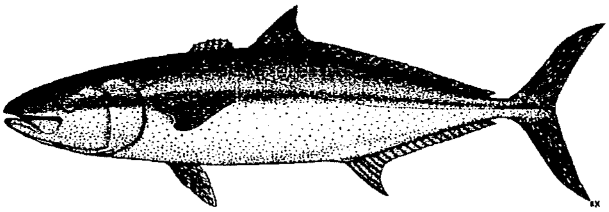
# Determination of Ageing in Kingfish (*Seriola lalandi*) in New South Wales



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## Non-technical summary

**95/128 Determination of ageing in kingfish (*Seriola lalandi*) in New South Wales**

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**OBJECTIVES:**

1. To critically examine the methods by which the age of kingfish can be estimated
2. To review all available information on the biology of *Seriola* spp.
3. To re-analyse all available data on the movement of kingfish
4. To provide preliminary estimates of size at maturity
5. If a reliable method of ageing can be found, then preliminary estimates of variability in growth and size at age will be made at several locations

**NON TECHNICAL SUMMARY:**

Yellowtail kingfish (*Seriola lalandi* Valenciennes, 1833) is one of the most popular angling fish in NSW and supports a significant commercial fishery. Despite this, and persistent controversies surrounding exploitation of the species, there is very little information on which to assess the status of the stock. Stock assessment requires knowledge of size at maturity, size at age, growth rate, and estimates of the variability in these parameters within the stock. This study was undertaken to determine a method for ageing kingfish and to provide preliminary estimates of growth rates. Size at maturity was also determined and data obtained from a cooperative tagging program were analysed to provide information on movement of kingfish.

*Age and growth*

Dorsal spines, otoliths, scales and vertebrae were evaluated as to their suitability as ageing structures for kingfish. Transverse sections of otoliths were considered uninterpretable, but whole otoliths that had been burnt showed interpretable patterns. Dorsal spines were also considered unsuitable for ageing because the core region of the spine became larger as fish grew, meaning that early growth zones may be lost or obscured in older fish, leading to underestimates of age. Relationships between spine diameter and size or age of fish were also poor suggesting that spines did not continue to grow throughout the life of the fish. Whole otoliths, scales and vertebrae appeared useful as structures for ageing kingfish. Although clarity of zones, ease of collection and processing, and precision of age estimates are important considerations, final choice of a structure for age determination will depend on the accuracy of the ages estimated. Analysis of marginal increments and marking of fish with tetracycline suggested that one zone may be laid down each year, but further research needs to focus on validating ageing methods for all age classes of fish.

Fitted growth curves from size at age data for all structures, except dorsal spines, seemed plausible given size at age data from other studies on *Seriola* spp. Growth curves from otoliths and vertebrae were similar, but growth curves from both structures were significantly different to the growth curve obtained from scales. Further research needs to focus on the position of the first zone in all structures because this may be contributing to differences in the shape of the growth curve between structures. No fish were found to be in their first year (i.e. $0^+$) when aged with scales, but fish were estimated to be in their first year when aged using otoliths and

vertebrae. Age estimates from scales, however, did not remain higher than estimates from otoliths and vertebrae across all ages. We therefore recommend retaining at least scales and otoliths until their relative accuracy is known. Our data suggest that if validations are possible, kingfish may be aged reliably.

*Reproduction*
The reproductive biology including size and age at maturity and seasonality of spawning was determined. Although some fish are maturing at a smaller size than the current size limit (600 mm TL), many fish may be harvested prior to first reproduction. Fifty percent of females were mature at 700mm FL. The mean age at sexual maturity ranged between 3.1 and 4.2 years for females and 0+ to 1.2 years for males, depending on the structure used. The impact of this on the stock remains unclear, as the species is both highly fecund and mobile. If all kingfish are available to the fishery, then the current minimum size limit may not be appropriate for the long term sustainability of the fishery. Gonad development was greatest in December and lowest in February/March, indicating summer spawning.

*Movement*
Data obtained from the NSW Fisheries Gamefish Tagging program were analysed to (i) investigate the distribution of tagged and recaptured fish, (ii) determine the size range of the population being tagged and recaptured, (iii) determine whether recapture rates vary among fishers and (iv) investigate patterns of movement of kingfish. A total of 17 190 tagged kingfish have been released between 1974 and 1995 and there have been 1 376 recaptures equating to an overall recovery rate of 8%. Quantitative analyses of the data are difficult. The majority of fish were recaptured in the same general area as they were tagged, although there was some evidence to suggest that fish which were at large longer may have moved further. There was also an indication that larger fish (>750 mm TL) moved greater distances than smaller fish (e.g. fish <600 mm TL). 119 fish moved greater than 50 km with three fish moving from NSW, Australia to northern New Zealand. Movement within NSW is probably sufficient to ensure the stock is well mixed. The merits and limitations of the Gamefish Tagging program are discussed.

**KEYWORDS:** Ageing, reproduction, movement, tagging, *Seriola*, Carangidae

# 1. Introduction

## 1.1. Background

The NSW Fishing Industry Research Advisory Committee (FIRAC) identified the stock assessment of kingfish as their highest priority for research in wild fisheries. The project was developed after discussions with the committee in spring 1994. As a result of those discussions the revised application focused on several aspects of the biology of kingfish, particularly age, growth, movement and size at maturity. This knowledge will be used as a basis for future assessments and to develop future research projects.

## 1.2. Need

Yellowtail kingfish (*Seriola lalandi* Valenciennes, 1833) is one of the most popular angling fish in NSW and supports a significant commercial fishery. In 1991, approximately 400 t of kingfish was caught by commercial fishers. Despite these facts and persistent controversies surrounding the exploitation of this species, there is very little scientific information on which to assess the status of the stock. Critically, there is currently no quantitative information on the sizes at maturity and age-structure of populations of kingfish in NSW. Stock assessments will require knowledge of size at maturity, size at age, growth rate, and estimates of the variability in these parameters within the stock.

A logical first step in a structured stock assessment of a fishery is to determine whether ages of individuals can be estimated from their bony parts. Other means of estimating age and growth (e.g. tagging programs or length-frequency analysis) are often less accurate and more expensive than analysis of hard parts (Bagenal and Tesch 1978). The examination of bony parts can include otoliths, scales, spines, fin-rays, sections of vertebrae or other bony structures (e.g. Lai *et al.* 1987). If suitable bony parts are found, preliminary (unvalidated) age estimates can be made. Preliminary estimates of age and growth from a range of locations will identify the spatial scale at which growth rates vary.

Ageing of many large pelagic fishes such as the billfishes, mackerels, tunas and carangids is known to be difficult (Radtke 1983). Baxter (1960) estimated ages of *Seriola lalandi* (ex *dorsalis*) from California with scales but commented on difficulties with a high proportion of regenerated scales. Baxter (1960) suggested that scales were superior to other structures including fin-rays, spines and otoliths but did not document the reason for their choice. Munekiyo *et al.* (1982) described an ageing method using the vertebral centrum and this approach has apparently been successfully applied by Murayama (1992*a*). Fin-ray sections and otoliths have also been suggested as appropriate methods to age similar species (e.g. Beamish 1981, Sudekum *et al.* 1991, Horn 1993). It was not known whether any of these methods could be successfully applied to age kingfish in NSW.

## 1.3. Objectives

The objectives of this project were:

(1) To critically examine methods by which the age of kingfish can be estimated (Chapter 3).

(2) To review all available information on the biology of *Seriola* spp. (Chapter 2).

(3) To re-analyse all available data on the movement of kingfish (Chapter 5).

(4) To provide preliminary estimates of size at maturity (Chapter 4).

(5) If a reliable method of ageing can be found, then preliminary estimates of variability in growth and size at age will be made at several locations (Chapter 3).

# 2. A review of the literature on *Seriola* spp.

## 2.1. Introduction

Yellowtail kingfish (*Seriola* spp., Carangidae) is a popular angling fish and supports significant commercial fisheries both in NSW and throughout temperate regions of the world. Despite their great economic importance and widespread occurrence, there is little scientific information on the biology of the species. This literature review is based on published scientific literature and personal communication with Andrew Penney (Sea Fisheries Research Institute, South Africa) and Graeme McGregor (MAF Fisheries North, Auckland, New Zealand), and focuses on tagging and movement, age, growth and reproductive biology of *Seriola* spp. We may, however, have missed some literature published locally and some literature in foriegn languages, for example, there is likely to be some relevant Japanese literature that was not available to us. This review does not attempt to encompass the broad literature from cultured *Seriola* spp.

There has been considerable scientific debate regarding the distribution and taxonomy of kingfish. The family limits of the Carangidae have not been clearly established, although it is estimated that worldwide there are approximately 140 species in 30 genera (Laroche *et al.* 1984). Within the genus *Seriola* there are nine species, of which four (*Seriola lalandi, S. dumerili, S. hippos* and *S. rivoliana*) are found in Australian waters (Laroche *et al.* 1984; Kuiter 1993). *Seriola lalandi* Valenciennes, 1833 is a circumglobal species restricted to subtropical waters and known from Australia, Japan, New Zealand, South Africa, St. Helena, southern Brazil, Gulf of California and the west coast of the United States, Peru, east coast of India and the islands of Rapa, Pitcairn, Hawaii, Easter, Juan Fernandez and the Galapagos (Smith-Vaniz 1984; Shameem and Dutt 1986). The Australian species of yellowtail kingfish (*S. lalandi lalandi*) is thought to be one of three physically similar but geographically separate populations or subspecies which do not interact: one off California (*S. lalandi dorsalis*), one in Asia (*S. lalandi aureovittata*) and a southern hemisphere group (*S. lalandi lalandi*; Smith-Vaniz 1984; International Gamefish Association 1995). In addition to occuring in Australian waters, *S. lalandi lalandi* also occurs in coastal waters bordering the western coast of the Americas (British Columbia to Chile), South Africa and New Zealand (McGregor 1995*c*) and was previously thought to be five separate species (Smith-Vaniz 1984; International Gamefish Association 1995). *Seriola lalandi* has, therefore, also been referred to as *S. pappei* and

*S. banisteri* (South Africa), *S. aureovittata* (Japan), *S. grandis* (Australia and New Zealand) and *S. dorsalis* (Eastern Pacific; Smith-Vaniz 1984). Within Australia, *S. lalandi* is distributed from North Reef in Queensland (23°11'S), around the southern coast of the continent to Trigg Island in Western Australia (31°52'S) and on the east coast of Tasmania and around Lord Howe and Norfolk Islands (Paxton *et al.* 1989; Kailola *et al.* 1993).

## 2.2. Description of the fishery

### 2.2.1. *Commercial fishery*

NSW commercial fishers have caught kingfish mainly by line fishing methods and also using pelagic fish traps (now banned). The NSW Fisheries database does not enable the total catch of kingfish to be differentiated by method. However, in the 1989/90 to 1991/92 financial years 12% of the catch was definitely caught in fish traps and 51% was definitely not caught in fish traps. Thirty seven percent of the catch listed fish traps as one of a group of methods used. Fish traps have now been banned (as of 1st April 1996). Currently there is a proposal to restrict the number of fishers in the trap and line fishery.

Total commercial landings in NSW have shown a gradual decline from 595 tonnes in 1985/86 to 346 tonnes in 1993/94, although there have also been restrictions imposed on the fishery over this time period (Fig. 2.1). For example, when fish traps were first used (which may have been as early as the 1970's), there were no restrictions of the number of traps a fisher could use. On the 3rd June 1988 a restriction of five traps per fisher or boat was imposed and remained in place until 1st October 1990, when a limit of three traps per endorsement on the boat license was imposed. A minimum legal size of 600 mm TL was imposed on 23rd February 1990.

Kingfish are landed throughout the state, but the largest commercial catches traditionally come from an area near Greenwell Point (Zone 7) and off Narooma (Zone 9; see Table 2.1). Kingfish are landed throughout the year, but there are higher catches during spring and summer months than in winter (Table 2.1).

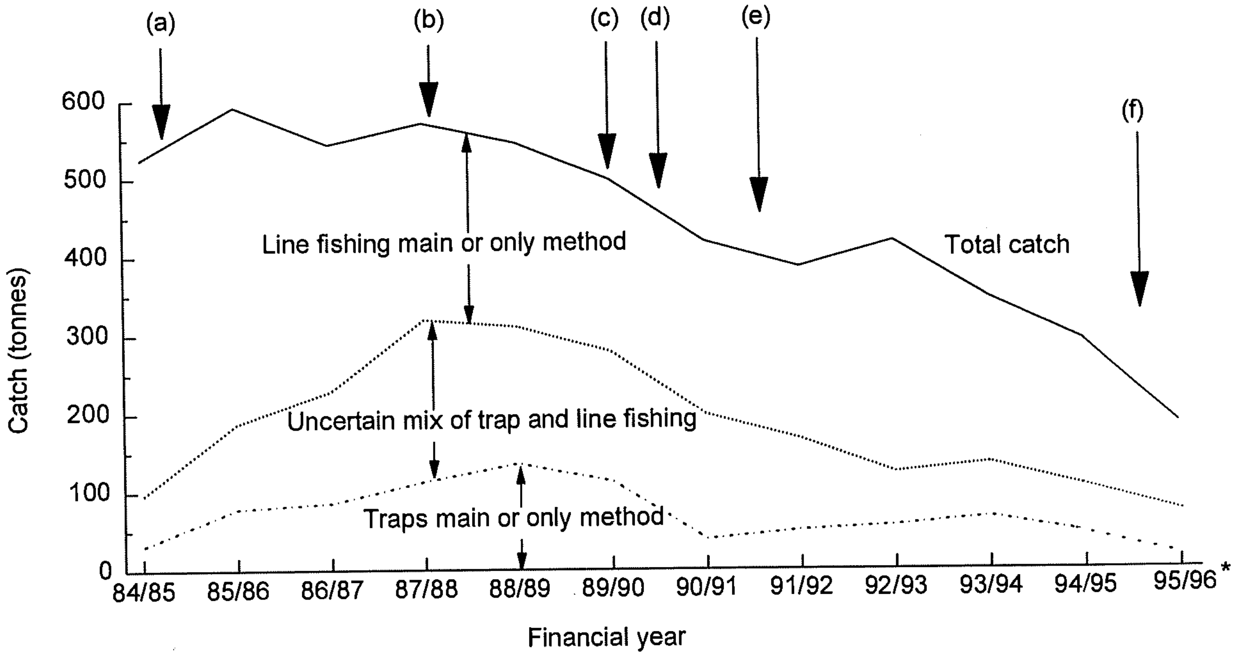

**Figure 2.1.** Commercial catch of kingfish in New South Wales distinguishing catch by method (cumulative) and showing introduction of different management regimes. (a) No restrictions on number of traps allowed per fisher, (b) 3rd June 1988, a limit of 5 traps/fisher or boat imposed, (c) 23rd February 1990 minimum legal size limit of 600 mm TL imposed and (d) 1st October 1990 a limit of 3 traps/endorsement on boat licence imposed.(e) 1 July 1991 change in catch return form (f) Pelagic traps were banned on 1st April 1996. * records for the 1995/96 financial year were about 85% complete at the time of analysis. Source: NSW Fisheries Licencing and Catch Statistics Database.

**Table 2.1.** Commercial catch of kingfish by NSW Fisheries Ocean Zones and by month for fish caught between July 1984 and June 1995 inclusive. Zones start at the Queensland/NSW border and divisions between zones thereafter are at 1° latitude intervals, on the degree.

| Ocean zone | % of total catch |
|---|---|
| 1 | 2 |
| 2 | 3 |
| 3 | 7 |
| 4 | 10 |
| 5 | 10 |
| 6 | 10 |
| 7 | 29 |
| 8 | 8 |
| 9 | 19 |
| 10 | 1 |

| Month | % of total catch |
|---|---|
| January | 9 |
| February | 10 |
| March | 9 |
| April | 7 |
| May | 6 |
| June | 4 |
| July | 4 |
| August | 4 |
| September | 5 |
| October | 9 |
| November | 16 |
| December | 19 |

### 2.2.2. *Recreational fishery*

An estimate of the total catch of kingfish taken by recreational fishers using trailer boats and limited information from a charter boat survey is available for 1993-95 (Steffe *et al.* 1996). Although difficult to survey, estimates of catch for representative locations along the NSW coast have been obtained, but these only reflect landings made during daylight hours. Estimated harvest of kingfish (for nine locations along the coast of NSW) by trailer boat fishers was greatest for the Sydney region for the two years surveyed, but varied greatly between years (10.9 (±2.2) t for September 1993 to August 1994 inclusive versus 4.9 (± 1.0) t for the same time period in 1994/95; Steffe *et al.* 1996). These estimates formed part of the harvests by trailer boat fishers at large access locations in NSW of 53.0 (± 5.6) t and 35.8 (± 3.3) t for September 1993 to August 1994 and for same period in 1994/95 respectively. Estimates of total recreational harvest of kingfish for NSW would be greater than these figures when small and medium access locations are also considered. In a study of recreational shore fishers along the coast of NSW, *Seriola lalandi* (ex *grandis*) formed 0.6% of the total catch of all species taken during summer, and was not a major species taken in winter (Kingsford *et al.* 1991). No indication of numbers of kingfish or biomass was given.

