)	-2.9 (2.1)	-4.1 (1.3)	-5.8 (1.3)
K	0.35 (0.02)	0.32 (0.17)	0.18 (0.05)	0.036 (0.03)
L_∞	278.0 (4.4)	237.5 (14.1)	307.5 (17.3)	576.1 (282.4)

B. Blue mackerel. Parameters y1 and y2 are the mean sizes (mm F.L.) at ages 1 and 3 respectively.

parameter	All locations	Bermagui/Eden	Sydney/Wollongong	Wooli
y1	254.8 (1.4)	262.2 (1.8)	261.1 (2.0)	218.3 (2.5)
y2	312.3 (2.0)	327.3 (3.0)	311.4 (2.2)	268.3 (3.9)
t_0	-1.1 (0.09)	-2.1 (0.4)	-2.5 (0.6)	-2.2 (0.4)
K	0.63 (0.05)	0.33 (0.06)	0.36 (0.09)	0.39 (0.1)
L_∞	341.5 (5.9)	405.2 (19.3)	363.1 (19.8)	309.6 (20.7)

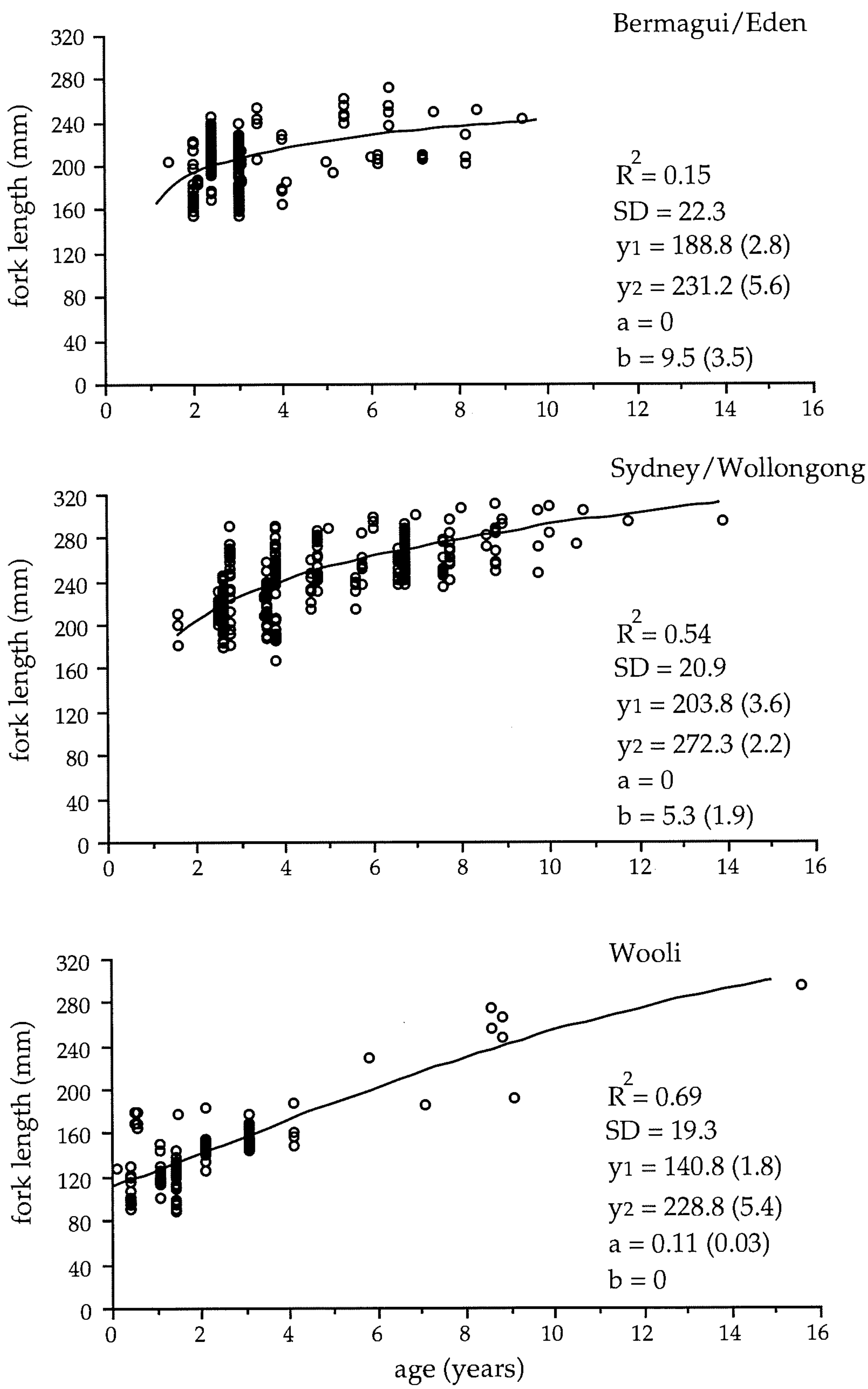


Figure 2.14. Growth curves calculated using Schnute's growth model for yellowtail from 3 locations. Parameters y1 and y2 are the mean sizes at ages 2 and 8 years. Standard errors are in parentheses.

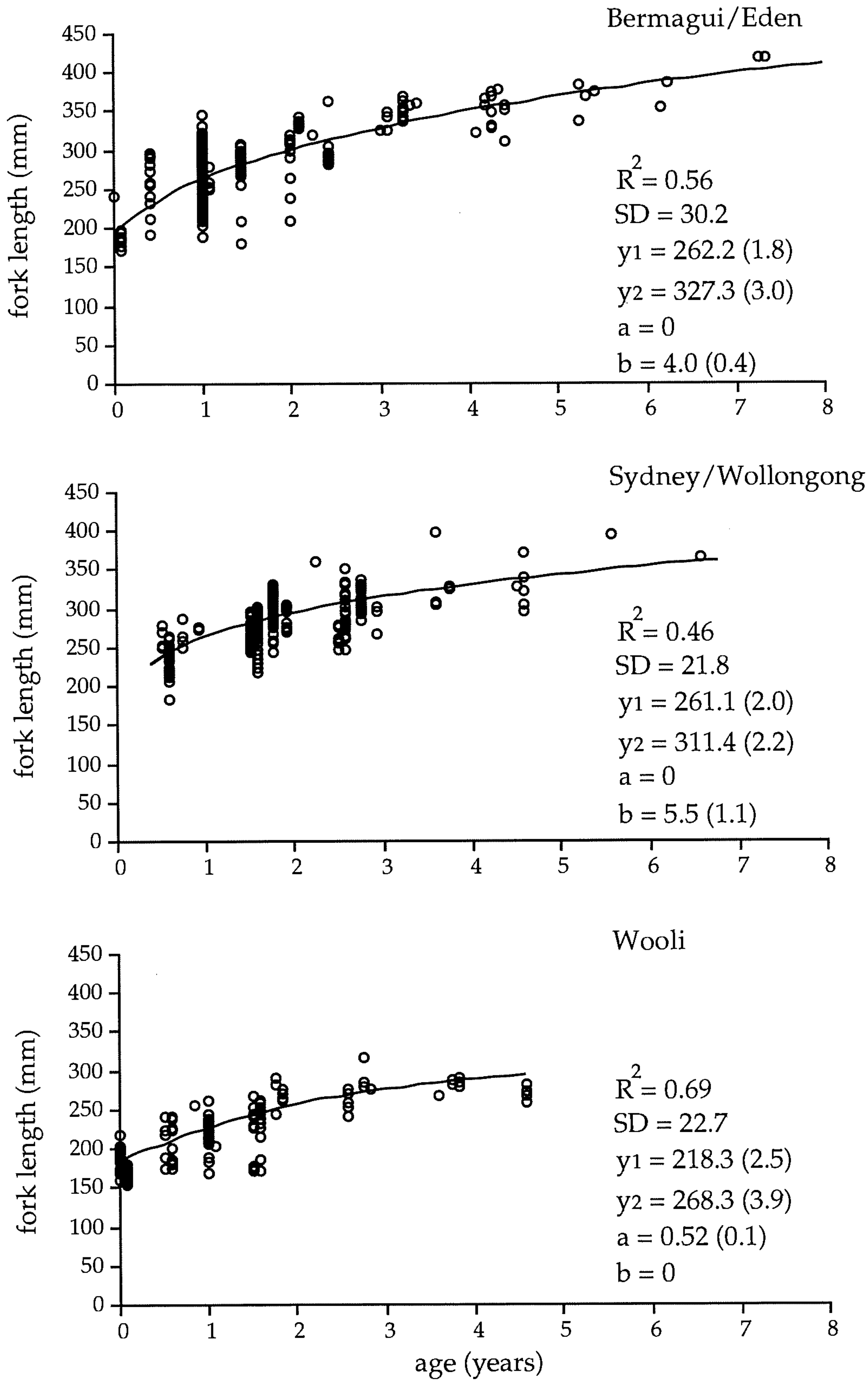


Figure 2.15. Growth curves calculated using Schnute's growth model for blue mackerel from 3 locations. Parameters y1 and y2 are mean sizes at ages 1 and 3 years. Standard errors are in parentheses.