Information on the harvest of kingfish by anglers fishing from charter boats is only available for the Sydney region. Data were obtained from voluntary logbooks, and if they are are assumed to be representative of the Sydney charter boat fleet, the estimated recreational harvest of kingfish by charter boat fishers was 7.4 (± 3.9) t for the period September 1994 to August 1995 inclusive (Steffe *et al.* 1996).

## 2.3. Tagging and movement data

Tagging studies and patterns of movement of individuals may aid in assessing the interaction between fisheries in different locations and in defining the discreteness of stocks, as well as in assessing total stock size, natural and fishing mortality (Hilborn 1990). The most common method of presenting movement data is to draw arrows from where the fish were tagged to where they were recovered (e.g. Smith *et al.* 1991; Saul and Holdsworth 1992); rarely are more quantitative analyses used. Hilborn (1990) stated that a major problem in quantitative analyses of tag recoveries is that the number of recoveries is related to the fishing effort in the area and that rarely is the probability of capture between time of release and location of recovery taken into account. For example, few fish may be caught in a particular area because there is a high probability of capture before reaching that area (Hilborn 1990).

There have been a number of tagging studies on *Seriola* spp. Both NSW Fisheries and the New Zealand gamefish tagging programs began in 1975, with one of the principal species being *S. lalandi*. Both programs operate with the cooperation of angling clubs. Equipment and a variety of types of tags are supplied by government agencies to recreational and club anglers. In addition to these programs, *Seriola lalandi* (ex *dorsalis*) was also tagged in the 1950's throughout southern and Baja Californian waters as part of a larger study on its biology (Baxter 1960) and there has also been a number of fish tagged in South African waters (A.J. Penney, Sea Fisheries Research Institute, South Africa, pers. comm.). A closely related species, *Seriola quinqueradiata*, has been the subject of a number of tagging programs in the Japan Sea and East China Sea regions since 1926 (e.g. Tanaka 1979; 1984; Murayama 1992*b;* and references therein). A summary of these studies is shown in Table 2.2. Recapture rates have ranged between 3.5% (California) and 16% (New Zealand). Tagged fish have been at liberty up to 3680 days and have moved up to 3000 km.

In Baxter's (1960) study, fish less than 600 mm FL and greater than 900 mm FL showed very little movement. In contrast, 62% of the 610-900 mm FL fish moved at least 50 miles. Juvenile kingfish (<600 mm) in NSW also remained relatively sedentary (Smith *et al.* 1991). McGregor (1995*a,c*) noted that most kingfish in New Zealand did not move far from the area in which they were released.

Tagging data for *S. lalandi* obtained from the NSW Fisheries Gamefish Tagging program have not been analysed since the mid 1980's. Further analysis of these data are reported in Chapter 5.

**Table 2.2.** Summary of tagging studies on *Seriola* spp. showing country in which the study was done (country), number tagged (tagged), number recaptured (recaptures), percentage recaptured (%), time at liberty in days (range and average), distance travelled in km (range and average), size of fish in mm (size) and source of information (source). Abbreviations: [a] nautical miles, * all part of NSW Fisheries Gamefish program, # all part of NZ cooperative tagging program, - information not provided.

| | | | | **Time at liberty** | | **Distance travelled** | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Country** | **Tagged** | **Recaptures** | **%** | **Range** | **Average** | **Range** | **Average** | **Size** | **Source** |
| Australia | - | - | 6.3 | - | - | - | - | - | Pepperell 1985* |
| Australia | 9 594 | 682 | 7.1 | - | - | - | - | - | Pepperell 1990* |
| Australia | ≈11 000 | 870 | ≈8 | 1-1205 | - | 0-2100 | - | <600 | Smith *et al.* 1991* |
| Australia | 17 190 | 1 376 | 7.9 | 0-1742 | 101 | 0-3000 | 26 | 200-1400 TL | NSW Fisheries Gamefish program* |
| New Zealand | 2 545 | 410 | 16.1 | 2-1491 | 286 | 0-1400[a] | 10.7[a] | - | Saul & Holdsworth 1992# |
| New Zealand | 2 584 | 423 | 16.4 | - | - | - | - | - | Murray 1990# |
| New Zealand | ≈4 000 | 650 | ≈16 | - | - | - | - | - | McGregor 1995*a,c*# |
| California, USA | 15 161 | 532 | 3.5 | 1-1433 | - | 0-651 | - | 300- >910 FL | Baxter 1960 |
| USA | 5 643 | 642 | 11.4 | 1-≈3680 | - | 0-2400 | - | - | Scott *et al.* 1990 |
| South Africa | 3 500 | ≈350 | ≈10 | - | - | - | - | - | Penney pers. comm. |
| Japan | 11 013 | 1 463 | 13 | - | - | - | - | 150-730 FL | Murayama 1992*b* |

## 2.4. Age and Growth

### 2.4.1. *Ageing*

A variety of methods and structures have been examined in the hope of ageing *Seriola* spp. Baxter (1960) used scales to estimate ages of *S. lalandi* (ex *dorsalis*) after attempts at ageing using otoliths, vertebrae, fin rays and opercular bones proved unsuccessful. *Seriola* spp. scales are small, cycloid and most studies attempting to use them have noted a large number of regenerated scales. Baxter (1960) noted, however, that although regeneration was observed in scales collected from all regions of the fish, fewer regenerated scales were found on the preopercle. Also, after the seventh year of life, annual marks became too close to differentiate, resulting in disagreement between readers as to the age of fish. Examination of scales over a period of one year suggested that a single annulus was formed between November and January (northern hemisphere; Baxter 1960). Studies in South Afrcia have also examined scales of *S. lalandi*, but described them as "useless" for ageing yellowtail (A. Penny, pers. com.). Scales have also been used to age *S. quinqueradiata* (Mitani 1955).

Several Japanese studies describe techniques for age estimation using vertebrae (e.g. Mitani 1958; Munekiyo *et al.* 1982; Murayama 1992*a*). Munekiyo *et al.* (1982) suggests that most age estimates using vertebrae have been done by cutting the vertebrae longitudinally and examining it with obliquely reflected light under a binocular microscope. Munekiyo *et al.* (1982) suggested that rings were difficult to read on the surface of a v-shaped structure and proposed making polyvinyl alcohol replicas from the vertebrae for convenience of reading. Murayama (1992*a*) has since used replicas of the vertebrae to age 815 *S. quinqueradiata* and to show seasonal changes in marginal growth of vertebrae. The centra of whole vertebrae have also been examined in studies of other species (e.g. Baker and Timmons 1991).

Otoliths have been used to age *S. lalandi* from South African waters, partly because of their convenience (A.J. Penney, Sea Fisheries Research Institute, South Africa, pers. comm.). Whole otoliths were difficult to interpret and therefore larger otoliths were sectioned for annulus counting. Penney (pers. comm.) does however describe otoliths as having numerous striations meaning that annuli were extremely difficult to determine. The South Africans also obtained some results from daily ring counts of SEM sectioned otoliths of one to two year old fish.

The opercular bone has been used to age *S. quinqueradiata* in Japan (Mitani and Sato 1959). They noted, however, that the first mark was difficult to see in larger fish (>300 mm) and that corrections for age estimates may therefore be necessary.

In summary, a variety of structures have been used to age *Seriola* spp., but there has been no comparative analysis to determine which method may be best. Consequently, in the present study, dorsal spines, otoliths, scales and vertebrae were assessed for their usefulness in determining the age of *S. lalandi* in NSW; the results are reported in chapter 3.

### 2.4.2. *Growth*

The majority of information on growth in *Seriola* spp. comes from Japan where *S. quinqueradiata* is cultured extensively. Consequently, most information on growth rates for this genus are from cultured fish (e.g. Shimeno *et al.* 1985). The following details refer only to growth rates of wild-caught fish which have been estimated from ageing and tag-recapture studies. American kingfish (*S. lalandi*) grew quickly in the first year but relatively slowly thereafter (Baxter 1960). The greatest range in size was found in one year old fish (371-633 mm FL); fish reached an average maximum length (asymptotic length) of 1291 mm. Growth per year established from tagging experiments ranged from 34 to 109 mm for age 1 fish, whereas that for age 7 fish ranged from 19 to 70 mm. In New Zealand, growth of tagged kingfish was calculated at 93±11 mm for a 500 mm fish and 44±4.5 mm for a 1000 mm fish (Holdsworth 1994, reported in McGregor 1995*c*). An asymptotic length of 1449 mm and a von Bertalanffy $K$ value of 0.103 was calculated using GROTAG (Holdsworth 1994, reported in McGregor 1995*c*). Growth of *S. quinqueradiata* in Japan showed considerable differences among different coastal regions, with southern areas having faster growth rates than northern areas (Murayama 1992*a*). This was especially the case for fish 1-3 years. Size at age estimates for *Seriola* spp., including size at age estimates from the present study (also see chapter 3), are summarised in Table 2.3.

**Table 2.3.** Size at age estimates for *Seriola* spp. from other studies and the current study. The species and ageing structure is also shown for each study. Size at age data from (1) Baxter (1960) - lengths from the fitted growth curve (95% confidence interval), (2) Mitani (1955) - average length at age, Mitani & Sato (1959) - lengths from the average growth curve, (4) Penney (pers. comm.) - range of sizes at age and (5) Current study lengths from the fitted growth curve (standard error; see also Chapter 3). All lengths are mm fork length.

| | **Baxter (1960)** | **Mitani (1955)** | **Mitani & Sato (1959)** | **Penney (pers. comm.)** | **Current study** | | |
|---|---|---|---|---|---|---|---|
| **Age** | *S. lalandi*<br>**Scales** | *S. quinqueradiata*<br>**Scales** | *S. quinqueradiata*<br>**Opercular bone** | *S. lalandi*<br>**Otoliths** | *S. lalandi*<br>**Otoliths** | *S. lalandi*<br>**Scales** | *S. lalandi*<br>**Vertebrae** |
| 1 | 488.3 (5.9) | 340 | 290 | 300-550 | 499 (5) | 418 (9) | 485 (7) |
| 2 | 590.1 (8.1) | 530 | 490 | 500-600 | 577 (4) | 561 (7) | 567 (5) |
| 3 | 679.2 (6.7) | 710 | 630 | 620-720 | 655 (4) | 665 (6) | 646 (4) |
| 4 | 756.8 (13.4) | 860 | 730 | 700-850 | 732 (6) | 750 (6) | 720 (4) |
| 5 | 824.7 (7.6) | 990 | 810 | 800-940 | 807 (8) | 823 (6) | 788 (6) |
| 6 | 883.9 (17.5) | | 860 | 860-960 | 879 (10) | 888 (10) | 849 (8) |
| 7 | 935.6 (20.5) | | | 940-1000 | 947 (12) | 947 (12) | 904 (10) |
| 8 | 980.7 (26.3) | | | 980-1080 | 1011 (15) | 1001 (15) | 952 (13) |
| 9 | 1020.2 (25.2) | | | 1020-1120 | 1071 (17) | 1052 (18) | 994 (16) |
| 10 | 1054.6 (23.5) | | | 1050-1160 | 1126 (20) | 1099 (21) | 1031 (19) |
| 11 | 1084.7 (28.7) | | | | | | |
| 12 | 1110.9 (16.7) | | | | | | |

## 2.5. Reproductive biology

Size at maturity, duration of spawning season and fecundity estimates all require knowledge of the stage of development in individual fish. In females, such knowledge can be achieved using a variety of methods including histology, visual staging based on the external appearance of the gonad (macroscopic) or of whole oocytes (microscopic), measurement of oocyte size, and gonad indices (West 1990). Males are more difficult to stage than females and therefore may give a less well defined estimate of the spawning season; they also do not show such large changes in gonad weight (West 1990). In the few studies on reproduction of *Seriola* spp., a variety of approaches have been used including measurement of oocyte size (Baxter 1960), histology (Micale *et al.* 1993), gonad indices (Smith 1987) and macroscopic staging (Marino *et al.* 1995; McGregor 1995*a,c*). Macroscopic staging of female gonads was also attempted in Baxter's (1960) study but found to provide inconclusive results; maturity of males was not assessed in their study.

### 2.5.1. *Spawning season*

All kingfish studied to date appear to be spring-summer spawners, although there have been few detailed studies. Garratt (1988) noted that most of the *S. lalandi* sampled in their study (Dec. 1975 and Nov 1986 - Jan. 1987; South Africa) were sexually mature and in spawning condition or spent, suggesting that sampling occurred late in the spawning season. As noted, Garratt's samples were taken over short time periods and therefore reproductive activity may be longer than the periods of time observed. This may be the case as Penney (A.J. Penney, Sea Fisheries Research Institute, South Africa, pers. comm.; also sampling in South Africa) noted that *S. lalandi* has a wide spawning season, with some gonad activity occurring year round. Peak spawning occurred in summer (November to February; Penney pers. comm.).

Off California, spawning generally began in July and continued until October (northern hemisphere summer-autumn) in *S. lalandi* (ex *dorsalis*). The timing of spawning was thought to be fairly uniform over the known range because ripe fish were found in different parts of the range at the same time (Baxter 1960). There has been little research on the timing of spawning in *S. lalandi* in NSW waters. Smith (1987) found that fish from Coffs Harbour had elevated gonad indices in February and March, but at the same time fish from Narooma did not. His sampling was, however, limited to three collections of fish (in February, March and August) from Coffs Harbour and one each from Narooma (in March) and Greenwell Point (in October).

### 2.5.2. *Size at sexual maturity*

Sexual maturation in *Seriola* spp. appears to be variable occurring from ≈500 mm FL and 2 years to 760 mm FL and 3 years. Garratt (1988) suggested that size of sexual maturity in *S. lalandi* from South Africa was 730 mm FL. This estimate was based on a sample of 50 fish taken in the spawning season, as well as information from an unpublished report (Penney 1982, cited in Garratt 1988). Fifty percent maturity occurs at about 620 mm FL (2-3 years of age; Penney pers. comm.). Baxter (1960) suggested that some fish (*S. lalandi* (ex *dorsalis*)) spawn during their second summer at approximately 506 mm FL, and that all fish spawn in their third summer when fish are approximately 634 mm FL. In New Zealand, *S. lalandi* mature between 580 and 670 mm FL; all fish larger than 700 mm were mature (McGregor 1995*a,c*). McGregor (1995*a,c*) also noted that the Japanese species matures between 625 and 765 mm FL (age 3 years). The smallest size of sexual maturation in *S. dumerili* from Japan was about 600 mm (Tachihara *et al.* 1993). Samples of *S. dumerili* from Sicily showed that first sexual maturity occurs at 4 years of age in males and 5 years in females; no information was presented on size at maturity (Micale *et al.* 1993 *S. dumerili* from elsewhere in the Mediterranean first matured at 2 years (males) and 3 years (females) and showed 50% maturity for both sexes between 3 and 4 years (Marino *et al.* 1995). The median standard length at which 50% of fish attained maturity was relatively large (1090 and 1130 mm for males and females respectively). With the exception of the study of Marino *et al.* (1995), it would seem likely that all fish larger than 800 mm FL may be sexually mature. The limited samples taken in Smith's (1987) study of *S. lalandi* in NSW waters support this observation (see also chapter 4).

### 2.5.3. *Spawning migrations*

*Seriola lalandi* forms spawning aggregations off Natal and Transkei during winter and spring, but spawning has also been reported in Cape waters (South Africa, Garratt 1988). Garratt (1988) suggested that *S. lalandi* is therefore flexible in the extent of its migration patterns from one year to the next with only part of the reproductive stock migrating north-eastwards into warmer waters. Northern hemisphere *S. lalandi* move from Baja California into Southern California (i.e. north) in the spring months and return south in the autumn and winter months (Baxter 1960). Smith *et al.* (1991) noted that there was no evidence for consistent patterns of kingfish movement in space or time in eastern Australia. This finding is in agreement with studies on N.Z. kingfish, which found no systematic seasonal movements (McGregor 1995*a,c*).

## 3. Ageing methods and preliminary results from age- and size-based growth models.

### 3.1. Introduction

Estimates of age of *Seriola* spp. have been derived from a variety of methods and structures. The Japanese species (*Seriola quinqueradiata*) is the most studied species in the genus because of its importance in aquaculture. Studies in the 1950's used scales, vertebrae and opercular bones for ageing (e.g. Mitani 1955; 1958; Mitani and Sato 1959). More recent studies have focused on the use of vertebrae (e.g. Munekiyo *et al.* 1982; Murayama 1992*a*). Scales have also been used to age *S. lalandi* (ex *S. dorsalis*, Baxter 1960), as have otoliths (A.J. Penney, Sea Fisheries Research Institute, South Africa, pers. comm.). Despite the use of a variety of structures for ageing *Seriola* spp., there has been no comparative analysis of structures to determine which method may be best. In addition, most studies have assumed that growth zones are annual and therefore there have been few validated studies (but see Mitani and Sato 1959; Baxter 1960).

The specific objectives of this study were to (1) assess the usefulness of several structures (scales, otoliths, dorsal spines and vertebrae) for determining the age of kingfish, (2) compare multiple age estimates for different structures to determine the most precise method for estimating age and growth parameters, (3) provide information on size at age for each structure and for different locations along the coast of NSW and (4) compare growth rates obtained from age-length data to those obtained from mark-recapture (tagging) data. We acknowledge that age-length and mark-recapture data are not directly comparable (see Francis 1988*a*), but follow the recommendations of Francis (1995).

## 3.2. Materials and Methods

### 3.2.1. *Fish collection and treatment*

Yellowtail kingfish (*Seriola lalandi*) specimens were collected from New South Wales, Australia between August 1995 and July 1996, either by commercial fishers or recreational fishers. Fish caught by commercial fishers were obtained after being processed (e.g. filleted for sale as sashimi). Fish were measured (total length, fork length) and the sagittal otoliths, dorsal spines, scales and vertebrae removed.

### 3.2.2. *Dorsal fin spines*

The second to fourth dorsal spines, which are the largest, were cleaned of tissue and embedded in resin. A thin cross section (700 μm) was cut from the lower portion of each dorsal spine with a low-speed saw and a diamond wafering blade. Mounted sections were viewed under reflected light (against a black background) with a compound microscope at 40x magnification. Thin sections of dorsal spines showed a pattern of alternating dark (translucent) and bright (opaque) zones when viewed under reflected light (Fig. 3.1a). For the purposes of assigning an age to each fish, the base section of the third spine was read by counting translucent zones. Where this spine section was not present or difficult to read, the other spine sections were also used. The centre (core) of the thin section was either occupied by vascularised bony tissue or was hollow, which may have complicated interpretation of early growth bands. The diameter of the spine and core (and microscopic measurements for other structures) were measured from video images on a computer screen using image processing software.

### 3.2.3. *Sagittae*

Whole sagittae were burned for 7-min at 500°C. They were viewed under a low power dissecting microscope (6x magnification) with reflected light against a black background. Assignments of age were based on counts of opaque (light) zones and/or ridges that were usually most visible at the base of the rostrum on the ventral surface (Fig. 3.1b). Otoliths were weighed (to 0.1 mg prior to burning) and otolith length and breadth measured (to 10 μm after burning). Otolith length was measured along the longest axis and otolith breadth was measured as close as possible through the otolith core perpendicular to the long axis. Sagittae were also embedded in clear resin, sectioned in a transverse plane using a low speed saw, mounted on glass slides, and viewed under a compound microscope (40x magnification) using reflected light against a black background.

### 3.2.4. *Scales*

Scales were removed from a position anterior and ventral to the pectoral fin. It was necessary to remove scales from such a position because most fish had been processed prior to the removal of scales. Scales from each fish were soaked in a solution of sodium hydroxide for 3 h, then rinsed and soaked in water for a further 3-12 h. Clean, non-regenerated ("original") scales were dry-mounted between two glass microscope slides. Scales were read under a compound microscope (20x magnification) with reflected light against a black background. Presumed annuli on scales were usually identified by cutting over (*sensu* Bagenal and Tesch 1978) in the lateral fields or by clear zones, where circuli were more widely spaced, in the anterior field. The radius of each scale was measured from the focus to the outer edge (see Fig. 3.1c).

### 3.2.5. *Vertebrae*

The second of 24 vertebrae present in kingfish was chosen, because this vertebra was most easily obtained from processed fish. Vertebrae were either stored frozen with flesh intact, or the flesh was removed, the vertebrae separated from each other and stored dry. The spines were removed from the vertebra and each vertebra was cut in half along the longitudinal-horizontal plane and stained in a solution of alizarin red (following Berry *et al.* 1977) for 8 h, rinsed in tap water for at least 1-min and dried at room temperature. Vertebrae were read under a dissecting microscope (6-12x magnification) with reflected light from a blue-filtered, high-intensity bulb against a black background. Age was estimated from counts of ridges on the inner surface of the vertebra from the core to the outer edge of the centrum (Fig. 3.1d). Vertebral cone depth was measured from the core to the outer edge of the centrum using dial callipers.

Two replicate counts of zones were made for each structure by the same person. Counts were usually separated by one month. All readings were done in a haphazard order, with no knowledge of date of collection or size of fish. Readings of transverse sections of otoliths were not made after preliminary investigations showed that they were extremely difficult to interpret (Fig. 3.2).

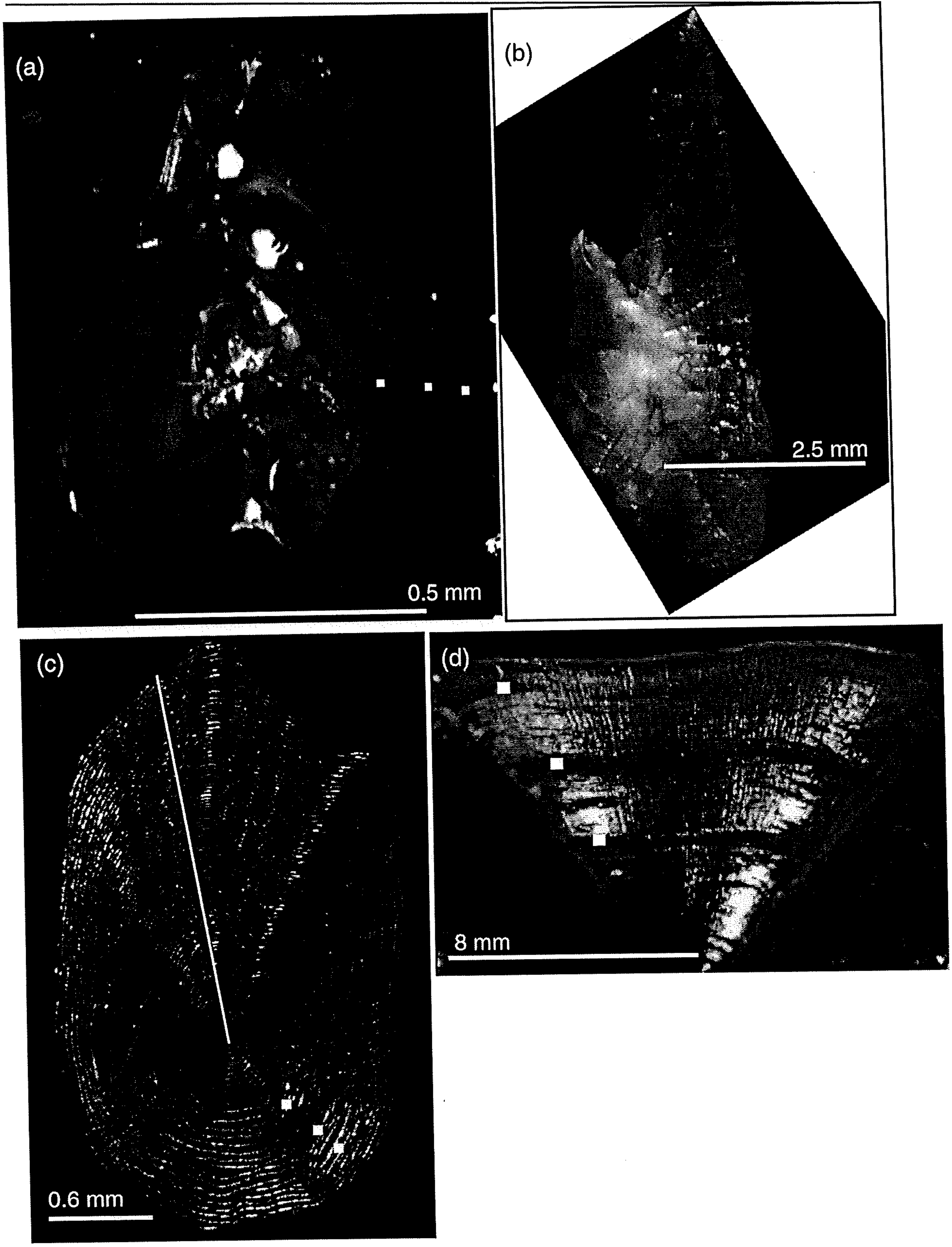

**Figure 3.1.** The four structures used to estimate the age of kingfish from New South Wales. (a) Dorsal spine (700 mm FL, age 3), (b) Otolith (860 mm FL,age 3), (c) Scale (618 mm FL, age 3) and (d) Vertebra (720 mm FL, age 3). All structures viewed with reflected light against a black background.

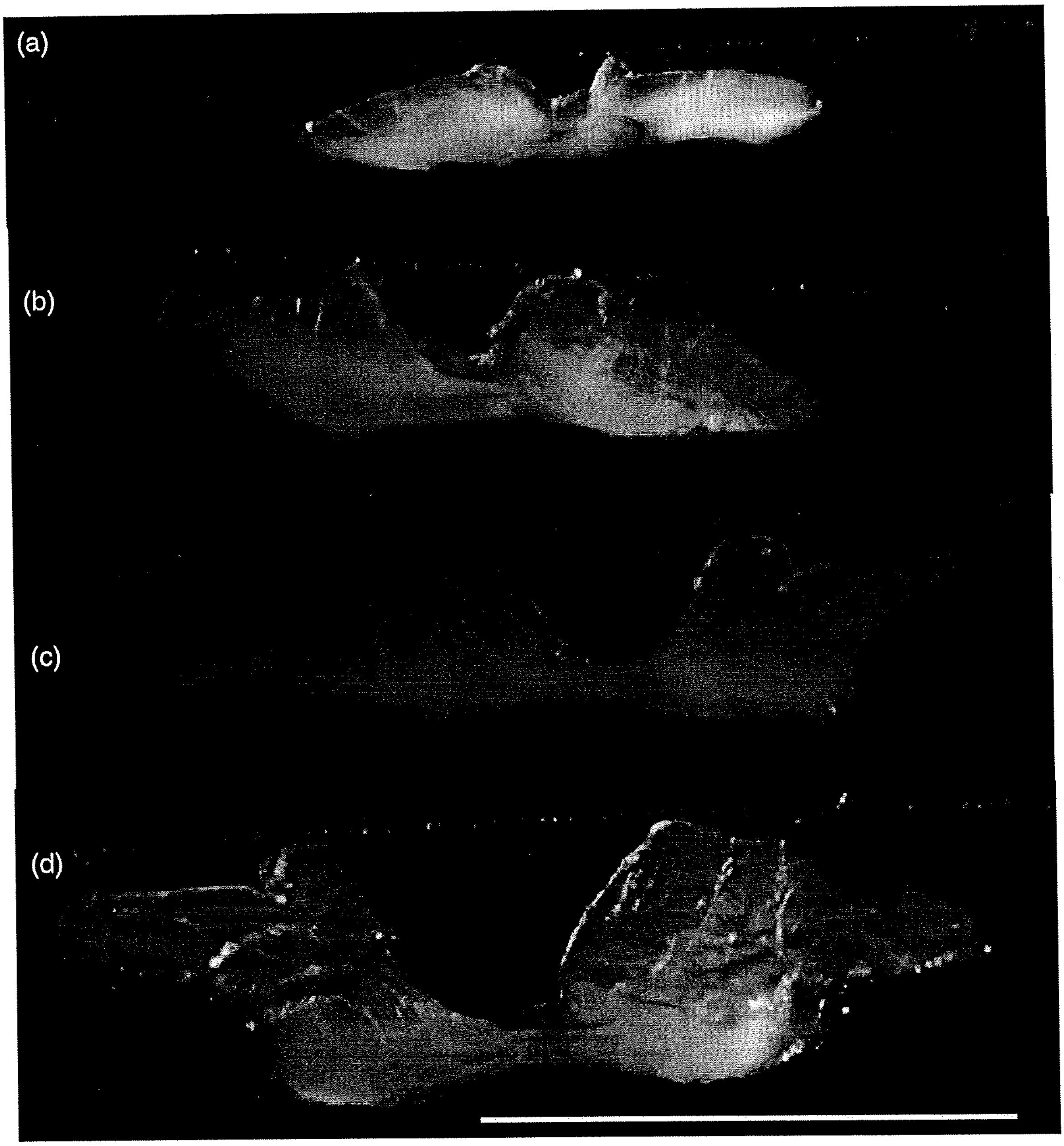

**Figure 3.2.** Transverse sections of sagittal otoliths of kingfish over a range of sizes viewed with reflected light against a black background. (a) 337 mm FL, (b) 638 mm FL, (c) 850 mm FL, (d) 1002 mm FL. Scale bar is 1.5 mm.

### 3.2.6. *Assessment of ageing techniques*

Prior to use of a structure for ageing, it is important to determine whether (1) the structure contains zones that can be interpreted, (2) the structure continues to grow throughout the life of the fish, (3) the number of zones on the ageing structure increase with growth of the structure, and (4) the zones present on the structure correspond to some regular time scale.

To determine whether the structure continued growing throughout the life of the fish, fork length was regressed against spine diameter (SD), scale radius (SR), otolith breadth (OB), otolith length (OL), otolith weight (OW) and vertebral cone depth (VCD). To determine whether the number of zones on each structure increased with growth of the structure, zone counts for each structure were regressed against SD, SR, OB, OL, OW and VCD.

For each structure, multiple counts of age were used to estimate a classification matrix, which defines the probability of assigning an age *a* to a fish with estimated 'true' age *b*[1], following maximum-likelihood estimation procedures outlined in Richards *et al.* (1992). A normal model (*sensu* Richards *et al.* 1992, pp. 1803) was used for the classification matrix. The classification matrix was then used to estimate the most probable age of each fish by determining the probability that a fish would be from each age class. A fish was assigned to the age class with the highest probability (Richards *et al.* 1992). This estimate of age was used for growth models. The first five age classes ($0^+$-$4^+$ for otoliths and vertebrae, $1^+$-$5^+$ for dorsal spines and scales) were used in the classification matrix because, although older fish occurred, sample sizes were small and some extrapolation for missing age classes would be necessary. Because data from older fish are important in estimating growth models, fish not used in the classification matrix were assigned an age by randomly selecting one of their two age readings.

Multiple readings for each structure were then used to examine the data for possible structure effects. Classification matrices indexed by structure were determined following the methods of Richards *et al.* (1992; outlined above) and the relative bias of each method at varying ages was determined. Only the first five age classes and fish for which readings were made for all four structures were used in the classification matrices.

To determine the timing of zone formation, the edges of the various structures were examined. The growth of the structure, subsequent to the most recent zone, was estimated as a proportion

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[1] True age - *sensu* Richards *et al.* (1992), does not refer to the accuracy of the age estimate and does not substitute for age validation procedures; best described as most probable age.

(20, 40, 60, & 80%) of the previously completed zone. It was also noted whether the zone was considered to be on the edge of the structure. Only fish aged 2-4$^+$ were used. Fish were examined individually by structure in a haphazard order with no knowledge of date of collection.

### 3.2.7. *Estimation of growth models*

Growth models using age estimates from different calcified structures were derived using procedures outlined in Schnute (1981). Schnute's model relates size to age by several parameters, including two that describe the shape of the curve ($a$ and $b$). These latter parameters combine to describe a range of common growth curves, including the von Bertalanffy ($a$>0, $b$=1), Richards ($a$>0, $b$<0), logistic ($a$>0, $b$=-1) and Gompertz ($a$>0, $b$=0) (Schnute 1981). The other parameters in Schnute's growth model were $y_1$ and $y_2$, the mean sizes at ages $\tau_1$ and $\tau_2$ respectively, where the value of $\tau_1$ and $\tau_2$ are specified, but usually chosen to be near the lower and upper ends of the range of ages in the data set being modelled. In this study, $\tau_1$ and $\tau_2$ were set at 1 and 5 respectively. All growth models were calculated using additive error models because variation in size at age was similar for all ages of fish (see results).

Initially, a two parameter model ($y_1$ and $y_2$) was fitted to the data. Two types of three parameter model (parameters were $a$, $y_1$ and $y_2$, and $b$, $y_1$ and $y_2$) and a four parameter model ($a$, $b$, $y_1$ and $y_2$) were then fitted to the data. To determine whether the addition of extra parameters resulted in a significantly better fit, significance tests based on the $F$-distribution were used (Schnute 1981). Where the same number of parameters was present in the models (e.g. comparison of the two models with three parameters), the model with the lowest residual Sums of Squares was selected as the best fit.

Growth curves obtained from otoliths, scales and vertebrae were compared with likelihood ratio tests following methods outlined in Kimura (1980). For each comparison between structures, it was necessary to fit data to five models corresponding to different constraints (see Table 3.1). Data fitted to Schnute's (1981) Case 2 growth model were used for the comparisons: $Y(t) = y_1 \exp\left[\log(y_2 / y_1)\frac{1-e^{-a(t-\tau_1)}}{1-e^{-a(\tau_2-\tau_1)}}\right]$, where $Y(t)$ is size at age. Dorsal spines were not used in the comparisons because the growth curve was markedly different to the other three structures.