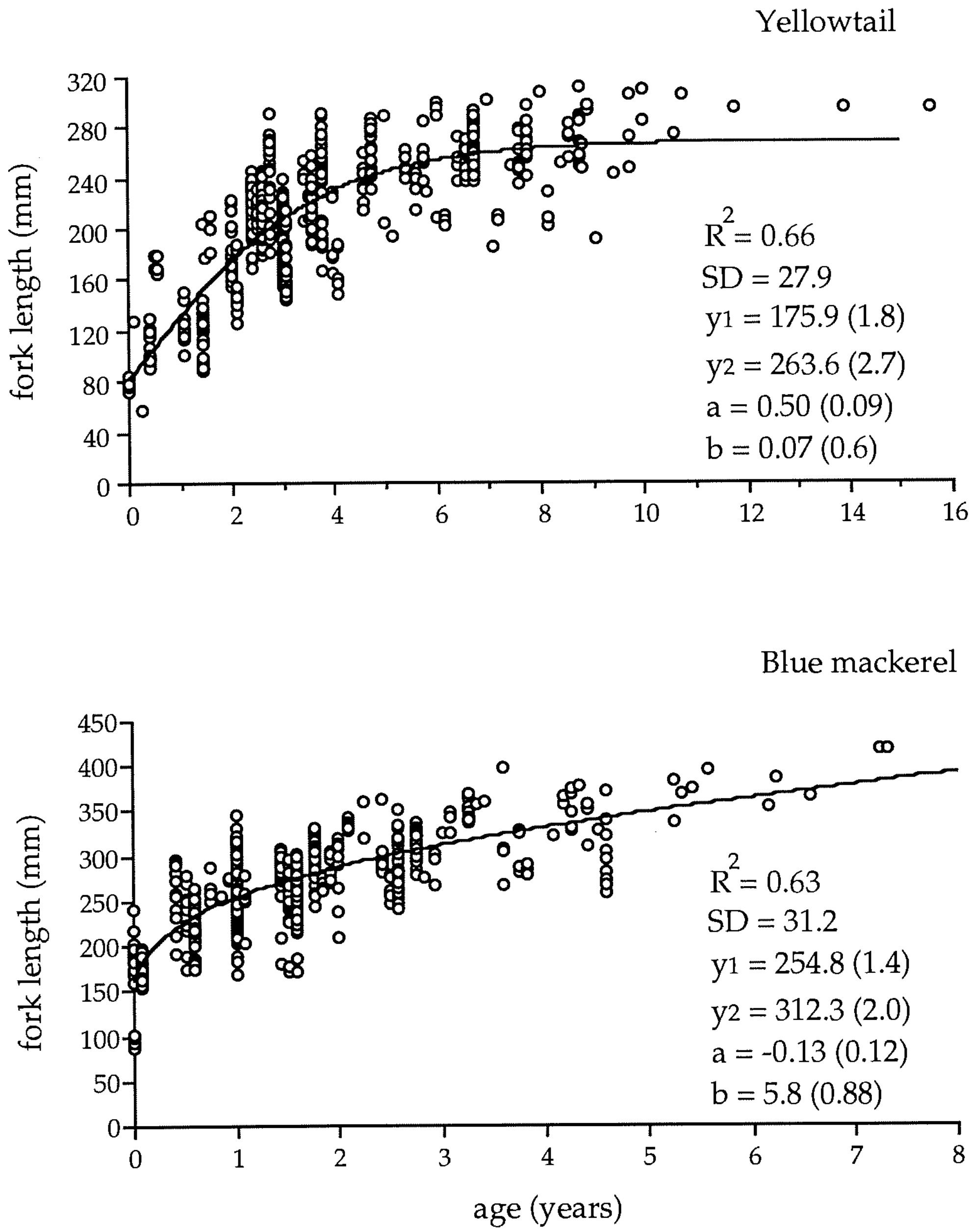


Figure 2.16. Growth curves calculated using Schnute's growth model for yellowtail and blue mackerel from all locations. Parameters y1 and y2 are mean sizes at ages 2 and 8 years for yellowtail and 1 and 3 years for blue mackerel. Standard errors are in parentheses.

2.4 Discussion

These results indicate that the commercial catches of blue mackerel from Sydney/Wollongong and Bermagui/Eden consist of similar sized and aged fish with the bulk of catches consisting of 25 to 35 cm (0+ to 2+ year old) fish. In contrast to blue mackerel, the commercial fishery for yellowtail is quite different between Sydney/Wollongong and Bermagui/Eden with respect to the sizes of fish landed (Fig. 2.4). Yellowtail landed from Bermagui/Eden were generally smaller than those landed from Sydney/Wollongong, despite the bulk of catches from both locations comprising 2 and 3 year old fish.

There is some evidence of geographic variation in growth between locations sampled for both species. Blue mackerel may have slower growth rates the further north they are found. Blue mackerel aged 1+ were significantly smaller at Wooli than at the more southern locations and the mean size of fish aged 3+ was larger at Bermagui/Eden than at Sydney/Wollongong than at Wooli. Size-at-age data for yellowtail suggests that growth is faster at Sydney/Wollongong than at either Bermagui/Eden or Wooli (Table 2.2, Fig. 2.14). Reasons for the apparent geographic variation in growth in the present study are unknown but may be related to the different sizes of fish sampled at each location. Fish sampled from Wooli were on average smaller than those sampled at the other locations and may have biased the estimated growth curve. The estimates of growth for yellowtail and blue mackerel pooled across all regions (Fig. 2.16) may be the most reliable.

The sizes of yellowtail and blue mackerel captured by recreational fishers at gamefishing tournaments and from boat ramp interviews were similar to those landed by commercial fishers. This result is not surprising as yellowtail and blue mackerel are exploited by both commercial and recreational fishers on well known areas of reef recognised as being "baitgrounds".

There is some evidence to suggest that blue mackerel much larger than those observed in the catches of the inshore commercial purse-seine fishers occur on the continental shelf further from the coast. The largest blue mackerel observed in the present study captured by an inshore purse seiner was 398 mm F.L. and most were smaller than 350 mm F.L. This is considerably smaller than the maximum reported size of 500 mm F.L. (Kailola et al., 1993). In addition, catches of blue mackerel by recreational fishers comprised some larger fish than those seen in commercial catches. These larger fish may have been captured further from the coast where the small commercial inshore pure-seine fishers do not fish.

These results show that despite being encountered together on baitgrounds and generally considered as "small pelagic baitfish" by most fishers, blue mackerel and yellowtail have very different life histories. Blue mackerel fit the "small pelagic baitfish" stereotype of having fast growth rates, a fishery consisting mainly of a couple of early age classes and one that is highly variable between years (Fig. 1.1). Fisheries for *Scomber scomber* in the U. S. A. and for *Scomber japonicus* in Japan are also dependent upon recruitment which is highly variable between years (Jones, 1983). In contrast, the fishery for yellowtail consists of many age classes, growth is relatively slow and landings are more consistent among years.

Our estimate of L_∞ for yellowtail of 278 mm F.L. is considerably smaller than that estimated by Horn (1993) for yellowtail in New Zealand (between 350 and 400 mm F.L.). Horn (1993) found many larger and older yellowtail than we did in the present study suggesting that either yellowtail live longer and grow larger in New Zealand, or, more likely, that the inshore fishery in New South Wales does not exploit the oldest, largest fish.

Our estimates of growth for blue mackerel differ to those described for blue mackerel in the Great Australian Bight (Stevens et al. 1984) and off Taiwan (Chang & Chen 1976). Stevens et al. (1984) estimates of the von Bertalanffy growth parameters were L_∞ = 441 mm, k = 0.24 and t_0 = -1.79 whereas our estimates were of lower L_∞ (341.5 mm) but higher K (0.63). Stevens et al. (1984) sampled larger fish than we did which may explain the differences. Chang & Chen (1976) estimated mean size at age to be 31 cm F.L. at 1 year and 34 cm F.L. at 2 years.

It is important to note that our validation of these ageing techniques is restricted to the ages of fish we were able to study. We have little information of the growth of the otolith prior to the appearance of the first opaque band in either yellowtail or blue mackerel. The opaque core of the otolith may hide the opaque mark deposited in the first winter after both species' spring/summer spawning (Kailola et al. 1993). This would mean the first opaque mark we counted was formed in the animals' second winter, at a true age of about 1.5 years. A further complication arises when comparing our growth estimates with other studies where translucent, rather than opaque marks have been enumerated (Baird, 1977), or where the method of counting was not clear (Stevens et al., 1984). Without knowing what marks were counted, and whether the authors believed them to be formed in summer or winter, we cannot suggest what relative bias there may be between our growth estimates and others.

Independent surveys of the sizes of yellowtail and blue mackerel during the 1996 and 1997 Port Stephens Interclub tournaments showed that estimating the sizes of baits used by gamefishers by measuring unused baits at the completion of a days fishing may be of limited use (Fig. 2.8). During the 1996 Interclub tournament the sizes of baits measured from competitors was very similar to the sizes of baits encountered on the local baitgrounds. However, during the 1997 Interclub tournament the sizes of baitfish measured from competitors was generally smaller than those captured alongside them on the local baitgrounds. The 1997 tournament was notable for an exceptional run of small black marlin, with 854 black marlin, 139 striped marlin and 21 blue marlin being captured (during the 1996 tournament 104 black marlin, 168 striped marlin and 15 blue marlin were captured). These small marlin are best targeted using slow-trolled livebait and are the reason why so many competitors used so many baitfish this year. The smaller retained baitfish were probably the result of competitors preferentially using the largest baits in their bait-tanks, leaving on average smaller fish at the end of the day to be measured. This result emphasizes the difficulties in estimating any component of recreational fishing harvests as well as the importance of considering possible biases from such studies.