**Table 3.1.** Likelihood ratio tests comparing Schnute's Case 2 parameter set ($a$, $y1$, $y5$) estimates from otoliths, scales and vertebrae based on age-size data. Five models corresponding to different constraints were used (Model 1 had no constraints, Model's 2-4 each had one constraint and Model 5 had three constraints. Sample sizes: $n$=473 (otoliths), 432 (vertebrae) and 482 (scales). Abbreviations, subscripted 1 and 2: structures being compared as indicated at top of each comparison, * $P<0.05$, ** $P<0.01$.

| | **Linear constraints** | $y1_1$ | $y1_2$ | $y5_1$ | $y5_2$ | |
|---|---|---|---|---|---|---|
| **Otoliths =1, Vertebrae=2** | | | | | | |
| 1 | none | 499.03 | 484.49 | 806.73 | 787.99 | |
| 2 | $a_1=a_2$ | 496.84 | 490.02 | 805.27 | 786.23 | |
| 3 | $y1_1=y1_2$ | 494.53 | 494.52 | 808.31 | 784.41 | |
| 4 | $y5_1=y5_2$ | 500.76 | 480.55 | 796.17 | 796.17 | * |
| 5 | $a_1=a_2$<br>$y1_1=y1_2$<br>$y5_1=y5_2$ | 494.35 | 494.35 | 793.87 | 793.87 | * |
| **Otoliths=1, Scales=2** | | | | | | |
| 1 | none | 499.03 | 434.66 | 806.73 | 834.68 | |
| 2 | $a_1=a_2$ | 493.55 | 453.40 | 800.19 | 836.90 | ** |
| 3 | $y1_1=y1_2$ | 478.19 | 478.19 | 813.95 | 821.92 | ** |
| 4 | $y5_1=y5_2$ | 496.88 | 436.27 | 819.02 | 819.02 | * |
| 5 | $a_1=a_2$<br>$y1_1=y1_2$<br>$y5_1=y5_2$ | 478.65 | 478.65 | 817.67 | 817.67 | ** |
| **Vertebrae=1, Scales=2** | | | | | | |
| 1 | none | 484.49 | 434.66 | 787.99 | 834.68 | |
| 2 | $a_1=a_2$ | 474.20 | 447.72 | 789.38 | 837.23 | ** |
| 3 | $y1_1=y1_2$ | 458.88 | 458.88 | 796.15 | 829.04 | ** |
| 4 | $y5_1=y5_2$ | 476.08 | 436.59 | 805.52 | 805.52 | ** |
| 5 | $a_1=a_2$<br>$y1_1=y1_2$<br>$y5_1=y5_2$ | 459.86 | 459.86 | 809.07 | 809.07 | ** |

### 3.2.8. *Estimation of rates of growth from tagging data*

Kingfish tagged as part of the NSW Fisheries Gamefish Tagging program (see Pepperell 1985; 1990 for further details) were used to estimate growth. A major limitation of this data set was that measurement methods were not standard and some measurements appeared spurious. Although most anglers measured total length, some measured fork length only. Where this occurred (17% of fish), fork length was converted to total length using the equation [TL(cm) = 1.122 * FL(cm) +.9 021]. This equation was calculated from fish obtained for ageing in which both fork and total lengths were measured ($n \approx 570$). All data ($n = 816$) were initially included in analyses even if they were highly improbable, for example, measurements indicating shrinkage of between 100 and 350 mm (Fig. 3.3a).

Growth estimates were obtained from the tagging data by using the maximum-likelihood method and computer program GROTAG (Francis 1988*b*). This provides estimates of $g_\alpha$ and $g_\beta$, the mean annual growth of fish of lengths $\alpha$ and $\beta$ respectively, where $\alpha$ and $\beta$ are chosen to span the range of lengths at tagging. With the initial data set, the estimated proportion of outliers was 0.04. Outliers were removed from the final analysis because, although having little effect on estimates of the parameters, they compromise significance testing (Francis 1988*b*). A simple three parameter model was initially fitted and then additional parameters added in a step-wise manner. At each step, likelihood ratio tests were used to determine whether addition of extra parameters resulted in significantly better fits (Francis 1988*b*).

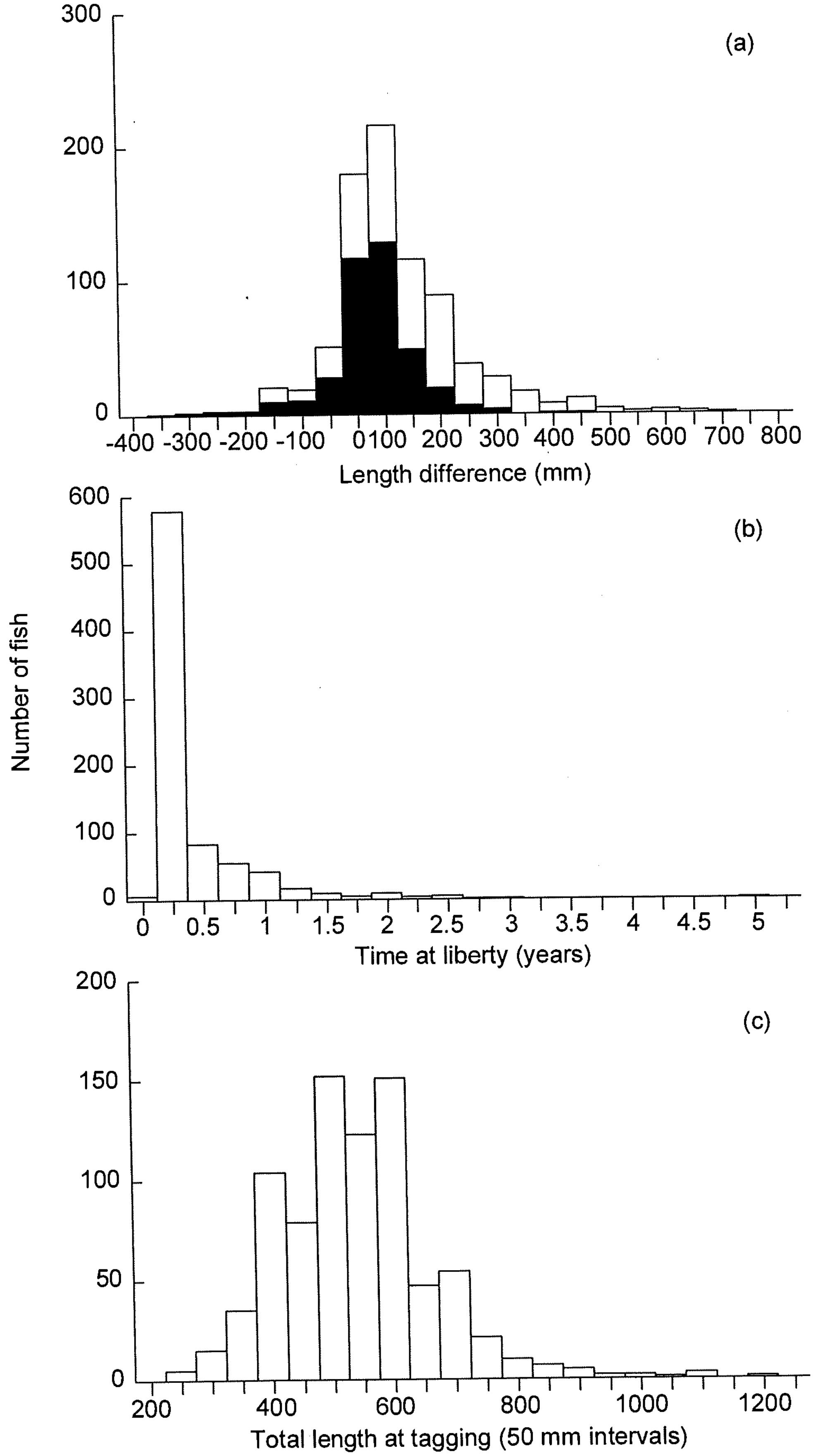

**Figure 3.3.** Distribution of (a) differences in length between tagging and recapture (b) time at liberty, and (c) length at tagging for kingfish (*n* = 816). Fish recaptured within 30 days are also indicated in (a) with shading (n = 384).

## 3.3. Results

Structures for ageing kingfish were collected from a total of 572 fish ranging in size from 323 to 1090 mm FL, but not all structures were collected from all fish. Although *S. lalandi* is reported to reach a total length of almost 2000 mm (1700 mm FL) and a weight of 60 kg (Kuiter 1993), fish of this size are uncommon. In New South Wales, commercial fishers rarely catch fish over 20 kg (about 1200 mm FL) and the largest fish recorded in boat ramp surveys of amateur fishers over 2 years was 1140 mm FL (Steffe *et al.* 1996). We were unable to obtain any very large fish (> 1500 mm FL).

All four structures showed zones that could be interpreted as annuli (Fig. 3.1). However, zones were not interpretable in all fish. Transverse sections of dorsal fin spines often showed a hollow core region and an outer region containing growth zones. Growth zones may have been lost as the core region hollowed out (Fig. 3.4a), especially in larger fish. Growth zones in whole otoliths were more easily interpretable than those in sectioned otoliths (Fig. 3.2); the latter showed numerous striations, which could rarely be interpreted. Zones in sectioned otoliths were, however, clearer in larger fish (Fig. 3.2). A large number of scales had to be collected as preliminary results showed that two-thirds of fish had at least some regenerated scales. Vertebrae did not always stain well and show pronounced ridges which reduced readability in many fish.

### 3.3.1. *Size of ageing structures*

The relationship between spine diameter, and core diameter of spines, and fork length (FL) was best described by logarithmic equations, although the relationships were weak compared to the other structures (Fig. 3.4a). An exponential equation best described the relationship between otolith weight and FL (Fig. 3.4b). Relationships between otolith breadth, otolith length, scale radius, and vertebral cone depth, and FL were linear (Fig. 3.4c-f). With the exception of spines, each ageing structure showed a positive increase in size with increasing size of fish suggesting that the structures continued to grow throughout the life of the fish.

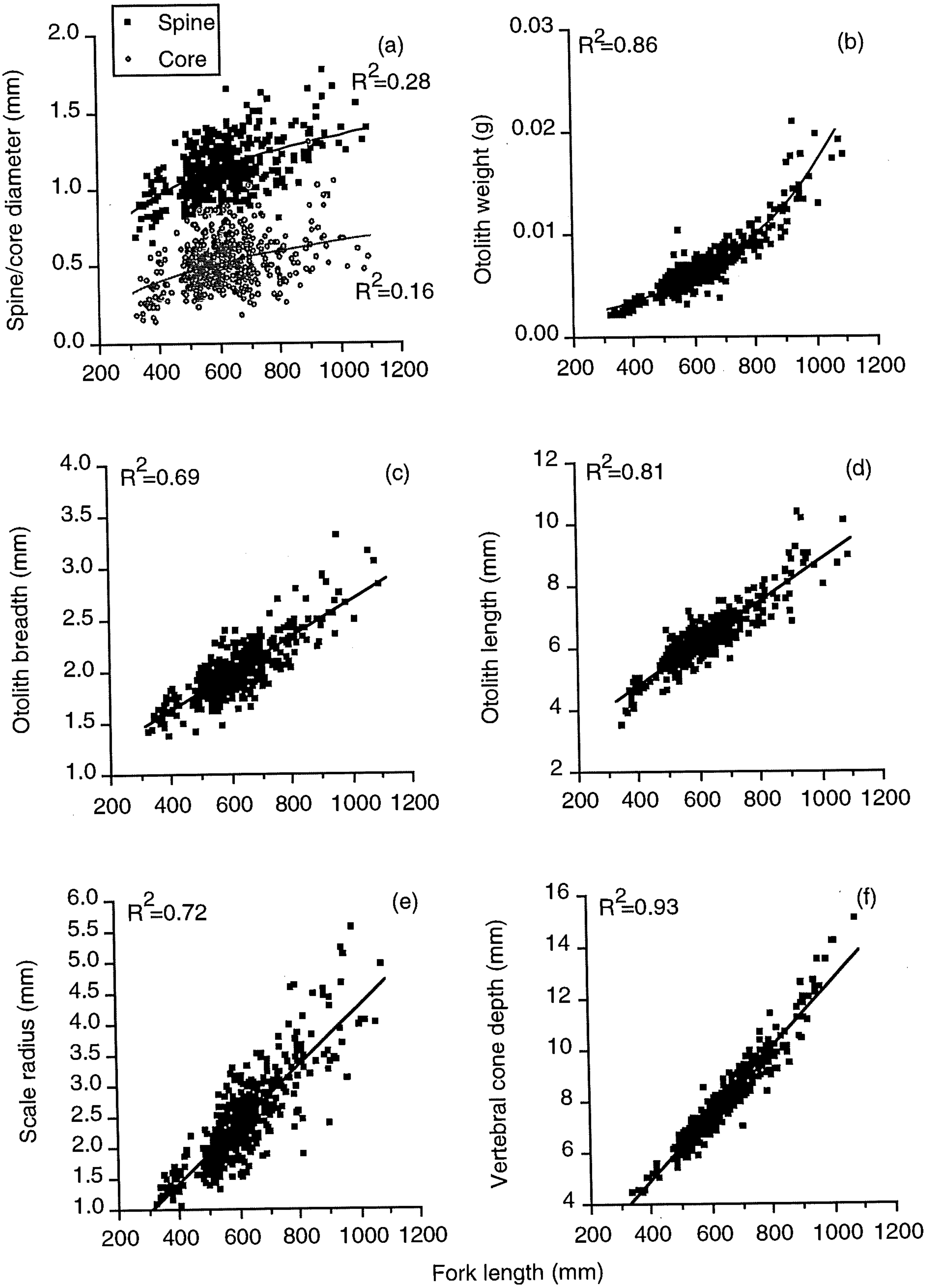

**Figure 3.4.** Relationship between size of the ageing structure and fork length. Lines of best fit are shown.

Counts of zones increased with size of the structure for three of the four structures examined (Fig. 3.5). A logarithmic equation best described the relationship between spine diameter/core diameter and age of fish, although the fits were poor suggesting that the data showed no relationship with age (Fig. 3.5a). The relationships for the other structures were linear, although the amount of variation accounted for by the size of the structure varied ($r^2$ ranged from 0.50 for otolith breadth to 0.69 for vertebral cone depth; Fig. 3.5b-f).

### 3.3.2. *Validation of each ageing method*

Analysis of marginal increments showed different patterns among structures (Table 3.2). Otoliths and scales showed some suggestion that one zone was laid down per year, namely in August/September (otoliths) and between October and January (scales; Table 3.2). No data were, however, obtained for scales in August/September and sample sizes were small between April and July ($n$=1-7 fish per month) for all structures. Dorsal spines always had marginal zones close to the edge and no clear pattern was observed in vertebrae (Table 3.2).

### 3.3.3. *Within structure precision*

Comparisons of two independent blind counts of zones in a structure resulted in a relatively low level of exact agreement (50-65%). Between 92 and 96% of readings, however, agreed within one zone, depending on the structure (Fig. 3.6). Differences in counts ranged from -4 to +4 (Fig. 3.6). Mean coefficients of variation ranged from 7.6% (scales) to 12% (otoliths).

### 3.3.4. *Among structure comparisons*

Comparison of readings between structures showed a large amount of variation, with differences ranging from -6 to +5 (Fig. 3.7). Agreement between any two methods decreased with age, but otoliths and vertebrae had the greatest concordance in fish aged 4 and over. Estimates using spines consistently underestimated the age of older fish and vertebrae tended to overestimate the age of older fish compared to other structures. Fish were never assigned an age of $0^+$ when aged with scales and there was only one fish aged $0^+$ from spines. Readings between structures agreed within one zone between 77% (between spines and otoliths) and 91% (between scales and otoliths) of the time. Comparisons with dorsal spines showed the lowest agreement (77% - otoliths, 81% - vertebrae, and 84% - scales).

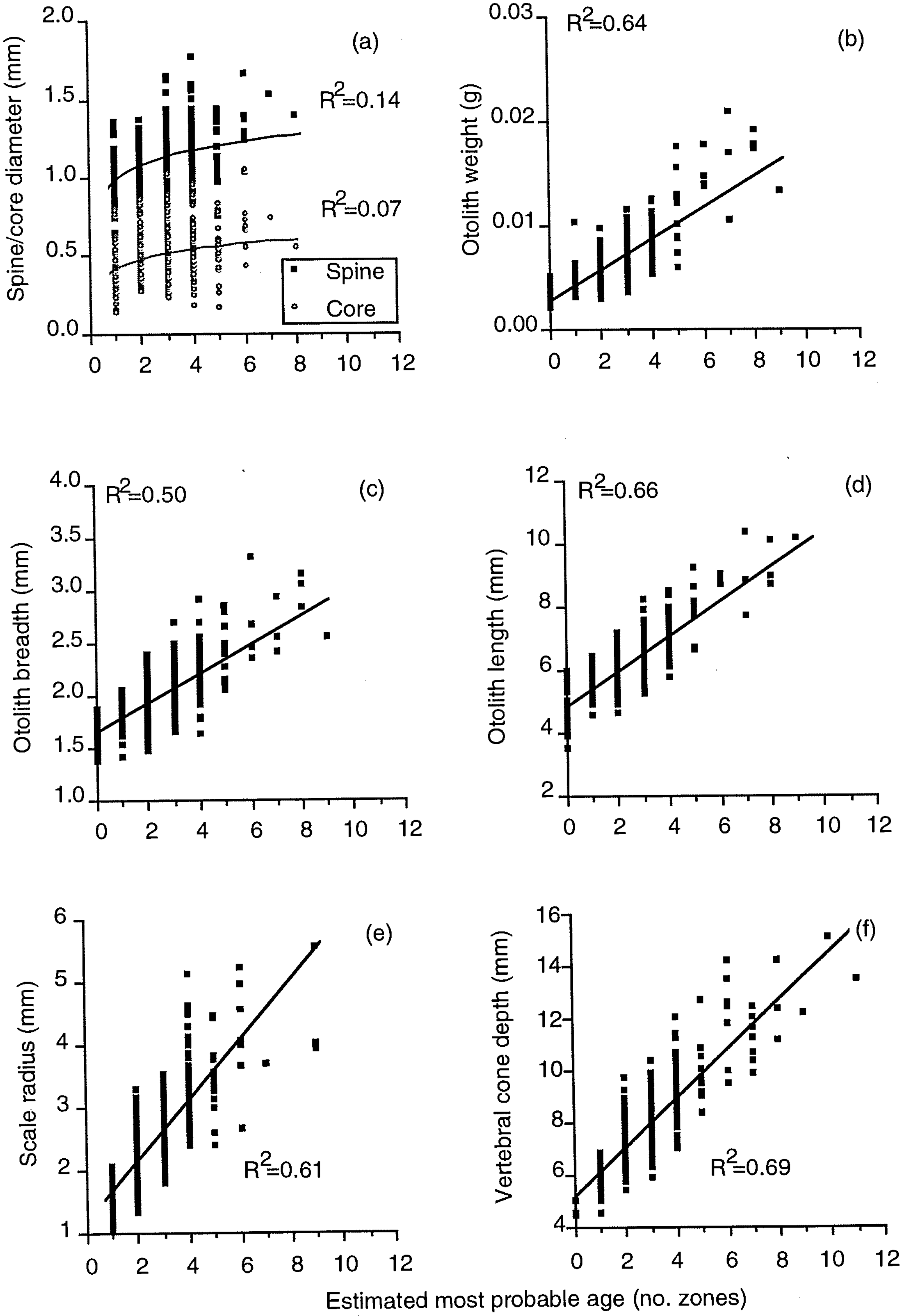

**Figure 3.5.** Relationship between size of the ageing structure and estimated most probable age (see text for details of how most probable age was estimated). Lines of best fit are shown.

**Table 3.2.** Results of analyses of marginal increments for kingfish aged by dorsal spines, otoliths, scales and vertebrae. Each category is the growth of the structure, subsequent to the most recent zone, as a proportion of the previously completed zone. The percentage of fish in each category for each two month period is shown, sample sizes are also indicated (in brackets beside month). Only fish aged 2-$4^+$ were used for analyses. For each row, the highest percentage of fish is shown in bold.

| **Month** | **Category** | | | | |
|---|---|---|---|---|---|
| | Edge | 20 | 40 | 60 | 80 |
| **Dorsal spines** | | | | | |
| Aug/Sep (20) | 15 | ***35*** | 15 | 10 | 25 |
| Oct/Nov (151) | 15 | ***44*** | 20 | 13 | 8 |
| Dec/Jan (87) | 8 | ***47*** | 20 | 11 | 14 |
| Feb/Mar (86) | 22 | ***41*** | 20 | 7 | 10 |
| **Otoliths** | | | | | |
| Aug/Sep (34) | ***44*** | 35 | 15 | 0 | 6 |
| Oct/Nov (149) | 16 | ***36*** | 24 | 10 | 13 |
| Dec/Jan (87) | 9 | 7 | 18 | 24 | ***41*** |
| Feb/Mar (68) | 1 | 13 | ***31*** | 24 | ***31*** |
| **Scales** | | | | | |
| Aug/Sep (0) | | | | | |
| Oct/Nov (181) | 15 | 12 | 21 | 24 | ***29*** |
| Dec/Jan (94) | 22 | ***34*** | 21 | 7 | 15 |
| Feb/Mar (101) | 1 | 19 | 28 | ***34*** | 19 |
| **Vertebrae** | | | | | |
| Aug/Sep (51) | 8 | 16 | 16 | 10 | ***51*** |
| Oct/Nov (173) | 16 | 20 | ***24*** | 16 | 23 |
| Dec/Jan (50) | 14 | 12 | ***28*** | 20 | 26 |
| Feb/Mar (70) | 14 | 13 | ***37*** | 11 | 24 |

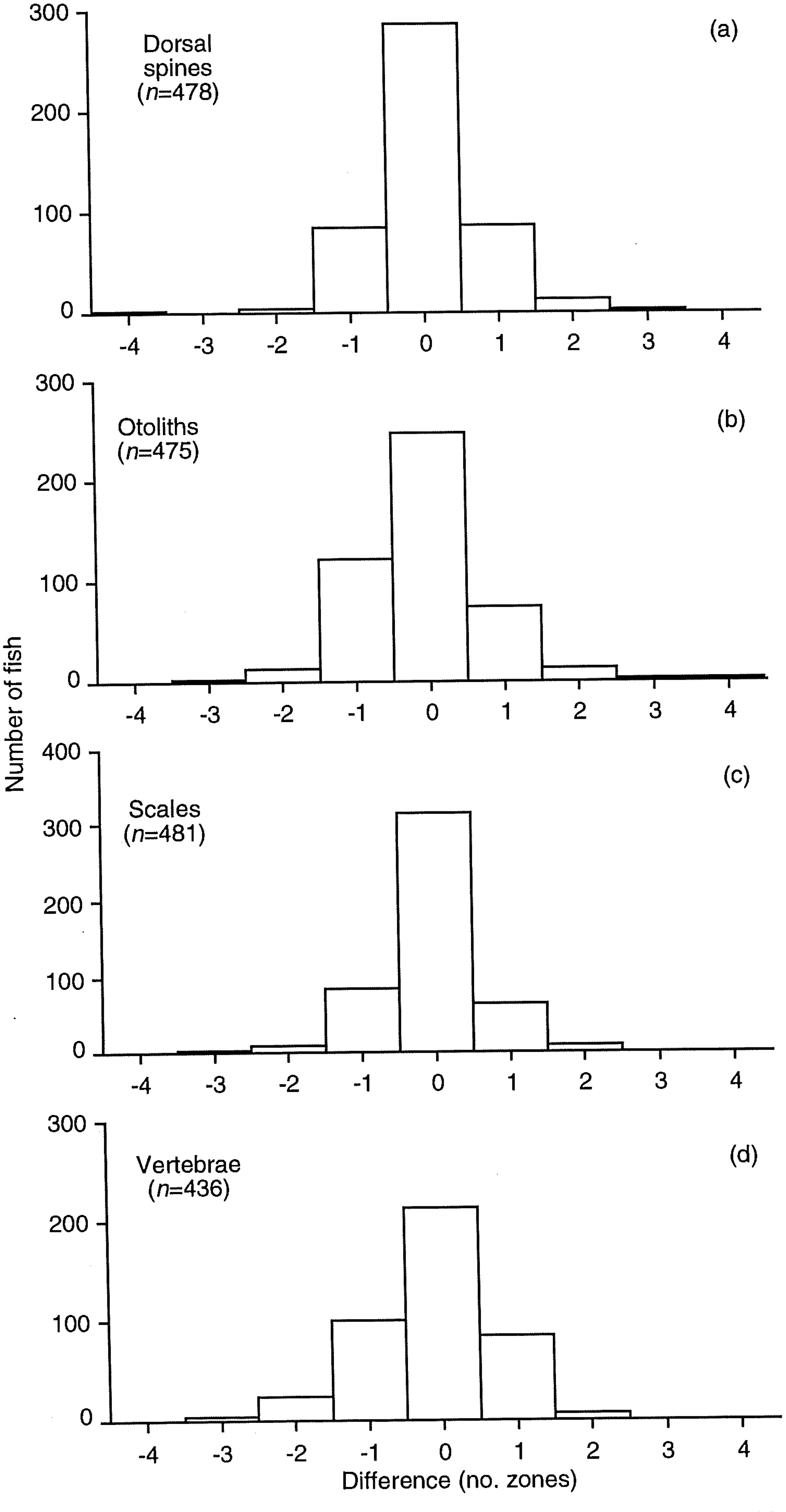

**Figure 3.6.** Differences in zone counts of four structures used to age kingfish. Each comparison represents independent counts from a single reader.

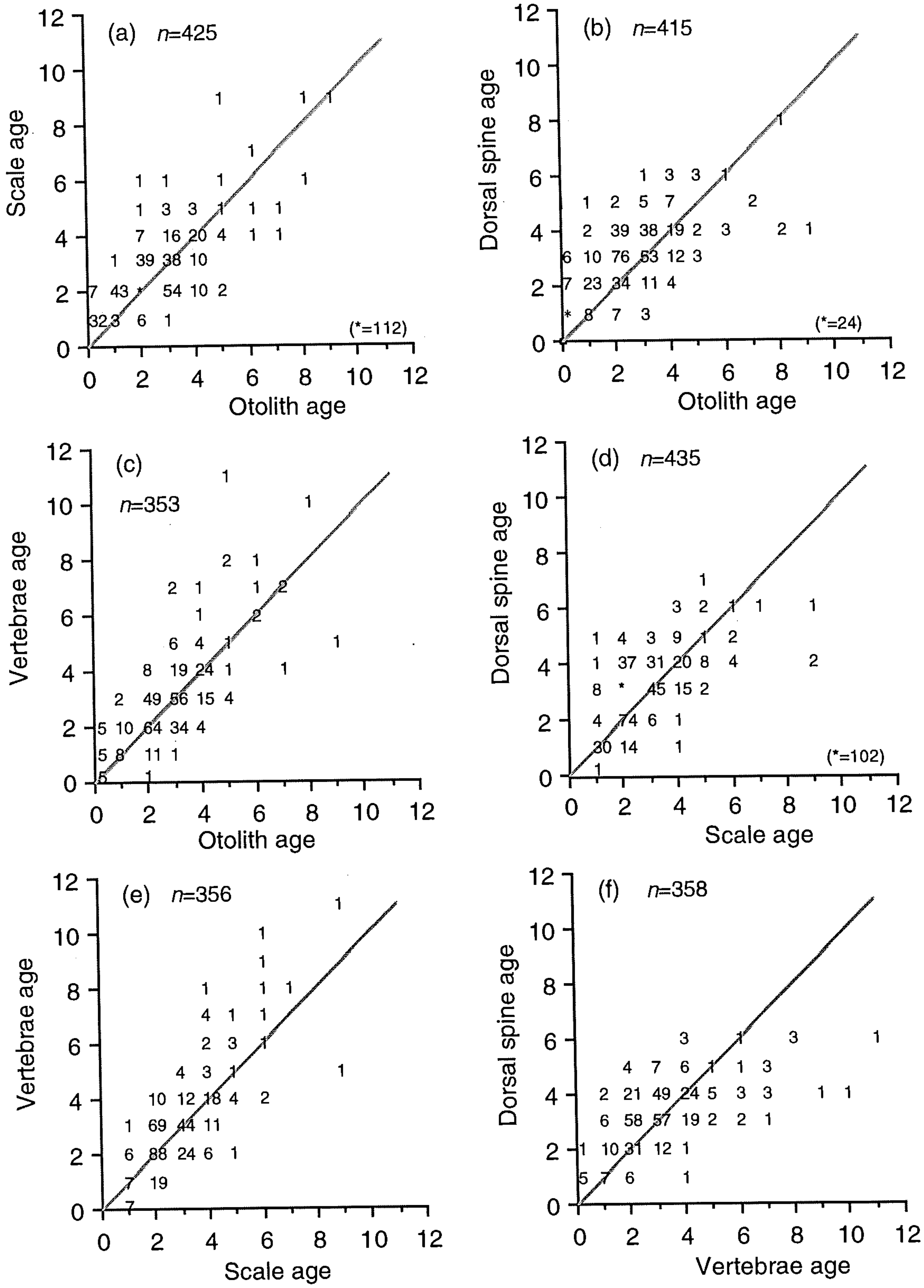

**Figure 3.7.** Counts of zones from kingfish dorsal spines, otoliths, scales and vertebrae compared with the other ageing structures. A line of slope 1, indicating 100% agreement is shown. The number of fish each point represents is shown. Ages are estimated most probable age (no. zones).

### 3.3.5. *Estimates of ageing error*

Analysis of ageing precision using the methods of Richards *et al.* (1992) showed that the likelihood of correctly selecting the most probable age generally decreased with increasing age of the fish (Table 3.3, Fig. 3.8). For example, using dorsal spines, 93% of fish with an estimated most probable age of 1 were correctly aged as 1, whereas only 32% of fish with a most probable age of 5 were correctly aged as 5. These probabilities can be compared with those obtained from other structures (e.g. otoliths, scales and vertebrae; Table 3.3, Fig. 3.8). Scales had a higher probability of correctly assigning most probable age fish of 1 and 2 to their respective ages than the other structures. Dorsal spines, however, had a higher probability of correctly assigning most probable age fish of 3 and 4 to ages 3 and 4 respectively and scales had a higher probability of correctly assigning most probable age fish of 5 to this age (Fig. 3.8).

A more complex ageing error model, with extra parameters that accommodated effects due to ageing structures, showed that dorsal spines underestimated ages compared to vertebrae, scales and otoliths (Fig. 3.9).

### 3.3.6. *Relationship between size and age*

Estimates of growth of kingfish in NSW were obtained from Schnute's (1981) growth model fitted to the estimated most probable ages of fish calculated from the different ageing structures (Fig. 3.10). Size-age data from dorsal spines were best fitted to the four parameter model, whereas the three parameter models showed the best fit for otoliths, vertebrae (both case 2) and scales (case 3). Using the best fitting model for each structure, the average length of $1^+$ fish was 434 (±14), 499 (±5), 418 (±9), and 485 (±7) mm FL for dorsal spines, otoliths, scales and vertebrae respectively. At age 5, fish were 759 (±10), 807 (± 8), 823 (±8) and 788 (±6) mm FL for dorsal spines, otoliths, scales and vertebrae respectively. Differences in size at age between the different ageing structures were generally only seen in the younger and older age classes.

Results of likelihood ratio tests indicated that there was no significant difference between values of $a$, and $y_1$, but a minor difference between values of $y_2$ for comparisons of growth curves using otoliths and vertebrae (Table 3.1). Growth curves estimated from ageing data based on otoliths and vertebrae, therefore, only showed significant differences in older fish. Significant differences in all aspects of growth curves were found for comparisons between scales and either otoliths or vertebrae (Table 3.1).

**Table 3.3.** Classification matrices for the different age structures. The first five age classes for each structure were used to calculate the matrices. Rows are observed ages and columns are estimated most probable ages. Only fish that had both estimates of age less than or equal to the maximum age (4 or 5 depending on structure) were used in the analyses.

| | **Most probable ages** | | | | |
|---|---|---|---|---|---|
| **Dorsal spines** | 1 | 2 | 3 | 4 | 5 |
| 1 | 0.930 | 0.066 | 0.000 | 0.000 | 0.057 |
| 2 | 0.070 | 0.868 | 0.074 | 0.002 | 0.122 |
| 3 | 0.000 | 0.066 | 0.851 | 0.161 | 0.209 |
| 4 | 0.000 | 0.000 | 0.074 | 0.676 | 0.289 |
| 5 | 0.000 | 0.000 | 0.000 | 0.161 | 0.322 |
| | | | | | |
| **Otoliths** | 0 | 1 | 2 | 3 | 4 |
| 0 | 0.897 | 0.098 | 0.0003 | 0.000 | 0.000 |
| 1 | 0.103 | 0.805 | 0.111 | 0.001 | 0.0002 |
| 2 | 0.0002 | 0.098 | 0.778 | 0.147 | 0.018 |
| 3 | 0.000 | 0.0002 | 0.111 | 0.704 | 0.281 |
| 4 | 0.000 | 0.000 | 0.0003 | 0.147 | 0.700 |
| | | | | | |
| **Scales** | 1 | 2 | 3 | 4 | 5 |
| 1 | 1.000 | 0.047 | 0.002 | 0.0001 | 0.000 |
| 2 | 0.000 | 0.905 | 0.150 | 0.009 | 0.001 |
| 3 | 0.000 | 0.047 | 0.698 | 0.206 | 0.029 |
| 4 | 0.000 | 0.000 | 0.150 | 0.578 | 0.305 |
| 5 | 0.000 | 0.000 | 0.002 | 0.206 | 0.666 |
| | | | | | |
| **Vertebrae** | 0 | 1 | 2 | 3 | 4 |
| 0 | 0.939 | 0.062 | 0.0001 | 0.000 | 0.0001 |
| 1 | 0.061 | 0.876 | 0.079 | 0.001 | 0.004 |
| 2 | 0.000 | 0.062 | 0.843 | 0.142 | 0.063 |
| 3 | 0.000 | 0.000 | 0.079 | 0.714 | 0.339 |
| 4 | 0.000 | 0.000 | 0.0001 | 0.142 | 0.594 |

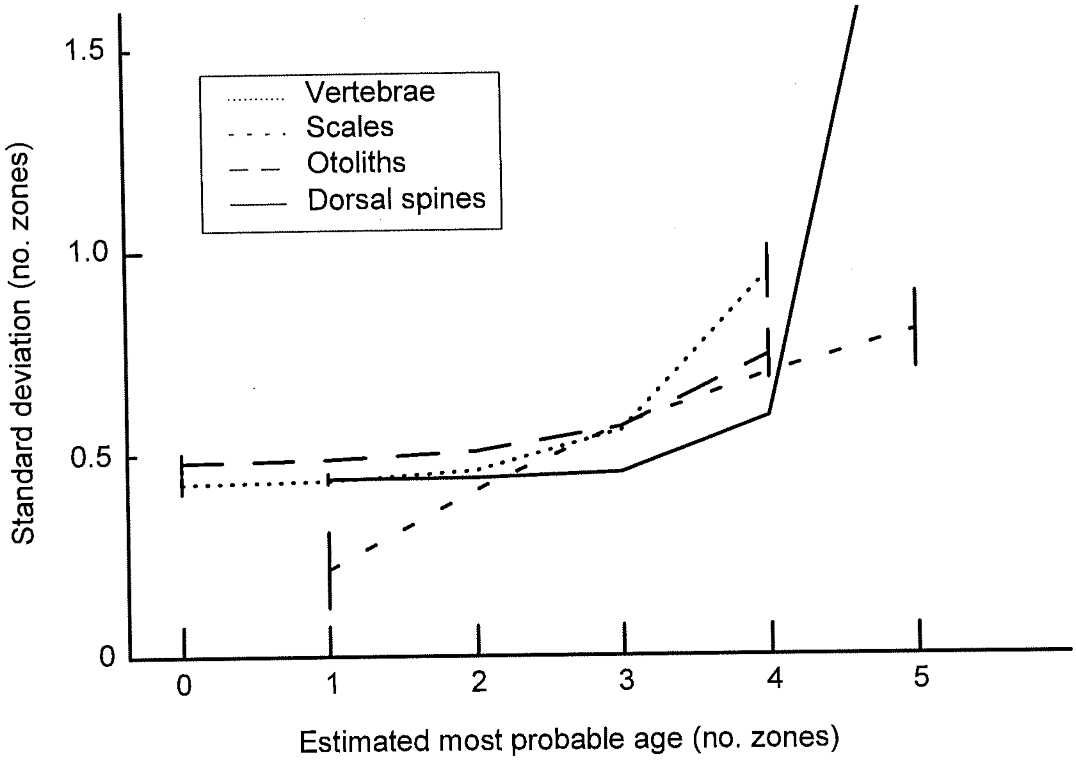

**Figure 3.8.** Ageing error versus estimated most probable age for kingfish aged using dorsal spines, otoliths, scales and vertebrae. Estimated most probable age was obtained using the methods of Richards *et al.* (1992), see text for further details. Errors around the youngest and oldest age classes are indicated by vertical lines with the exception of age 5 for dorsal spines where the value was off the y-axis scale.