We have provided an initial assessment of the sizes and ages of yellowtail and blue mackerel in commercial and recreational catches, however much of the harvest of these species is difficult to quantify. Bait taken by the commercial longline fleets has traditionally not been recorded but may be large (300 tonnes /yr, Glaister & Diplock, 1993). Recent changes to the management of the commercial fishery in New South Wales includes a requirement to record the amount of bait taken for own use. This will help to improve the accuracy of our catch statistics in the future. The recreational harvests of these species will always be difficult to asses. Future work should concentrate on monitoring the size and age composition of commercial catches, assess the available biomass of each species and determine patterns of movements for these species to better understand their life-histories.

3. Validation of ageing techniques

The results in this chapter address objective 3.

Objective 3. To provide preliminary validations of age estimates in these species

Marking otoliths of yellowtail and blue mackerel with oxytetracycline revealed that one opaque mark is formed within their otoliths per year. Counts of these opaque marks can be converted into estimates of age for these species and the accuracy of this process is described.

3.1 Introduction

Methods to estimate fish age by counting annuli (zones or patterns of growth formed annually) within calcified structures such as otoliths have been well documented (Beamish & McFarlane, 1987). In recent times the importance of validating, or assessing the accuracy of, these techniques has been highlighted (Beamish & McFarlane, 1983). Validation of an ageing technique should ideally address three issues (i) that there are periodic marks formed in some body part eg. otoliths, (ii) that these periodic marks can be reliably identified and (iii) that counts of these periodic marks can be accurately converted into age classes (Francis et al., 1992). Many studies claim that an ageing technique is validated if they show annual formation of marks within a structure, but do not attempt to estimate the accuracy of converting counts of these annuli into age classes. As argued by Francis et al. (1992) any validation of an ageing method should include some measure of the errors expected from all three sources of variation.

In the present study we examine the timing and periodicity of formation of opaque marks in the otoliths of yellowtail and blue mackerel. We demonstrate that these marks are formed annually using data from 2 sources: (i) marking otoliths with oxytetracycline (OTC), and (ii) measuring distances between the otolith edge and the most recent annulus (marginal increments) of otoliths from wild fish. By examining the position of the OTC mark in relation to the otolith edge and to any subsequent annuli we describe otolith growth through time and determine when annual marks become visible. We use this information to estimate errors in identifying annuli and in converting ring counts to age classes.

Studies of age and growth of trachurids and scombrids have generally attempted to validate the annual nature of ring formation in otoliths using techniques such as marginal increment measurements, back calculation and by following strong year classes through time. Previous studies suggest that trachurids form one mark per year in their otoliths: annual marks have been recorded in *Trachurus novaezelandiae* (Horn, 1993), *T. declivis* (Stevens & Hausfeld, 1982), *T. Murphyi* (Kaiser, 1973) and *T. trachurus* (Macer, 1977). There has only been one published study on age and growth of blue mackerel *Scomber australasicus* (Stevens et al., 1984) and they were unable to validate the formation of annuli in otoliths. Baird (1977) and Lorenzo et al. (1995) have successfully aged *Scomber japonicus* using alternating opaque and translucent zones within otoliths. Both studies validated the annual nature of ring formation by examining the timing of the appearance of opaque and translucent edges. The results suggest that the opaque zones are formed during the spring and summer months.

3.2 Materials and methods

3.2.1 *Marking with a vital stain*

With little knowledge of expected ages in the present study, we injected fish with OTC over as wide a size-range as possible. Yellowtail and blue mackerel were captured off Port Hacking using small baited hooks and transported to aquaria facilities at the Fisheries Research Institute, Sydney (34°04'S). Fish were placed in 4500 l round tanks, treated with formaldehyde (25 mg/l) to remove parasites and given a mild antibiotic bath (oxytetracycline solution at 100 g/1000 l) to reduce the risk of infection from handling. After acclimation for at least 1 week, fish were anaesthetized using benzocaine, weighed, measured and given an intraperitoneal injection of OTC at a dose of approximately 75 mg/kg of fish. Initial trials using the dosage used in many published age validation studies (50 mg/kg) proved unsatisfactory with only approximately 50% of fish injected showing useable marks on their otoliths. Subsequent trials using dosages of 75 mg and 100 mg of OTC per kg of fish showed greater proportions of fish had been successfully marked at both dosages.

Yellowtail and blue mackerel were injected with OTC at the beginning of May 1996 and were stocked separately at approximately 100 fish per 4500 l tank with flowing seawater at ambient temperatures and salinities. Blue mackerel did not do well in the 4500 l round tanks. We believe this was caused by the flight response in this species causing fish to smash into the walls of the tanks when alarmed. The mortalities which resulted were commonly associated with head injuries. Most blue mackerel and some yellowtail were subsequently moved into an 875 m^3 pond. All fish were fed a combination of chopped pilchards, minced tuna and 3 mm pelletised fish food.

To describe otolith growth and the appearance of opaque marks our intention was to sample otoliths from OTC marked fish monthly during the year following marking. Each month between July 1996 and May 1997 the otoliths were removed from fish which died and also from a random sample of fish killed (Table 3.1). A large number of blue mackerel died during December 1996 decreasing the stock of fish to a level where only small numbers of fish were sampled towards the end of the experiment.

Otoliths were prepared for viewing as described previously (section 2.2.3). All otoliths were viewed after the experiment was terminated and were mixed randomly with otoliths from 30 non-experimental fish. This was done to ensure that the reader had as little knowledge of each otolith as possible in order to reduce biases. Otoliths were initially viewed under normal reflected light to assign an age and measure the position of opaque marks. The otolith was then viewed under ultra-violet light to reveal the position of any OTC marks. Measurements were made along the longest axis on the posterior part of the otolith for blue mackerel and along the ventral edge of the sulcus for yellowtail (Figs 3.7 & 3.8).

3.2.2 *Marginal increment measurements*

The distance from the otolith edge to the most recent annulus was measured on otoliths collected to determine size at age, and sample sizes varied between months. For blue mackerel the distances from the first opaque mark to the otolith edge for all 1+ fish and from the centre of the second opaque mark to the otolith edge for all 2+ fish were measured to show the timing of the most recent opaque marks becoming visible for 1+ and 2+ fish. For yellowtail, each month's sample of otoliths included a wide range of ages and the distance from the most recently formed opaque mark to the edge of the otolith was expressed as a proportion of the previous growth zone (ie. the distance between the two previous annuli). Means of these proportions each month were used to show when opaque marks were closest to the otolith edge.

Table 3.1. Details of blue mackerel and yellowtail injected with OTC in May 1996 that had their otoliths removed and had visible OTC marks per month.

	Blue mackerel		Yellowtail	
Month	No. sampled	% with visible OTC marks	No. sampled	% with visible OTC marks
May	36	13.9	0	-
Jun	24	37.5	0	-
Jul	20	80	9	88.9
Aug	5	60	15	46.7
Sep	12	91.7	18	61.1
Oct	2	100	9	77.8
Nov	14	92.9	16	68.8
Dec	51	76.5	18	88.9
Jan	17	100	31	80.6
Feb	2	100	51	88.2
Mar	4	100	31	100
Apr	1	100	18	100
May	1	100	7	100
Total	189	65.1	223	83.4

3.2.3 *Errors in assigning age classes*

In any ageing study it is important to distinguish between the time of year that annuli are deposited and the time of year that they become visible. This 'edge interpretation problem' described by Francis et al. (1992) stems from the hypothesis that opaque marks in otoliths identified as annuli are only visible after additional material is deposited on the otolith edge. As a result of this, fish from the same age classes may have the most recent annulus becoming visible at different times of the year and, depending upon the time of sampling, may be classified into different age classes. Monthly sampling of fish injected with OTC shows those months during which a new opaque mark can be seen subsequent to the OTC mark. Months when not all otoliths have opaque marks subsequent to the OTC mark are those in which errors in assigning age classes directly from ring counts are likely to be greatest.

One way of minimizing errors due to edge interpretation is to set some criteria by which to make a judgement about the most recent annulus. An objective criteria by which to decide whether the terminal opaque mark has formed recently is the following ratio:

$$\text{ratio} = \frac{\text{Distance from the terminal mark to the otolith edge}}{\text{distance between the two most recent opaque marks}}$$

Fish with relatively small ratios during these months appear to have the most recently formed opaque mark visible. Converting ring counts into age classes may need to be adjusted relative to fish were the ratio is large.

Reading otoliths with OTC marks under normal light prior to any knowledge of the position of the fluorescent mark allows estimates of errors in identifying annuli. Once the position of the OTC mark is known, along with the timing of injection (which was constant in the present study), then the number of annuli subsequent to the OTC mark can be predicted. Where the observed and predicted number of annuli differ it can be due either to the edge interpretation problem described above, or because of mis-identification of annuli, eg. double marks being scored as 2 separate annuli.

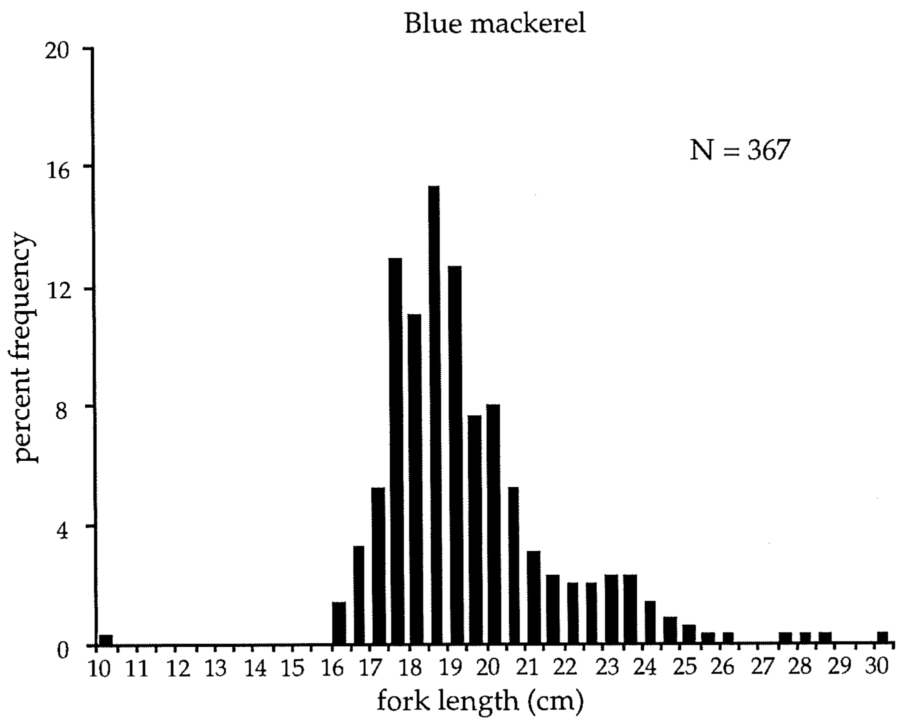
3.3 Results

3.3.1 *Oxytetracycline marking*

Fish injected with OTC in May 1996 ranged between 10 cm and 30 cm F.L. for blue mackerel and between 12 cm and 23.5 cm for yellowtail (Fig. 3.1). Otoliths were removed from 189 blue mackerel and 223 yellowtail during the 12 months after injection and of these, 123 blue mackerel (65.1%) and 186 yellowtail (83.4%) had visible OTC marks on their otoliths (Table 3.1). Only 14 of 60 blue mackerel sampled during May and June had visible OTC marks on their otoliths. Many of these fish had died, possibly because of the injection or associated handling. 84.5% of blue mackerel sampled after June 1996 had visible OTC marks on their otoliths.

Within the 186 yellowtail with visible OTC marks on their otoliths there were 9 age classes when injected (0+ to 7+ and one 12+ fish) and formation of one opaque mark subsequent to the OTC mark was observed in 8 of these age classes. The 12+ fish was sampled during September and did not have an opaque mark near the edge of its otolith. Otolith growth was associated with estimated fish age, for example the mean amount of otolith growth subsequent to the OTC mark by February 1997 was 0.08 mm (S.E. = 0.004) for 2+ yellowtail and 0.05 mm (S.E. = 0.004) for 6+ yellowtail. Most yellowtail were either 2+ or 3+ when injected, but sufficient numbers of 4+, 5+ and 6+ fish were included to observe otolith growth in these age classes (Fig. 3.2). An opaque mark subsequent to the OTC mark was visible in only some fish sampled between August and December but in all fish by January.

Of the 123 blue mackerel with visible OTC marks on their otoliths 121 were aged 0+ when injected. There was a lot of variation in the growth of otoliths and in the timing of appearance of the 1st opaque mark (Fig. 3.3). An opaque mark was present subsequent to the OTC mark in 2 fish as early as July, and in all fish by January. One fish had formed 2 relatively thin opaque marks subsequent to the OTC mark and these 2 marks were interpreted as separate annuli. There were 2 fish which were older than 0+ when injected. These older fish were 2+ and 1+ and neither had formed new opaque marks when sampled in August and September respectively. These otoliths had grown much less from the OTC mark to the otolith edge (along the longest posterior axis) than 0+ fish sampled during the same months.



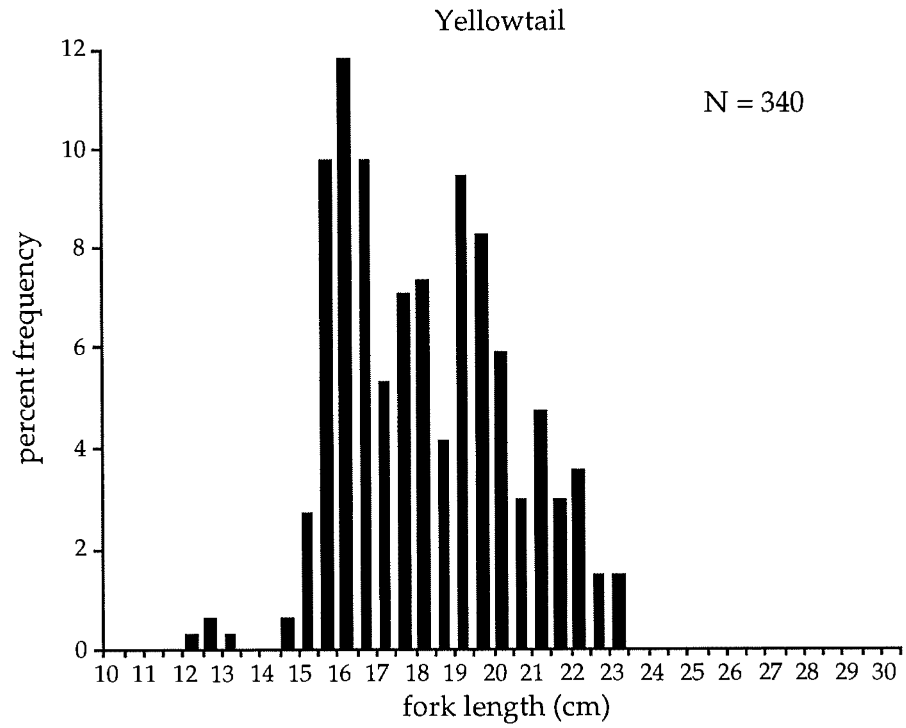


Figure 3.1. Initial size-distribution of blue mackerel and yellowtail used in the validation experiment in May 1996.

Yellowtail and blue mackerel with faster growing otoliths tended to have the most recently formed opaque marks visible first (Figs. 3.2 & 3.3). This is particularly obvious for blue mackerel sampled during December (Fig 3.3). The OTC marks in both species were always present just prior to the opaque marks (Figs. 3.7 & 3.8), indicating that they were formed soon after injection (ie. winter) but were not always visible until later in the year. This suggests that opaque marks form at the same time of year in all fish but do not become visible until sufficient otolith growth subsequently occurs. Trends in the rates of otolith growth in both species were similar, with growth increasing during the summer months from approximately November onwards.

3.3.2 *Errors in assigning age classes*

For yellowtail in captivity August to December were the months during which the terminal ring was visible in only some fish (Fig. 3.2). 31 of 46 (67.4%) yellowtail sampled during this period had formed 1 opaque mark subsequent to the OTC mark. If fish sampled during this period were assigned to age classes based on ring counts alone, and using a birthday of 1 January, there is the potential for up to 67.4% to be assigned to an incorrect age class. To decrease this error during these months, the ratio of the distance from the terminal opaque mark to the otolith edge over the distance from the terminal opaque mark and the previous one can be used to help assign correct age classes. For example, if this ratio is less than 0.65 then the most recently deposited opaque mark has become visible early and age class = ring count - 1. This produces an error rate of 10.9% of yellowtail in the experiment being assigned a wrong age class during August to December, fish sampled during the rest of the year are assumed to have no errors due to edge interpretation.

Distances from the OTC mark to the otolith edge for all blue mackerel 0+ when injected (Fig. 3.3) show that edge interpretation errors may occur between July and December, during which time 52 of 83 (62.6%) blue mackerel had formed an opaque mark subsequent to the OTC mark. It may be possible to use an age assignment rule similar to the one described for yellowtail to reduce errors in assigning age classes based on ring counts for older blue mackerel, but because the fish used here were only in their first year there were no previous growth increments with which to compare recent growth.