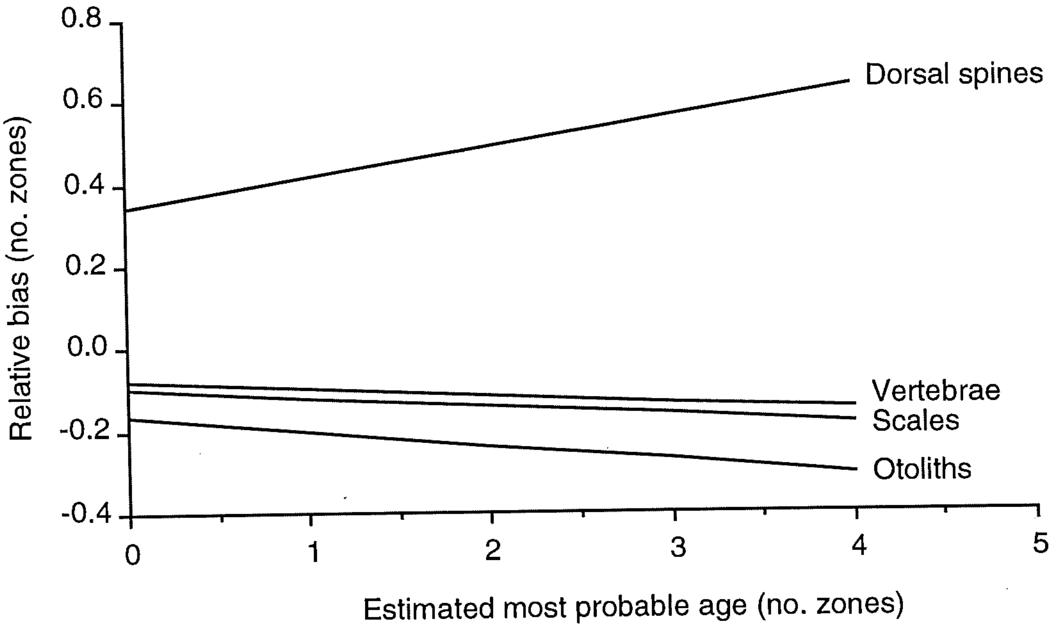

**Figure 3.9.** Relative bias versus estimated most probable age for kingfish aged by the structures. Relative bias was calculated by determining structure effects from a model that included all fish where readings were obtained for all structures.

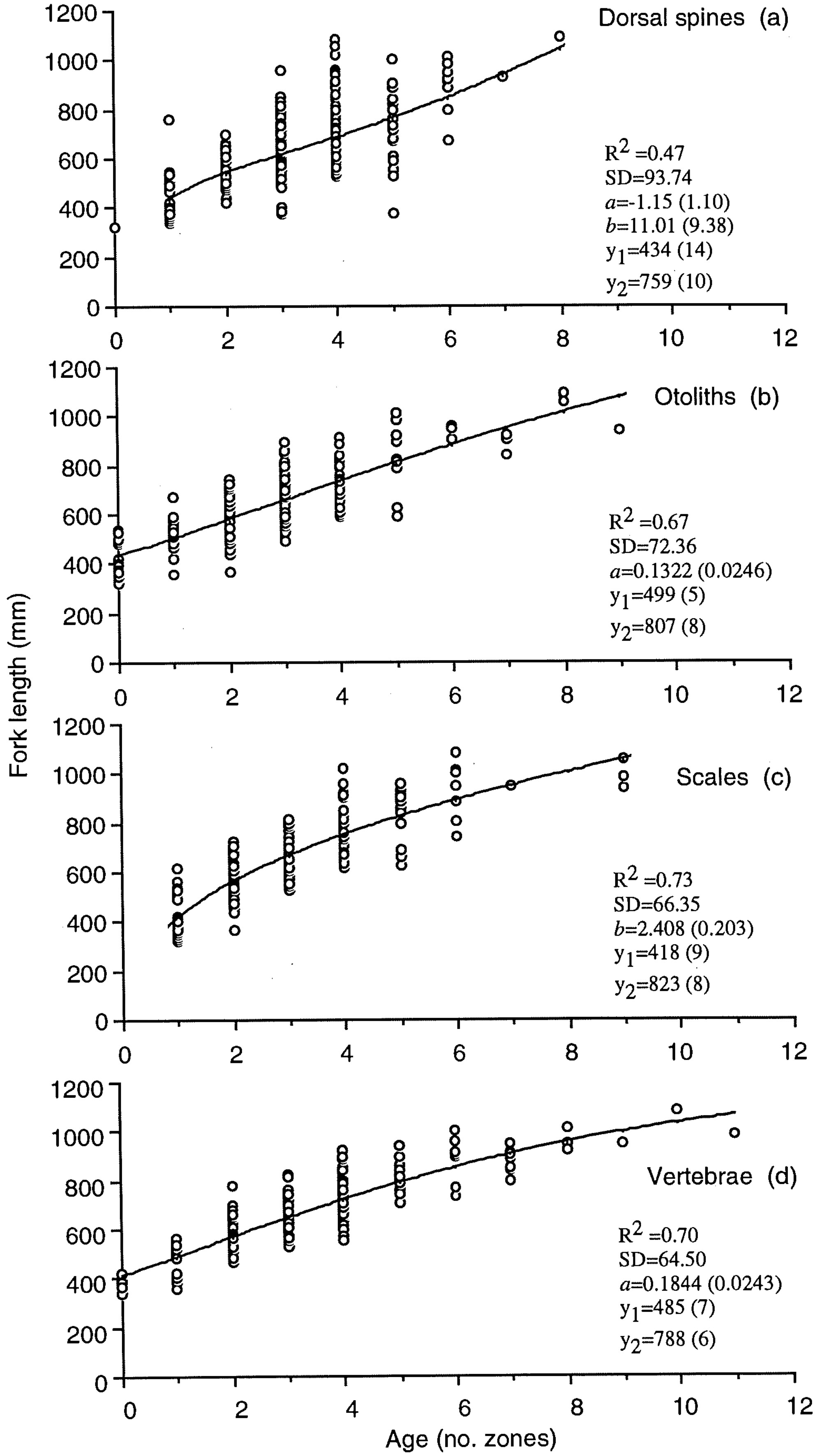

**Figure 3.10.** Relationship between fork length and age for the different structures used to age kingfish. The growth curves were calculated using Schnute's growth model. R-squared, overall standard deviation (SD) and the parameters (standard error) describing the growth model are shown. $y_1$ is size at age 1, $y_2$ is size at age 5, $a$ and $b$ are parameters describing the shape of the curve.

Preliminary estimates of growth for three locations along the coast of NSW showed that a three parameter model showed the best fit for northern NSW locations, whereas four and two parameter models showed the best fit for central and southern NSW locations respectively (Fig. 3.11). Using the best fitting model for each location, the average length of $1^+$ fish was 445 (± 13), 464 (± 10) and 538 (± 11) for northern, central and southern locations respectively. At age 5, fish were 831 (± 11), 844 (± 23) and 806 (± 19) for northern, central and southern locations respectively.

### 3.3.7. *Estimates of rates of growth from tagging data*

Kingfish that were measured at both tagging and recapture were at large for between 0 days (i.e. recaptured the same day that they were tagged) and 5 years (Fig. 3.3b). Differences in growth of recaptured fish ranged from a decrease of 350 mm to an increase of 800 mm (Fig. 3.3a). The frequency distribution of fish at large < 30 days showed a normal distribution suggesting that there was no bias in measurements (Fig. 3.3a). Size of fish at tagging ranged from 220 to 1200 mm, although the majority of fish were between 400 and 600 mm TL (Fig. 3.3c).

The best fit to the complete data set (Model 1 in Table 3.4) showed a high proportion of outliers ($p$=0.04). Twenty two fish (or 2.7%), all being data points with absolute standardised residuals greater than 3 in the Model 1 fit, were removed to facilitate significance testing. Initially, a simple three-parameter model was fitted (Model 2 in Table 3.4), which indicated growth rates of 260 mm and 180 mm for 400 mm and 600 mm fish respectively. The first additional parameter selected was that describing the shape of the growth curve (Model 3 in Table 3.4). Model 3 showed annual growth rates of 270 and 140 mm. There was a significant improvement in fit when a term describing growth variability was added (Model 4 in Table 3.4). Additional parameters (e.g. seasonal growth terms) did not result in significant improvements of fit. Plots of standardised residuals against length at tagging, time at liberty and expected growth increment showed no pattern (correlations were 0.022, 0.003 and 0.005 respectively) suggesting that the model was appropriate (Fig. 3.12).

Comparison of annual growth between age-based (age-length) and length-based (mark-recapture) data, although not strictly comparable, showed a decrease in growth in length with age/size of fish (Fig. 3.13). Both estimates of growth were within the 95% confidence intervals of the length-based data.

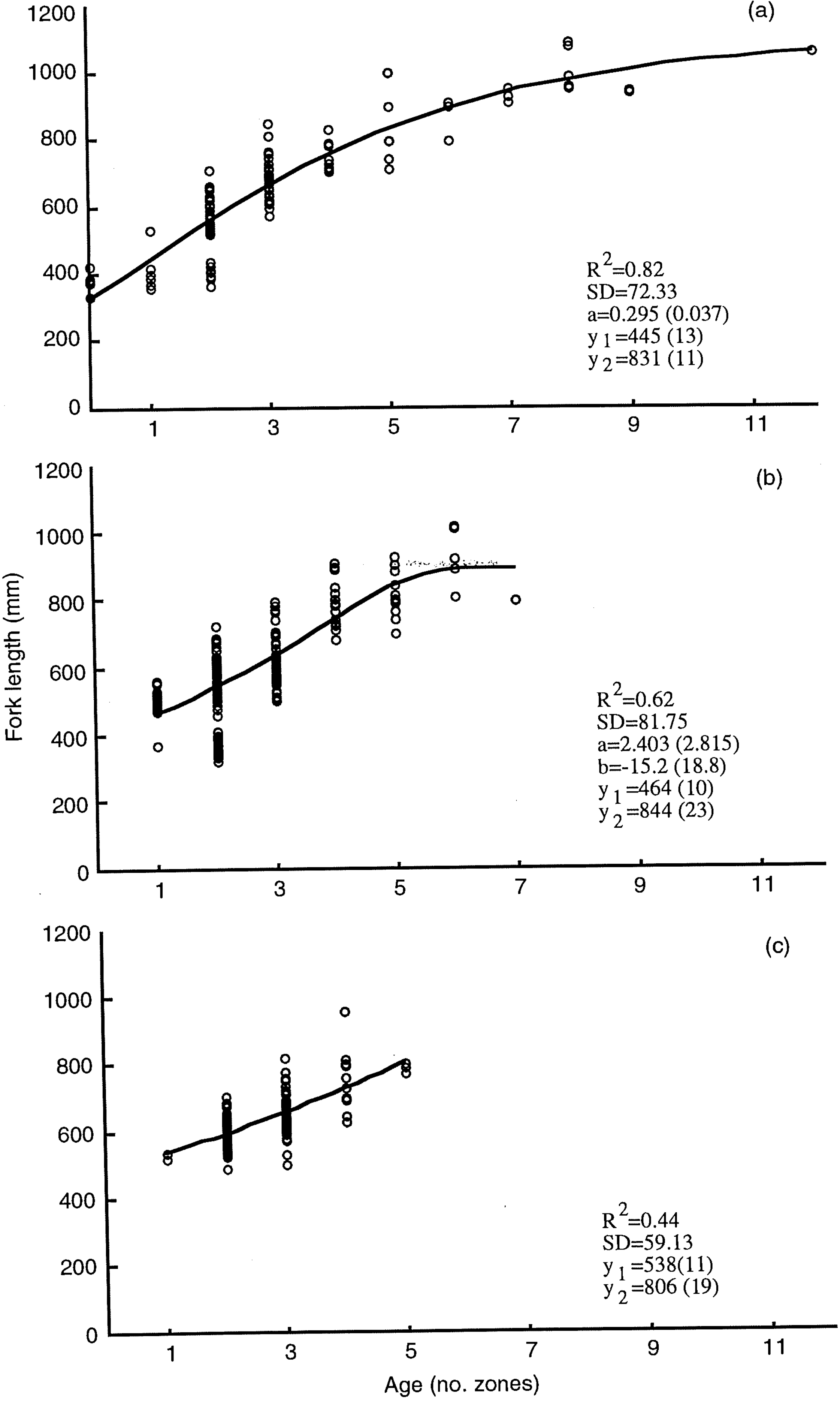

**Figure 3.11.** Relationship between fork length and age for fish collected from (a) Northern, (b) Central and (c) Southern NSW locations. The growth curves were calculated using Schnute's growth model; abbreviations are described on page 39.

**Table 3.4.** Log likelihood function values, growth parameter estimates and standard errors (Model 4 only) for kingfish (*Seriola lalandi*) tagging data. * indicates parameters held fixed. Standard errors of parameter estimates were estimated from simulated data (*n*=100 simulations). Growth rates are shown in cm for 40 cm TL (g40) and 60 cm TL (g60) fish. Note total length used in these analyses, not fork length as elsewhere.

| **Parameter** | | **Model 1** | **Model 2** | **Model 3** | **Model 4** | **s.e.** |
|---|---|---|---|---|---|---|
| Log-likelihood | | 2890.67 | 2797.80 | 2735.35 | 2706.21 | |
| Mean growth rate | g40 | 26.38 | 25.53 | 26.96 | 26.03 | 0.81 |
| | g60 | 13.21 | 17.64 | 14.01 | 13.11 | 0.73 |
| Seasonal variation | u | 0.164 | 0* | 0* | 0* | |
| | w | 0.706 | 0* | 0* | 0* | |
| Growth variability | v | 0.397 | 0* | 0* | 0.40 | 0.045 |
| s.d. measurement error | s | 6.69 | 8.21 | 7.58 | 6.64 | 0.170 |
| Outlier contamination | p | 0.037 | 0* | 0* | 0.000 | |
| Shape of curve | b | 5.47 | 0* | 5.21 | 5.66 | 0.568 |
| Sample size | *n* | 816 | 794 | 794 | 794 | |