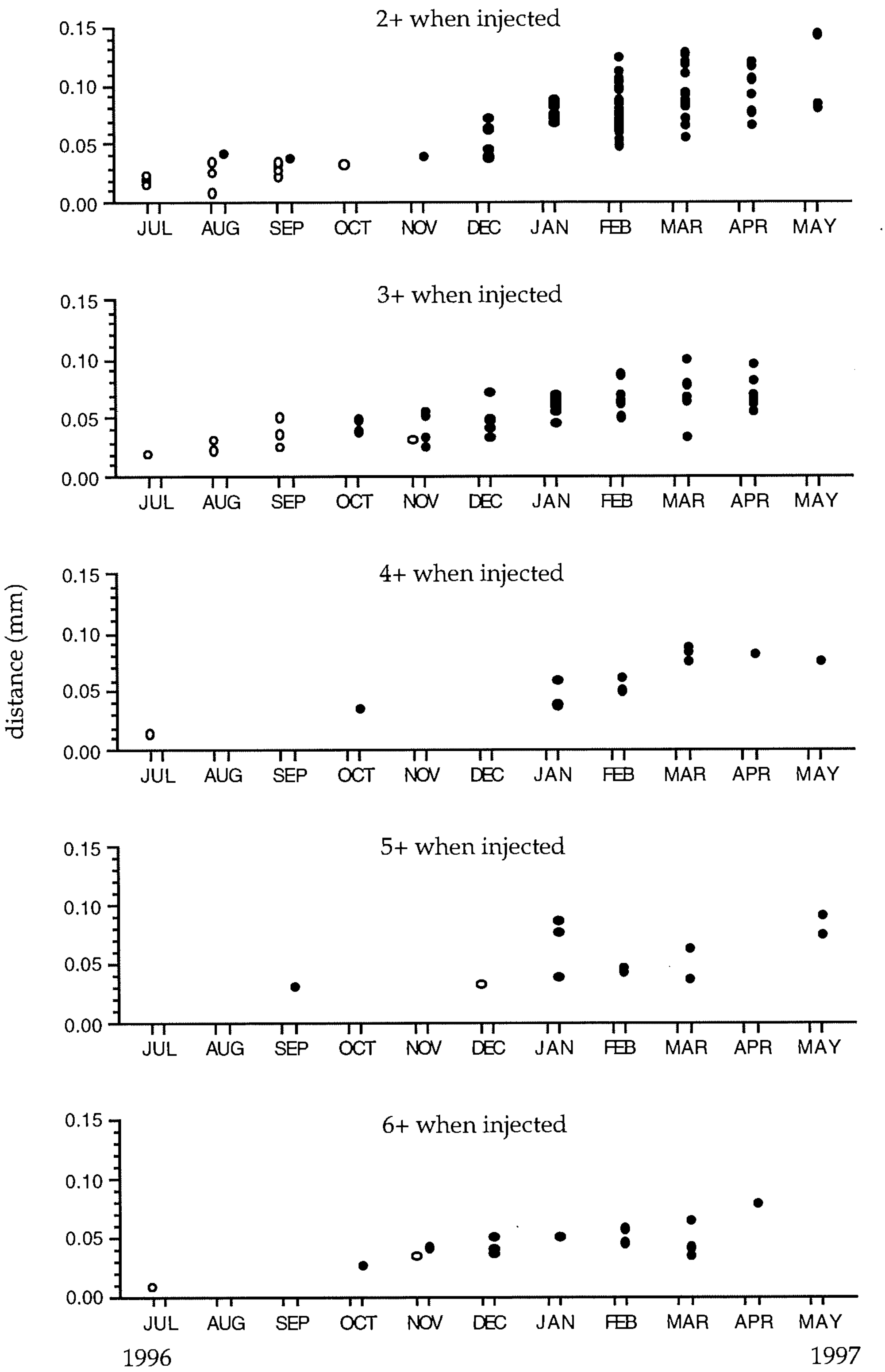


Figure 3.2. Distances from the OTC mark to the otolith edge for all yellowtail injected with OTC in May 1996. Animals which had formed an opaque ring after the OTC mark (filled-in circles) are slightly offset to those that had not formed an opaque ring (open circles).

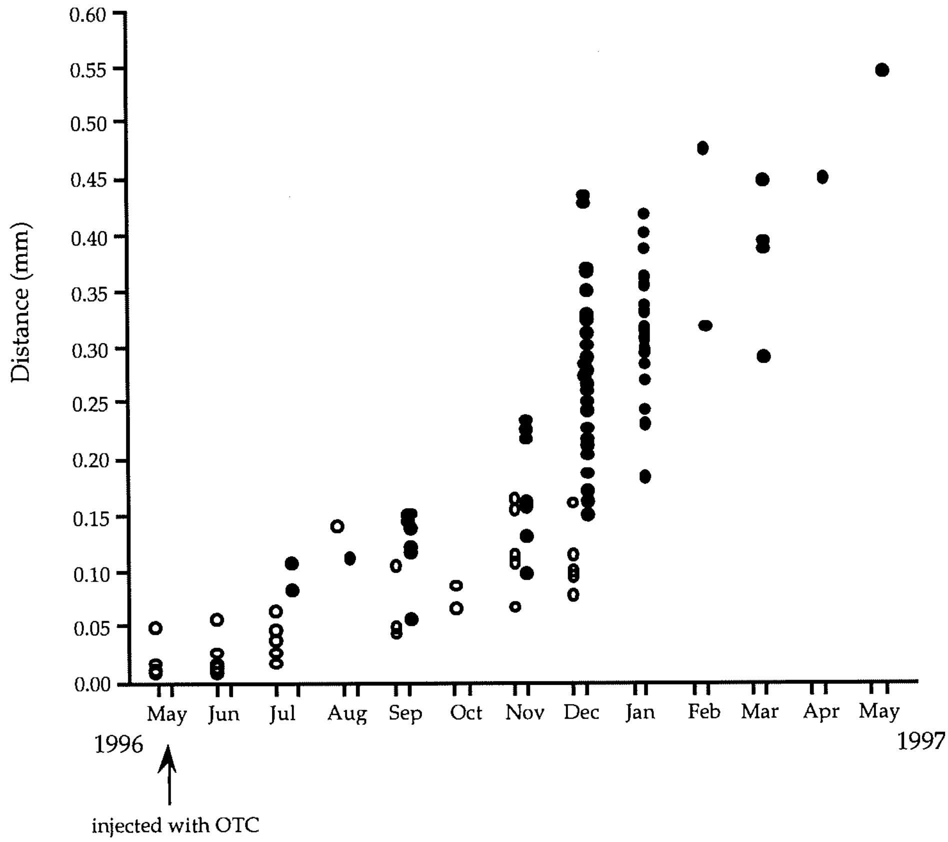


Figure 3.3. Distances from the OTC mark to the otolith edge for all blue mackerel aged 0+ when injected with OTC in May 1996. Animals which had formed an opaque ring after the OTC mark (filled-in circles) are slightly offset to those that had not formed an opaque ring (open circles).

3.3.3 *Otolith marginal increments*

To examine whether otolith growth in fish kept in aquaria was typical of their earlier growth we measured the ratio of the distance from the OTC mark to the otolith edge with the distance between the last two annuli. This ratio was often greater than 1 in April and May 1997 (Fig. 3.4) and suggests that otolith growth in captivity may have been greater than otolith growth in the wild (Fig. 3.5).

Marginal increment measurements for wild yellowtail 2+ and older indicate that visible opaque marks were closest to the otolith edge during January and tended to be at a maximum distance during August to December (Fig. 3.5). This suggests that only 1 opaque mark is laid down per year. Large standard errors during December suggest that some yellowtail may have a new opaque mark visible while others do not.

Distances from the centre of the first opaque mark to the otolith edge for all 1+ blue mackerel and from the centre of the second opaque mark to the otolith edge for all 2+ blue mackerel indicate that opaque marks are closest to the otolith edge during January/February in 1+ fish, but there is no indication of the timing of appearance of the 2nd opaque mark in 2+ fish (Fig. 3.6). Unfortunately no samples of 1+ blue mackerel were collected during March, April, May, or September, but the samples collected suggest that for 1+ fish only 1 opaque mark becomes visible per year and that it is usually visible by January.

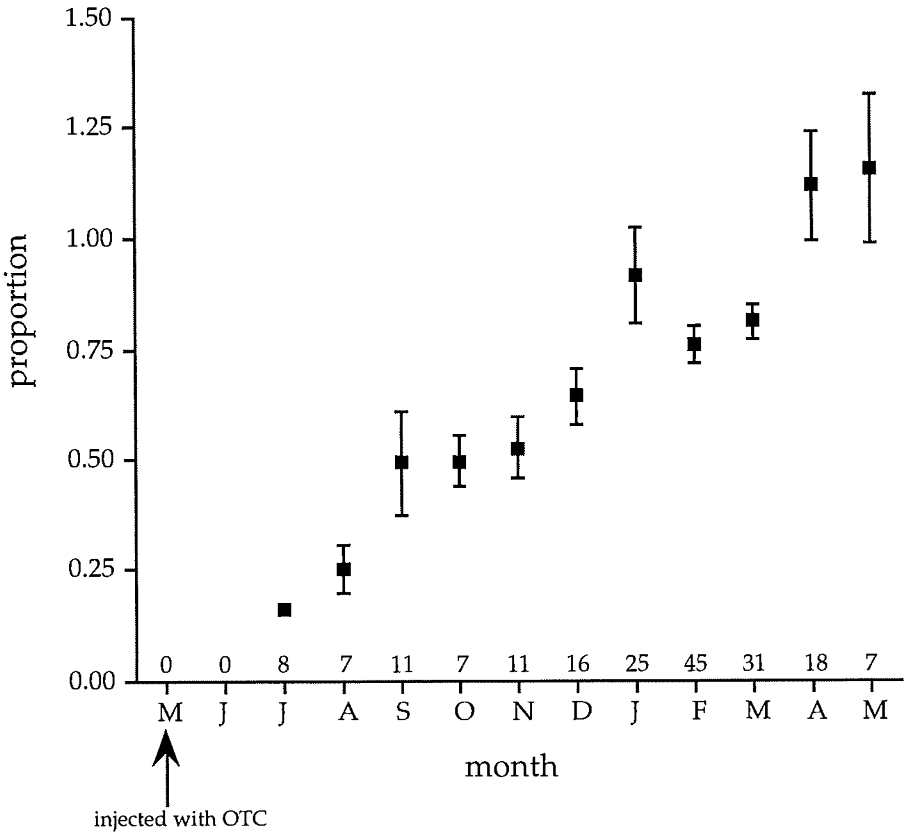


Figure 3.4. Distances from the OTC mark to the otolith edge expressed as a proportion (mean with standard error) of the previous complete increment for captive yellowtail 2+ and older. Numbers indicate sample sizes.

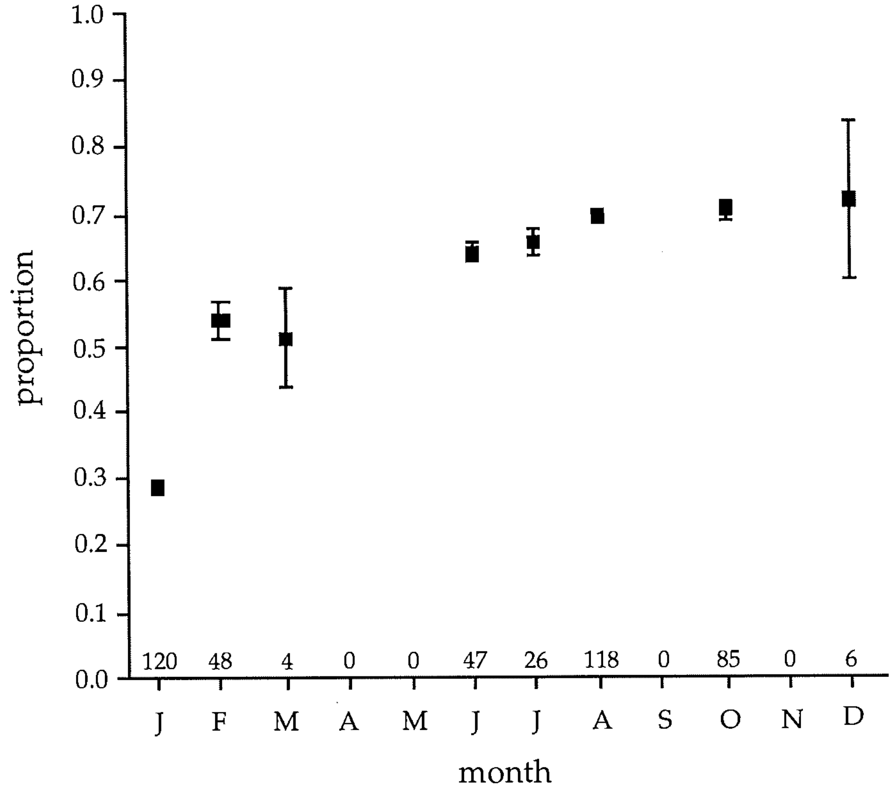
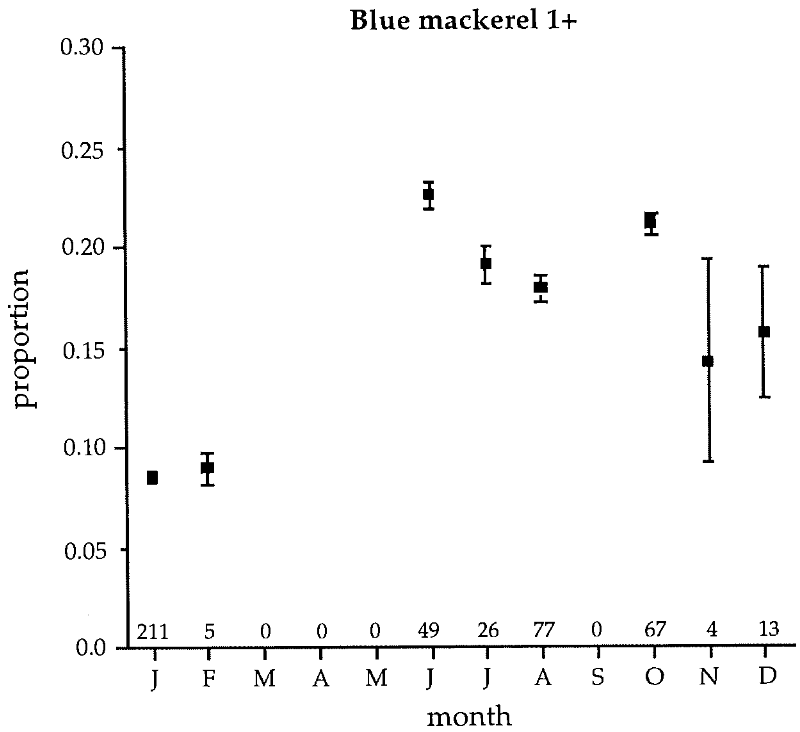


Figure 3.5. Distances from the most recent annulus to the otolith edge expressed as a proportion (mean with standard error) of the previous complete increment for wild yellowtail 2+ and older. Numbers indicate sample sizes.

3.4 Discussion

These results represent sound preliminary validations of ageing methods for yellowtail and blue mackerel. For yellowtail we have shown that for age classes 2+ through to 6+ one opaque mark is deposited per year. This annual mark is deposited in winter in all yellowtail but may not become visible until anytime between August and December. There was no evidence of non-annual marks forming subsequent to any OTC mark and all yellowtail which survived until at least January had formed an opaque mark subsequent to the OTC mark. These results, from fish in captivity, agree with the observations of Horn (1993) as to the timing of appearance of opaque marks in the otoliths of wild yellowtail in New Zealand. Horn also observed opaque marks to become visible anytime between August and December, with most fish having visible marks by October.

A.



B.

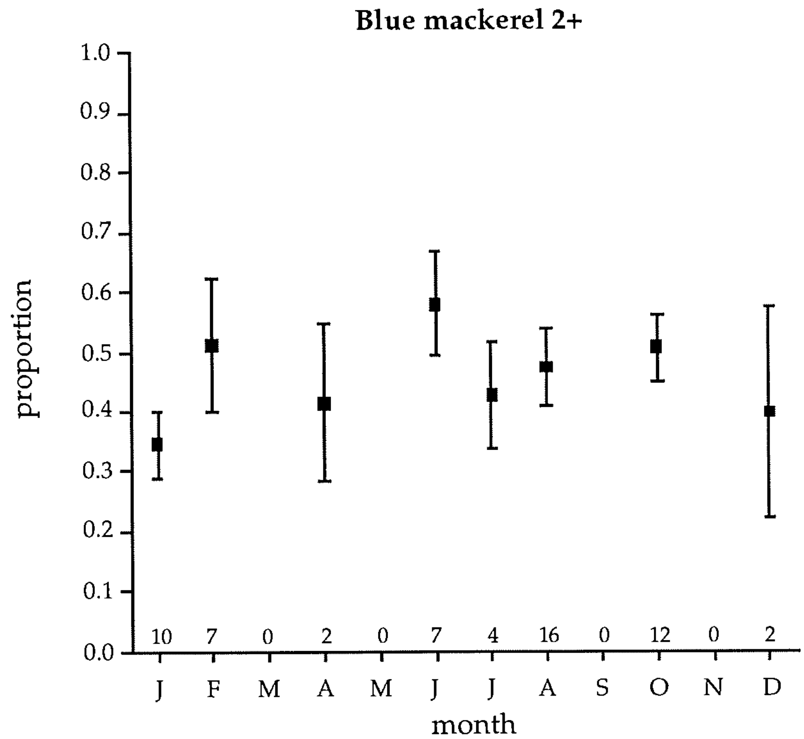
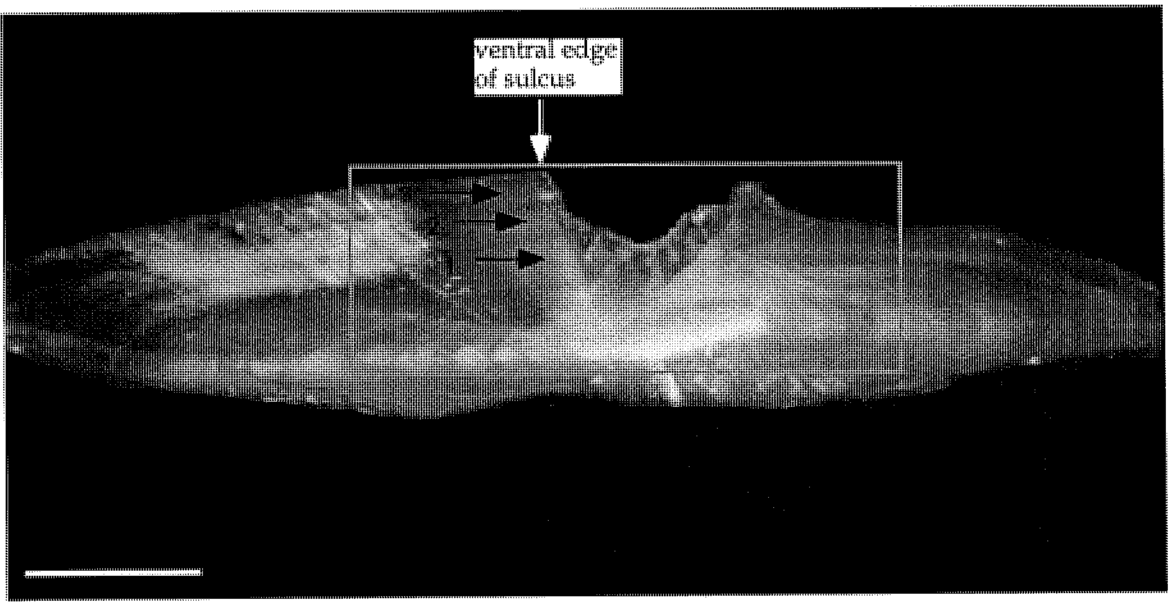


Figure 3.6. Distances from the most recent annulus to the otolith edge expressed as a proportion (mean with standard error) with **A.** the distance from the core to 1st annulus for wild 1+ blue mackerel and **B.** the distance between the 1st and 2nd annuli for wild 2+ blue mackerel. Numbers indicate sample sizes.

A.



B.