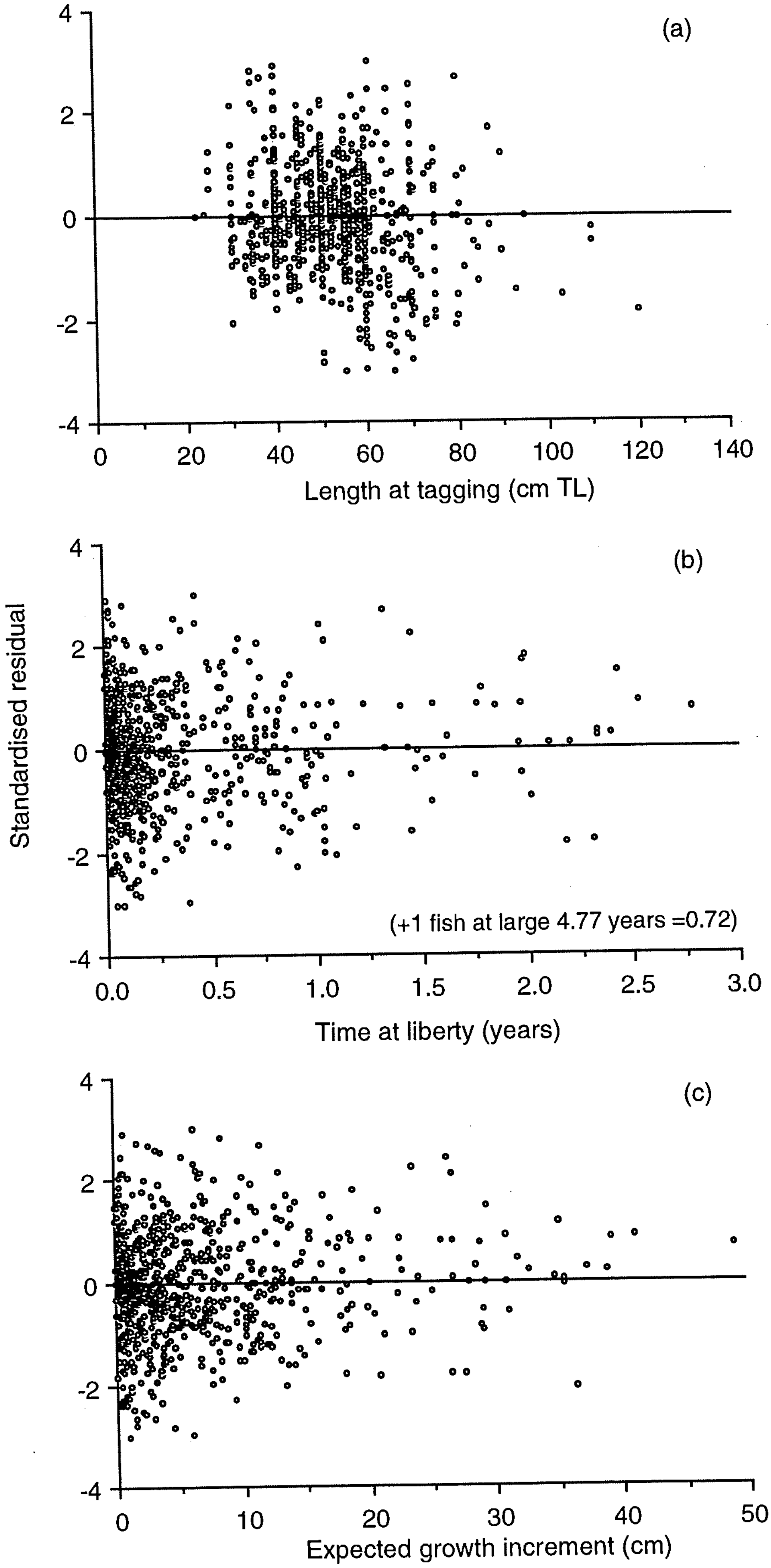

**Figure 3.12.** Scatterplots of standardised residuals against (a) length at tagging, (b) time at liberty and (c) expected growth increment. Lines indicating standardised residual of zero are shown.

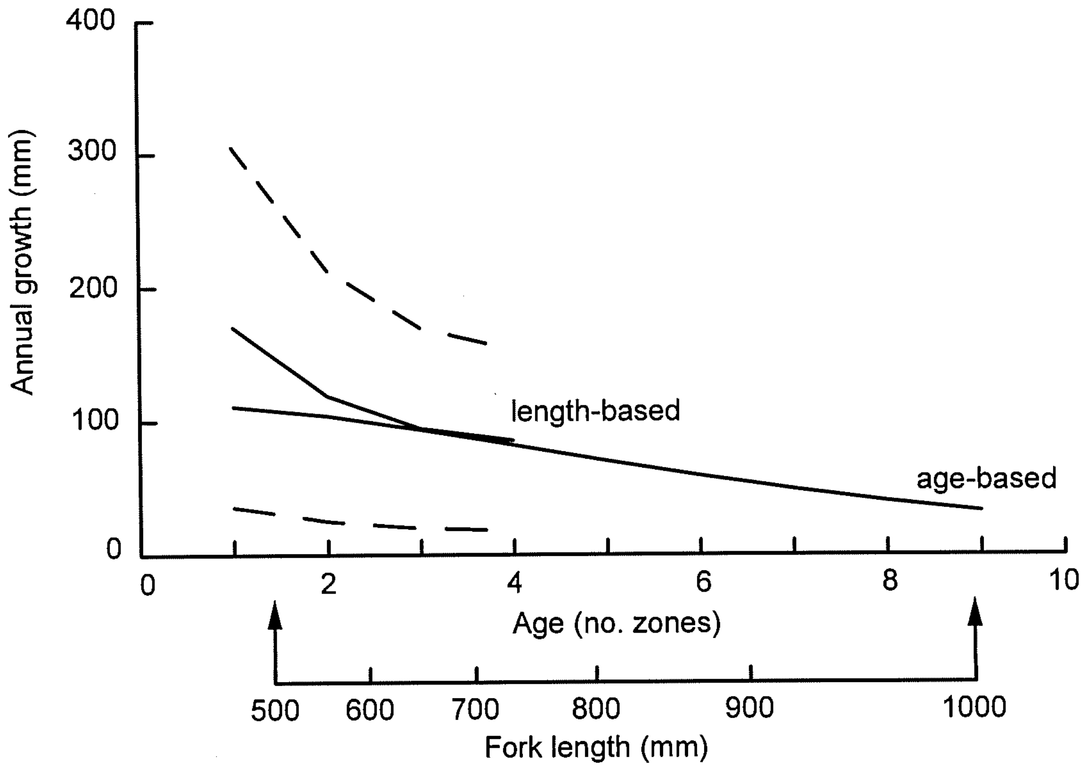

**Figure 3.13.** Comparison of estimated growth rate estimates for kingfish using length- and age-based methods. The broken lines are 95% confidence intervals around the length-based data. The mean length at any age is aligned with the corresponding point on the age axis. Growth was calculated according to Francis (1995). Mean sizes were calculated using Schnute's growth curve (Case 2) fitted to the size-age data; growth increments at corresponding points on the length-based line were calculated from the best fit (Model 4 in Table 2) to the mark-recapture data obtained using GROTAG. Note that length-based growth rates have been plotted by fork length.

## 3.4. Discussion

Four structures were selected to assess the usefulness of each structure for ageing *Seriola lalandi*. Historically, a variety of structures have been used to age *Seriola* spp. (Mitani 1955; 1958; Mitani and Sato 1959; Baxter 1960; Murayama 1992*a*), but no study has compared several structures for determining age and growth parameters and there have been no ageing studies on *S. lalandi* within Australia. Final choice of a structure for age determination should depend on the accuracy of ages estimated from the structure but will also depend on clarity of zones, precision of age readings, and ease of collection and processing.

Initially, most ageing studies focused on the use of scales. More recently scales have been shown to underestimate the age of older fish compared to otoliths (e.g. Lowerre-Barbieri *et al.* 1994) and therefore there has been a tendency to focus on otoliths. Many studies have used whole otoliths, but again these are thought to give misleading results compared to sectioned otoliths (e.g. Beamish 1979; Campana 1984). It has been recommended that age estimates be compared using several structures before deciding on a structure(s) suitable for ageing (Beamish and McFarlane 1987).

### 3.4.1. *Assumptions of ageing methods*

All four structures showed patterns of growth that were, to varying degrees, quantifiable. Delineation of each zone, however, was sometimes difficult, as has been found in other studies (e.g. Brennan and Cailliet 1989), and the clarity of zones varied among individuals for all structures.

Positive relationships were found between size of the structure and fork length for all structures, although the relationship between dorsal spine diameter and fork length was poor. Dorsal spines may, therefore, not be the best structure for ageing kingfish. A linear increase in size of structure with size of fish has also been found for scales and vertebrae of *S. quinqueradiata* (Mitani 1955; Murayama 1992*a*). Zones increased in number with the size of the structure, although the trend was less clear for dorsal spines, again suggesting that dorsal spines may not be an appropriate structure for ageing kingfish.

To accurately reflect the age of a fish, the zones must be formed on a regular and determinable time scale. Small sample sizes during the winter months (April to July) made analysis of marginal increments problematic, especially for scales because samples were also not obtained in August/September. With the exceptions of otoliths and possibly scales, our data were not sufficient to suggest that only one zone was formed per year. No single category of marginal growth ever had more than 50% of fish for any structure. A previous study (Mitani and Sato 1959) also found that fish collected in any one time period showed a wide range of marginal growth conditions. This wide range of marginal growth patterns may in part be due to grouping of samples into two-monthly intervals or because fish from three age classes ($2\text{-}4^+$) were used in analyses. Fish from different age classes have previously been shown to lay down zones at slightly different times of year (e.g. Jones 1980).

Analysis of marginal increments often provides only partial validation of a method, because older age classes in which growth is considerably reduced do not show seasonality in formation of zones. A method should not be considered accurate until all reported ages are validated (Beamish and McFarlane 1983). Validation of older fish will require a mark-recapture study, but further work on validation of younger fish may use a variety of approaches (e.g. length-frequency analyses of young individuals for which cohorts are easily recognised, mark-recapture etc.).

There have been few validation studies on *Seriola* spp. and all have involved analysis of marginal increments. Mitani and Sato (1959) suggested that one zone was laid down each winter in opercular bones of *S. quinqueradiata* and Baxter (1960) found that zones formed between November and January in scales of *S. lalandi* (ex *dorsalis*). In otoliths of *S. lalandi* zones appeared to be laid down in August/September. Timing of zone formation in dorsal spines, scales and vertebrae was more variable and may differ between structures because processes involved in deposition vary among bone, scales and otoliths (Simkiss 1974).

### 3.4.2. *Precision of ageing estimates*

Multiple readings showed good agreement within one zone for all structures. Percent agreement (i.e. percent of fish aged alike between sets of multiple readings) has been criticised because it fails to take into account the range of fish year classes and therefore can only be used for age-specific comparisons (Kimura and Lyons 1991). More recently, the belief that percentage agreement is inappropriate has been questioned. While it is acknowledged that percent agreement is not interpretable as a property of the species, stock etc., it is thought to be more intuitive than other methods (Hoenig *et al.* 1995). Coefficient of variation (CV) is thought to adjust for the absolute age of the fish and therefore is frequently used to compare among species of varying ages. Kingfish had values of CV within those of previous studies, but at the higher end (present study 7.6-12% versus other species 3.2-12.9%, Kimura and Lyons 1991) suggesting that *S. lalandi* was a more difficult species to age. For kingfish, scales (7.6%) and spines (8%) had lower values of CV than otoliths (12%) and vertebrae (11%). The lowest CV values were for structures where no fish were in their first year (or one fish in the case of spines) and the highest values were for structures where fish were aged as in their first year. Likewise, Kimura and Lyons (1991) found that the CV was highest for species in which $1^+$ age classes were present and lowest where the youngest age classes were 2 or 3. Coefficient of variation therefore seems to depend on age of fish. Such indices, if averaged over fish, are thought to simplify the data by ignoring any trends that might occur with age (see Hoenig *et al.* 1995). Precision of ageing decreased with age of fish for all structures, but especially for spines, suggesting that estimates of precision should not be averaged over all ages of fish. We believe that the methods of Richards *et al.* (1992) give a better indication of ageing error and therefore precision than methods that summarize over all age classes.

### 3.4.3. *Problems with use of dorsal spines*

Although dorsal spines were easy to collect and could be collected without killing the fish or altering its market value, they appear to be of limited use for age determination in *S. lalandi.* Many zones appeared to split in two, natural oils in the bony matrix decreased clarity, ageing precision decreased with age of fish and the small size of the structure meant rings were closely spaced and marginal increments were difficult to interpret. The core region of the spine is also vascularised and became larger as fish grew. It is probable that early growth zones are lost or obscured in older fish, causing under-estimates of age. No corrections were made for possible missing zones, although corrections have been used for other pelagic fishes (e.g. Cayre and Diouf 1983; Hill *et al.* 1989; Tserpes and Tsimenides 1995). Such corrections may, however, introduce bias to final estimates of age (Hill *et al.* 1989).

Simkiss (1974) noted that fish bone (e.g. dorsal spines, vertebrae) is regarded as 'dead', but that there is evidence that resorption and remodelling occurs in some species. Likewise, there is also evidence for resorption of scale material, particularly when fish are stressed (e.g. starved; Simkiss 1974). Only for otoliths is there no evidence of resorption. Implications of resorption for ageing studies may be great, but have largely been ignored.

### 3.4.4. *Length at age*

The resulting growth curves from otoliths and vertebrae were similar, but growth curves from both structures were significantly different to the growth curve obtained from scales. The growth curve from dorsal spines also differed from all other structures, being the only curve in which a four parameter model gave the best fit. Although other ageing studies on *Seriola* spp. have calculated length at age, few have fitted models to the data (but see Baxter 1960). Other studies have only shown average length at age data (e.g. Mitani 1955; Mitani and Sato 1959). Size at age data from the fitted growth curves for all structures, except dorsal spines, were comparable to size at age data from other studies on *Seriola* spp. Significant differences among growth models fitted to fish from different areas in NSW were not large and may have been the result of patchy data from some areas.

Further research needs to focus on the position of the first zone in all structures because this may be contributing to differences in the shape of the growth curves between structures. No fish were found to be in their first year (i.e. $0^+$) when aged with scales, but fish were in their first year when aged with otoliths and vertebrae. Either scales are laying down a false first zone or the first zone is not being detected in otoliths and vertebrae, possibly because it is close to the edge of the structure. Collections of fish from recruitment over a 12 month period and sampling of all structures may help elucidate the position of the first zone.

Although, it is well known that estimates using scales are inaccurate once growth becomes asymptotic (Beamish and McFarlane 1987), scales did not appear to underestimate ages of kingfish in the present study. In a previous study on *S. lalandi,* spaces between circuli became increasingly narrow after the seventh year, so that it was impossible to differentiate between one year's growth and the next (Baxter 1960). Few fish older than six years were sampled in the present study, which may be why few difficulties were experienced in use of scales.

Many studies have found that sectioned otoliths are preferable to whole otoliths for ageing, because examination of whole otoliths does not take into account the asymmetric deposition of material (Campana 1984). After a certain age deposition may thicken the otolith and growth along the anteroposterior axis may decline, therefore only transverse sections would reveal recently formed growth zones (Beamish 1979). It was unusual to find that whole otoliths were better for ageing kingfish than sectioned otoliths; in the latter it was difficult to discern any growth zones especially in small fish. Because whole otoliths may underestimate age of large fish (e.g. Beamish 1979, Campana 1984), it may also be useful to look at transverse sections of otoliths of kingfish for extremely large fish (>20 kg).

### 3.4.5. *Comparison of age- and length-based data*

Although not strictly comparable (see Francis 1988*a*; 1995), estimates of growth from age-based (estimated from age-length data) and length-based (estimated from tagging data) data showed agreement within 95% confidence intervals. Differences in rates of growth were greater for younger fish than older fish and may be caused by inaccuracies in ageing, influence of tagging on growth (e.g. McFarlane and Beamish 1990), within- or between-year differences and variations in year-class strength. While estimates of growth from tagging data provide some indication that age-length data may be reasonable, it should not be used as a means of validation (see Francis 1988*a*).

Tagging data also suggests that *S. lalandi* in New South Wales has similar annual growth to the same species in New Zealand and USA (Holdsworth 1994, reported in McGregor 1995*c*; Baxter 1960). For *S. lalandi* in NSW, annual growth rates of 110 mm were found for 500 mm FL fish, compared to 93 mm (NZ) and a range of 34-109 mm (USA) for similar size fish overseas. In NZ, annual growth of 44 mm was found for 1000 mm FL fish, which is within the range found in USA (19-70 mm). Few large fish were tagged in NSW, preventing estimates of annual growth at this larger size.

### 3.4.6. *Cost/benefit considerations*

As mentioned previously, although dorsal spines were easy to collect and process, their use as an ageing structure appears limited. Of the remaining three structures, only scales can be easily collected without altering the market value of the fish because kingfish are preferentially sold whole in NSW. The usefulness of otoliths and vertebrae may therefore be limited by cost of fish.

### 3.4.7. *Summary*

Of the four structures assessed, otoliths, scales and vertebrae provided similar estimates of age. Estimates of age, and consequently growth, using dorsal spines were very different to the other three structures. Estimates from dorsal spines were considered unreliable because of the probable loss of annuli in the core region. The similarity of age estimates suggests that, were validations possible, kingfish may be aged reliably. Such validations would be required across the range of sizes found. Samples of very large fish (20-60 kg) are also needed to better interpret growth at older ages.

# 4. Reproductive biology

## 4.1. Introduction

Yellowtail kingfish (*Seriola lalandi*, Carangidae) are an important commercial fishery in many areas of the world including New South Wales. In NSW, catches have fluctuated between 400 and 600 metric tonnes per year over the last 10 years (Scribner and Kathuria 1996), although a number of management controls have also been initiated over this time period. Such controls include the introduction of a minimum size limit (in 1990). Despite controversies surrounding the exploitation of this species in NSW, there is little published information on their biology.