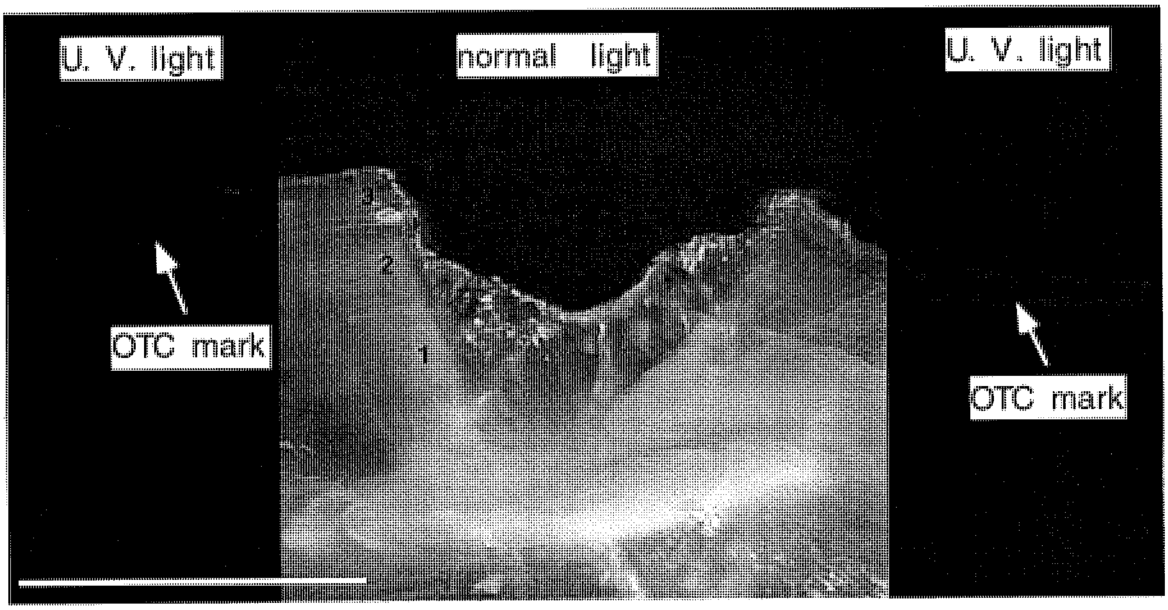


Figure 3.7. A section of a yellowtail otolith viewed under reflected light against a black background. The fish was injected with oxytetracycline (OTC) in May 1996 when aged 2+ and killed 289 days later in February 1997 when aged 3+ and 197mm F.L. **A.** shows the position of the opaque mark under normal light. **B.** magnified view from frame shown in A. showing the position of the opaque mark and of the OTC mark when viewed under ultra violet light. Scale bars are 1mm.

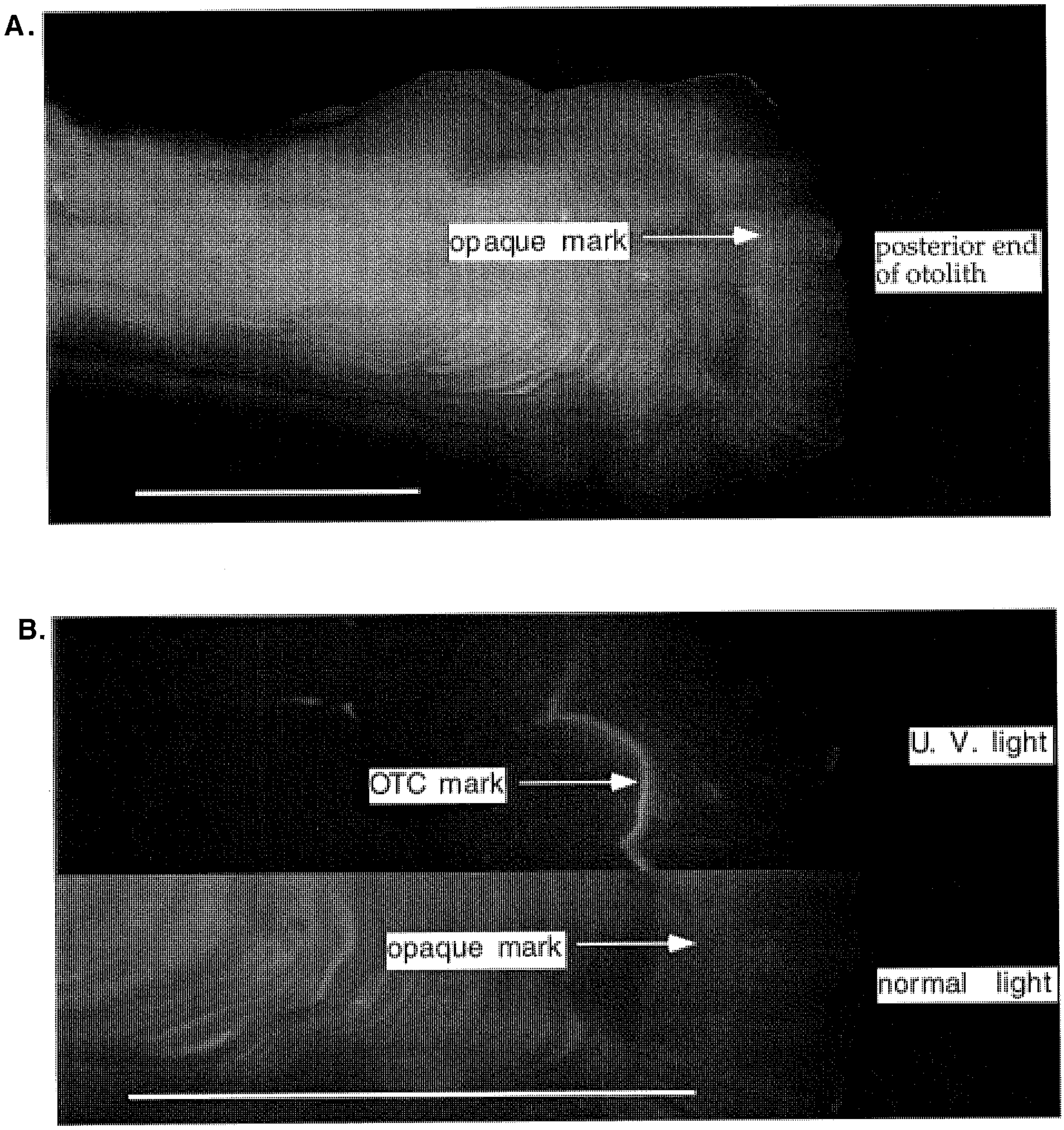


Figure 3.8. A whole blue mackerel otolith immersed in lavender oil and viewed under reflected light against a black background. The fish was injected with oxytetracycline (OTC) in May 1996 when aged 0+ and killed 245 days later in January 1997 when aged 1+ and 287mm F.L. **A.** shows the position of the opaque mark under normal light. **B.** shows the position of the opaque mark and of the OTC mark when viewed under ultraviolet light. Scale bars are 1mm.

We attempted to quantify errors in assigning age classes from ring counts for yellowtail during the experiment. If otolith growth of yellowtail kept in captivity can be compared to those from wild yellowtail (and the results of Horn, 1993 suggest they can) then errors due to edge interpretation can be large during certain times of the year, (ie. 67.4 % of fish aged between August to December may be assigned an incorrect age class based purely on ring counts when using a birthday of the 1st January). We have shown that these errors may be reduced by setting criteria for assigning age classes similar to those described for Yellowtail in New Zealand (Horn, 1993) and Snapper (Francis et al. 1992). Horn (1993) attempted to reduce errors in converting ring counts to age classes for yellowtail during August to December by setting criteria based on the width of the marginal increment:

month	margin narrow	margin wide
Jan - Jul	age = ring count	age = ring count
Aug - Sep	age = ring count -1	age = ring count
Oct - Dec	age = ring count	age = ring count + 1

These criteria were based on observations of the timing of appearance of opaque margins in otoliths of wild fish and using a birthday of 1 January. Unfortunately there are no estimates of the sizes of expected errors and the extent to which they may be reduced by applying these criteria.

Marking blue mackerel otoliths using OTC and subsequent periodic sampling has shown that 1 opaque mark is deposited during their first year. This opaque mark is deposited during winter but may not become visible until the following summer and is clearly visible in whole otoliths when viewed immersed in lavender oil using reflected light against a black background. In addition, our marginal increment measurements from wild fish aged 1+ suggest that only 1 opaque mark is deposited during the 1st year of life and that it is nearest to the otolith edge (ie. becomes visible) during summer (Fig. 3.6A). Marginal increment measurements from 2+ blue mackerel give no indications as to the timing of appearance of a second opaque mark, or even as to the nature of growth in the otolith at this age.

Approximately 70% of the commercial catch of blue mackerel is made up of fish aged 1+ (see section 2.3.4) meaning that this age class is the most important to have a validated ageing method for. Most of the blue mackerel we collected for the OTC experiment were 0+ at the time of their capture and we have validated the timing of formation of the first opaque mark. We have no information on the time between spawning and the first opaque mark becoming visible. The timing of formation of the second opaque mark in blue mackerel otoliths could not be validated from marginal increment data and estimates of ages older than 1 year are yet to be validated. This is likely to be an artefact of looking at whole otoliths, difficulty in measuring them and relatively small sample sizes.

Future attempts to validate the timing of opaque mark formation in blue mackerel should attempt to do so using 1+ and older fish at the time of injecting with a vital stain. Gaining access to these older and much larger blue mackerel is likely to be problematic and keeping them alive in captivity for any length of time difficult. Blue mackerel have long flight distances and need to be kept in large enclosures to reduce mortalities due to injuries from swimming into the sides of enclosures. Large sea cages may offer the best chance of keeping large blue mackerel alive in captivity.

The one blue mackerel which had formed 2 thin opaque marks subsequent to the OTC mark indicates that our identification of annuli was not 100% accurate. When this otolith was initially aged it was scored as a 2 year old, but when viewed under U.V. light and the position of the OTC mark was seen it became clear that it was a double opaque mark. If this event was not a result of being in captivity then similar marks may occur in wild fish and a small number of otoliths may have been wrongly scored. Blue mackerel scored as 4, 5, 6 and 7 year olds had opaque marks that became thinner and closer together towards the edge of the otolith thus increasing the likelihood of double marks being scored as 2 separate annuli. This result is important because it shows that there may have been a small amount of error within our ageing technique. However, the small numbers of old blue mackerel in the fishery means that we are confident that any such errors are insignificant in terms of our results.

These results show the value of using a time-marker such as OTC to study the timing of growth processes within otoliths. Blue mackerel are shown to deposit 1 opaque mark in their otoliths during winter which may not become visible until summer. Baird (1977) when studying age and growth of the mackerel *Scomber japonicus* used the opaque or translucent appearance of the otolith edge to determine the timing of annulus formation. Because he too observed opaque marks to become visible during summer he concluded that opaque bands were deposited during summer and that translucent bands were deposited during winter. In view of the present study this conclusion is likely to have been wrong.

Despite setting similar rules to Horn (1993) to reduce errors in assigning ages from ring counts for yellowtail in captivity, and the agreement in the timing of annuli becoming visible, we did not apply them to wild fish in the present study. Evidence that otolith growth in captivity may have exceeded that of wild fish (Fig. 3.4), together with reasonably small sample sizes for some age classes in some months and the short duration of the study, all reduced confidence in applying results to wild fish.

An important finding for future studies estimating growth rates from fish ages is our assessment of the edge interpretation problem described by Francis et al. (1992). We have used OTC marked yellowtail and blue mackerel otoliths to identify those months in which the terminal annulus may or may not be visible, and to estimate possible errors in assigning age classes based purely on ring counts during these months. In addition, we have shown that the terminal annulus becomes visible earliest in the fastest growing otoliths (see Figs 3.2 & 3.3). This finding, together with the fact that otolith growth and fish size are highly correlated (Boehlert, 1985), suggests that the fastest growing fish will have their terminal annulus visible earliest and will be more likely assigned an age class one year greater than slower growing fish of the same true age. This may have major implications for estimating growth from fish sampled during those months where edge interpretation errors are likely. The fastest growing 1 year olds may be assigned as 2 year olds, the fastest growing 2 year olds may be assigned as 3 year olds etc., effectively decreasing estimated mean size at age and under-estimating growth. It may be possible to overcome this problem by not sampling during those months identified as being problematic, or by formulating algorithms to reduce errors in assigning age class based purely on ring counts such as Francis et al. (1992), or Horn (1993).

Our marking of yellowtail otoliths with OTC and subsequent monthly sampling has given us an opportunity to quantify possible errors in assigning age classes directly from annuli counts. This is something which is rarely addressed in ageing studies (but see Francis et al. 1992) and a knowledge of such error rates is essential when designing future sampling regimes. We have shown that yellowtail during the months of January to July are unlikely to be effected by edge interpretation errors and sampling for age estimates during these months is preferable. Blue mackerel should be sampled between January and June. This criteria should eliminate errors due to edge interpretation and is appropriate because the fishery for both species is active during these times.

4. Recommendations and implications

4.1 Benefits

Benefits from this study will flow to both the commercial and recreational users of these resources. This report provides baseline information on the size and age compositions in catches of these species. The knowledge gained from sampling the commercial fisheries in this study will allow for future cost-effective monitoring of these species.

That some small pelagic species have unexpectedly long lives will come as a surprise to both commercial and recreational fishers. This report will assist in spreading that knowledge and so change the view of some users about the dynamics of the populations they are exploiting. This has already been demonstrated, with increased recent demands by industry for management changes and for further study. The improved understanding of age compositions in these species will facilitate industry adoption of changes in management that arise.

The attempt at estimating bait used at sea by gamefishers in tournaments is a useful example for both scientists and managers confronted with similar problems. Estimating the consumption of a resource that is largely used during the fishing trip is a difficult problem and our study demonstrates the value of one approach to making such estimates.

The validation of our ageing technique will benefit all future studies which estimate age in these species. Confidence in the age estimates produced in future monitoring programs will lead to better acceptance by client groups of statements about the catch structure of their fisheries.

4.2 Intellectual property

No patentable inventions or processes have been developed as part of this project. All results will be published in relevant scientific articles and other public domain literature.

4.3 Further development

The validation we have provided for age estimation in blue mackerel and yellowtail commences from the formation of the first opaque ring. We do not have sufficient understanding of age and growth of these species prior to the formation of that ring. Assessments that require absolute accuracy of age estimates may require further study of young fish to determine at what age the first annual mark forms.

The size composition of yellowtail and blue mackerel in commercial harvests suggests that the coastal seine fishery may not be accessing larger, older individuals in the stock. This situation should be monitored for change because a single-year study such as this one may prove unrepresentative in the longer term.

4.4 Staff

The following staff have been employed on the present project;

John Stewart	Technical Officer
Doug Ferrell	Principal Investigator
Neil Andrew	Principal Investigator

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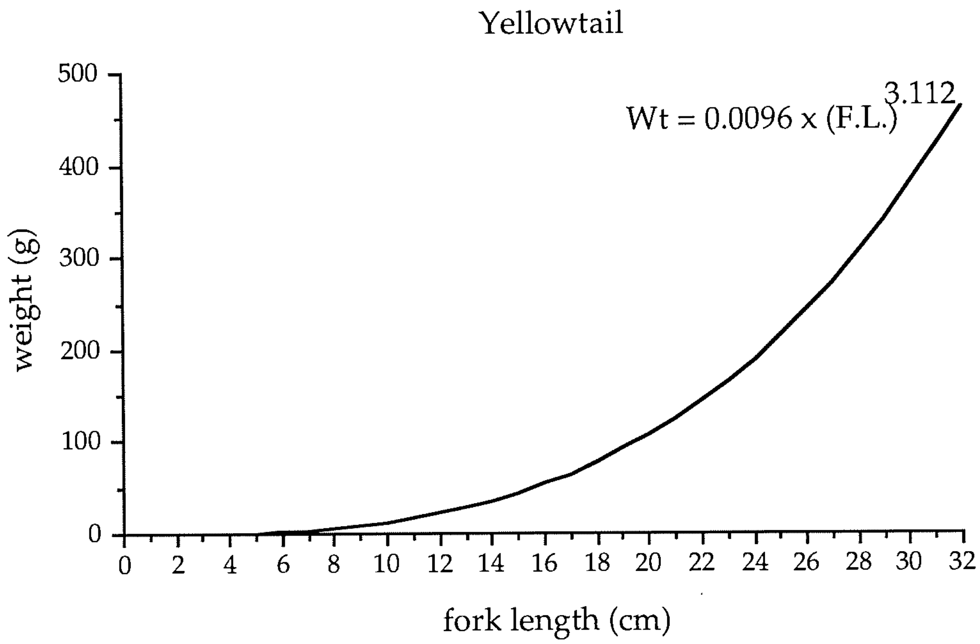
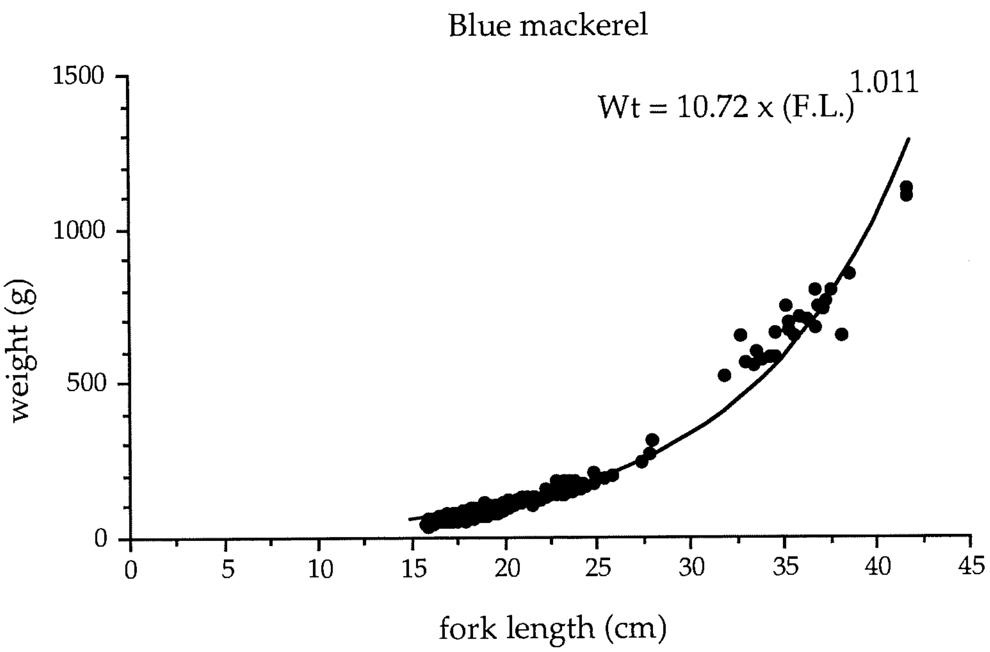
Appendix A.

Length weight relationships for yellowtail (from Steffe et al., 1996) and for blue mackerel (from the present study).





Other titles in this series:

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