Information on reproductive biology requires knowledge of the stage of development of gonads in individual fish. In females, such information can be achieved using a variety of methods including histology, visual staging based on the external appearance of the gonad (macroscopic) or of whole oocytes (microscopic), measurement of oocyte size, and gonad indices (West 1990). In the few studies on reproduction in *Seriola* spp. a variety of approaches have been used including measurement of oocyte size (Baxter 1960), histology (Micale *et al.* 1993; Marino *et al.* 1995), gonad indices (Smith 1987) and macroscopic staging (McGregor 1995*a,c*; Marino *et al.* 1995). Fewer studies have investigated the reproductive biology of male *Seriola* spp. (Micale *et al.* 1993; Marino *et al.* 1995). Males are more difficult to stage than females and will often give a less well defined estimate of the spawning season (West 1990). The aim of this study was to describe the reproductive biology of kingfish (*Seriola lalandi*), and to determine size/age at maturity and seasonality of spawning.

## 4.2. Materials and Methods

### 4.2.1. *Sampling*

Kingfish specimens were collected by commercial fishers and recreational fishers from along the coast of New South Wales, Australia, between August 1995 and June 1996. Removal of the gonads prior to sale would alter the market value of the fish, so fish were obtained after being processed. Fish were measured (fork length (FL) and total length (TL)), sexed and staged macroscopically (see Table 4.1). Because fish had been processed, we were not able to obtain a measure of body weight (BW), therefore, BW was calculated as 0.025 x $(\text{FL in cm})^{2.845}$ (from McGregor 1995*a*).

### 4.2.2. *Preparation and analysis of gonads*

Gonads were removed from each fish (*n*=509), weighed (±0.01 g) and preserved in 10% FAACC (formaldehyde, acetic acid, calcium chloride) for less than one week, then transferred to 70% alcohol. Eighty percent of fish were further processed for histological investigation. Sections were taken from the proximal, medial and distal parts of one gonadal lobe, embedded in paraffin and sectioned transversely at 5-10 µm. Sections were stained with Mayer's haematoxylin and eosin. Gonads from each fish were examined histologically to determine the stage of sexual maturity of each individual. Ovaries were classified based on the most advanced type of oocyte present, regardless of their abundance (West 1990). Males were classified based on the male gamete stages present in the testis and sperm duct development (Marino *et al.* 1995).

Oocyte diameters were measured from representative sections of ovaries at each stage of development. Oocyte measurements were also made for all fish larger than 700 mm FL to determine seasonality of spawning. For each female, the cross sectional area of 50 oocytes was measured with image-analysis software and the diameter calculated from the equivalent circle diameter. At least three fields of view were chosen haphazardly for each fish. To obtain information on seasonal spawning, oocyte measurements were pooled each month to determine the oocyte size-frequency distributions.

### 4.2.3. *Preparation and analysis of ageing material*

Sagittal otoliths, dorsal spines, scales and vertebrae were removed from each fish and prepared for ageing following the methods outlined in Chapter 3.

**Table 4.1.** Macroscopic and corresponding histological condition of gonads of female and male kingfish for each maturity stage. Descriptions of stages of oocytes in parentheses under histological condition are outlined in West (1990). Maturity stages in males are adapted from Marino *et al.* (1995).

| **Maturity stage** | **Macroscopic condition** | **Histological condition** |
|---|---|---|
| Females | | |
| 1. Immature | Lobes of gonads tend to be oval in shape, generally <6 cm in length; colour variable. | Chromatin nucleolar stage (1) (not numerous) and perinucleolar stage (2) oocytes present. |
| 2. Mature resting | Lobes of gonads more rounded in cross section and larger than immature fish; colour variable. | Stage 2 oocytes predominate with stage 1 and cortical alveoli stage (3) oocytes present. |
| 3. Developing | Similar to mature resting; lobes usually between 6 and 10 cm, range in colour between pale and bright orange. | Stage 2 & 3 oocytes dominate. Stage 1 and vitellogenic stage (4) oocytes also present. |
| 4. Late developing | Large eggs, clearly visible. | Stage 4 oocytes dominate but stage 1 to 3 oocytes are also present. |
| 5. Ripe mature (running) | | Ripe (mature) stage oocytes dominate - not observed. |
| 6. Spent (post spawning) | | All 5 oocyte stages present. Oocytes of stages 3 to 5 undergoing atresia. |
| Males | | |
| 1. Immature | Thin, flattened, thread-like lobes of gonads; variable in colour. | Crypts with spermatogonia (spg), $1^{\circ}$ and $2^{\circ}$ spermatocytes ($1^{\circ}$, $2^{\circ}$) and spermatids (spd). |
| 2. Developing | Elongated, ribbon-like testes; oval to triangular in cross-section; variable in colour. | Crypts with spg, $1^{\circ}$, $2^{\circ}$, spd and spermatozoa (spz). |
| 3. Mature | Similar to developing; whitish-cream in colour. | All germ cell stages present; Spz in lumen of lobules are evident. |
| 4. Ripe | Elongated | All germ cell stages present, Sperm duct filled with spz. |

### 4.2.4. *Size and age at maturity*

Size and age at maturity were defined as the length/age at which 50% of the fish had begun to show the first signs of maturation, namely the presence of spermatozoa in the sperm duct or stage 3 or more advanced oocytes in the ovary. Stage 3 oocytes indicate the onset of vitellogenesis and therefore the potential for spawning. For each sex, the proportion of mature individuals, by 50 mm FL or 1 year intervals, was fitted to the logistic function [% mature = $1/(1+\exp(-K((\text{length or age}) - L_{50})))$, where $K$ is curvature and $L_{50}$ is size/age at 50% maturity] by minimising the residual Sums of Squares from changing $K$ and $L_{50}$. An additive error model was used.

The relationship between gonad weight and body weight of both females and males was determined following the methods of Richards and Schnute (1990). Their model is based on five parameters that overcome inadequacies (e.g. failure to account for both curvilinearity and residual heterogeneity) of linear and logarithmic models. Conceptually, the model is: $y^{\gamma}_{i} = a + bx^{\alpha}_{i} + \sigma\varepsilon_{i}$, where $a$ and $b$ are regression parameters (related to two other regression parameters, $p$ and $q$, by a transformation), $\alpha$ and $\gamma$ are exponential parameters and $\sigma$ is a residual standard deviation parameter (Richards and Schnute 1990). Fitting of the predicted curve is based on likelihood inference methods.

## 4.3. Results

### 4.3.1. *Gonad development*

Different stages of development of ovaries are shown in Figure 4.1. Stage 1 ovaries (immature fish) only contained previtellogenic oocytes (Fig. 4.1a, 4.2a). Previtellogenic oocytes dominated stage 2 ovaries (mature resting fish), but cortical alveolar oocytes were also present (Fig. 4.1b, 4.2b). Stage 3 ovaries contained large numbers of previtellogenic and cortical alveolar oocytes, and there were also small numbers of vitellogenic oocytes present (Fig. 4.1c, 4.2c). Late developing females contained virtually all vitellogenic oocytes (Fig. 4.1d, 4.2d). Ripe oocytes or post-ovulatory follicles were not observed in any fish. Some fish showed evidence of atretic oocytes, although it was difficult to ascertain whether these were spent females.

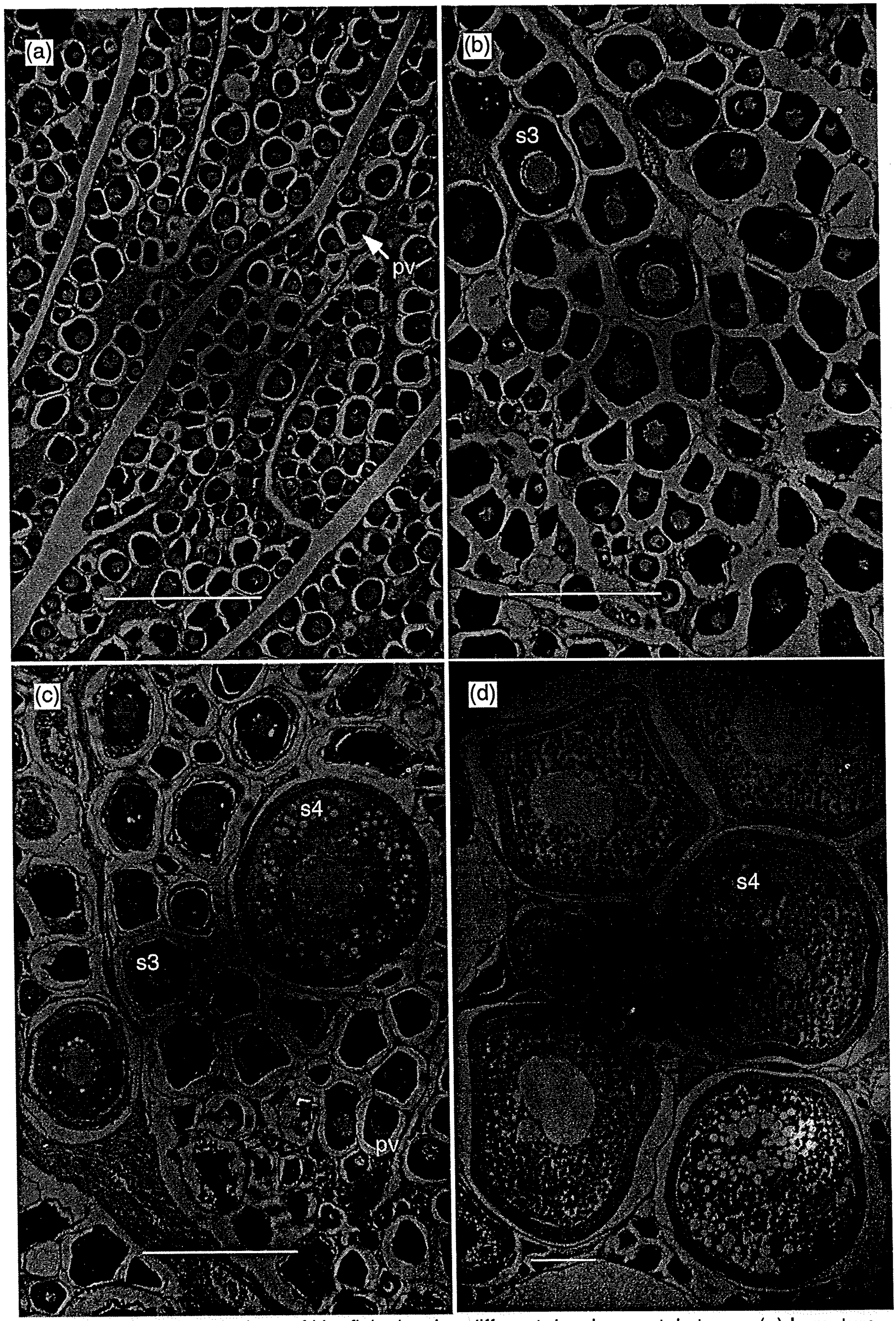

**Figure 4.1.** Ovarian sections of kingfish showing different developmental stages. (a) Immature (415 mm FL), (b) Mature resting (740 mm FL), (c) Developing (735 mm FL) and (d) Late developing (985 mm FL). Scale bar is 200μm; pv - previtellogenic, s3 - stage 3 oocyte, s4 - stage 4 oocyte.

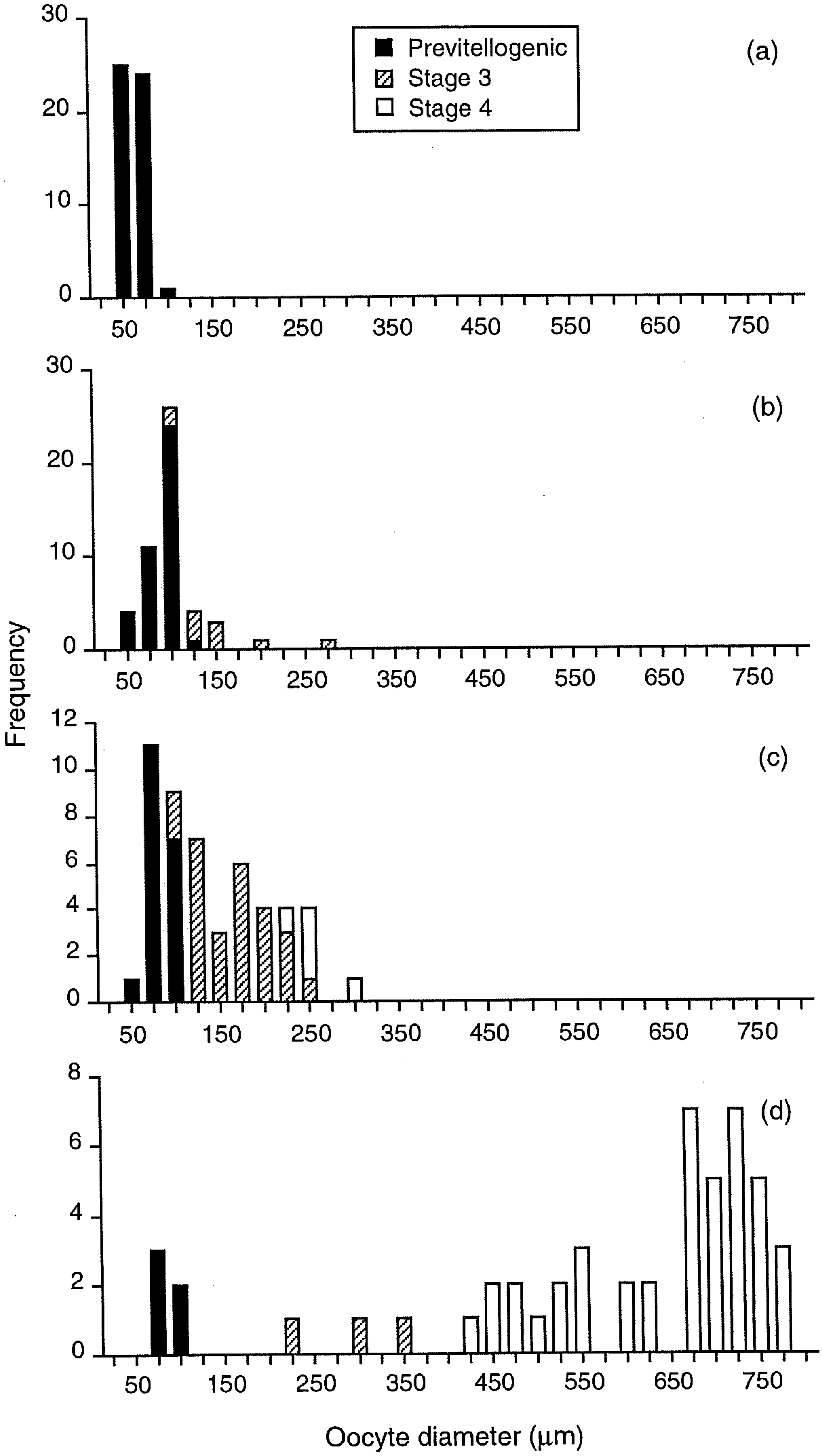

**Fig. 4.2.** Size-frequency distribution of different stage oocytes in the ovaries of *Seriola lalandi* at different stages of maturity. (a) Immature, (b) Mature resting, (c) Developing and (d) Late developing fish. Note y-axis scale varies.

Males were found at all stages of development (Fig. 4.3). Stage 1 testes (immature fish) were dominated by spermatogonia, although small amounts of primary and secondary spermatocytes and spermatids were also found (Fig. 4.3a). All stages of germ cells were found in the other maturity stages. Spermatozoa, although present in stage 2 testes, were not free in the lumen of lobules (Fig. 4.3b). In contrast, stage 3 and 4 testes had free spermatozoa in the lumen of lobules and stage 4 testes also contained free spermatozoa in the sperm duct (Fig. 4.3c, d).

### 4.3.2. *Size and age at maturity*

The smallest mature female observed during the present study was 525 mm FL and the smallest mature male was 360 mm FL. The estimated size at which 50% of females were mature was 702 (±5) mm FL, whereas the estimated size at which 50% of males were mature was 471 (±32) mm FL (Fig. 4.4a). Average age at maturity ranged from 3.1 to 4.2 years for females and $0^+$ to 1.2 years for males depending on the structure used for ageing (Fig. 4.4b,c).

Male and female kingfish both showed a good relationship between gonad weight and body weight for fish with body weights less than 6 kg (Fig. 4.5). Above 6 kg, the relationship was more variable with some fish having relatively large gonads, whilst similar sized fish had relatively small gonads (Fig. 4.5). This was especially true for males, indicating that at least some fish have the potential to be highly fecund. Richards and Schnute's (1990) model showed a better fit to the data than a linear or logarithmic model, because the values for $\alpha$ and $\gamma$ were not both equal to 0 (logarithmic) or 1 (linear) [parameter values ± standard error were females - $p$=0.463 (±0.019), $q$=0.667 (±0.037), $\alpha$=-0.515 (±0.089), $\gamma$=-0.195 (±0.031) and $\tau$=0.145; males - $p$=-0.107 (±0.045), $q$=0.984 (±0.056), $\alpha$=-0.056 (±0.105), $\gamma$=-0.201 (±0.026) and $\tau$=0.345].

### 4.3.3. *Spawning season*

Only data from fish greater than 700 mm FL were used to describe seasonal changes in gonad activity. In both females and males, gonad weight was greatest in December, then fell sharply in February/March (Fig. 4.6). The drop in gonad weight after December suggested that spawning had occurred. Oocyte size frequencies also showed a seasonal pattern that corresponded closely with changes in gonad weight (Fig. 4.7). Oocytes increased in size from October to December (reaching a maximum size of 800µm, Fig. 4.7). At all other times, oocyte diameters were less than 175µm (Fig. 4.7).

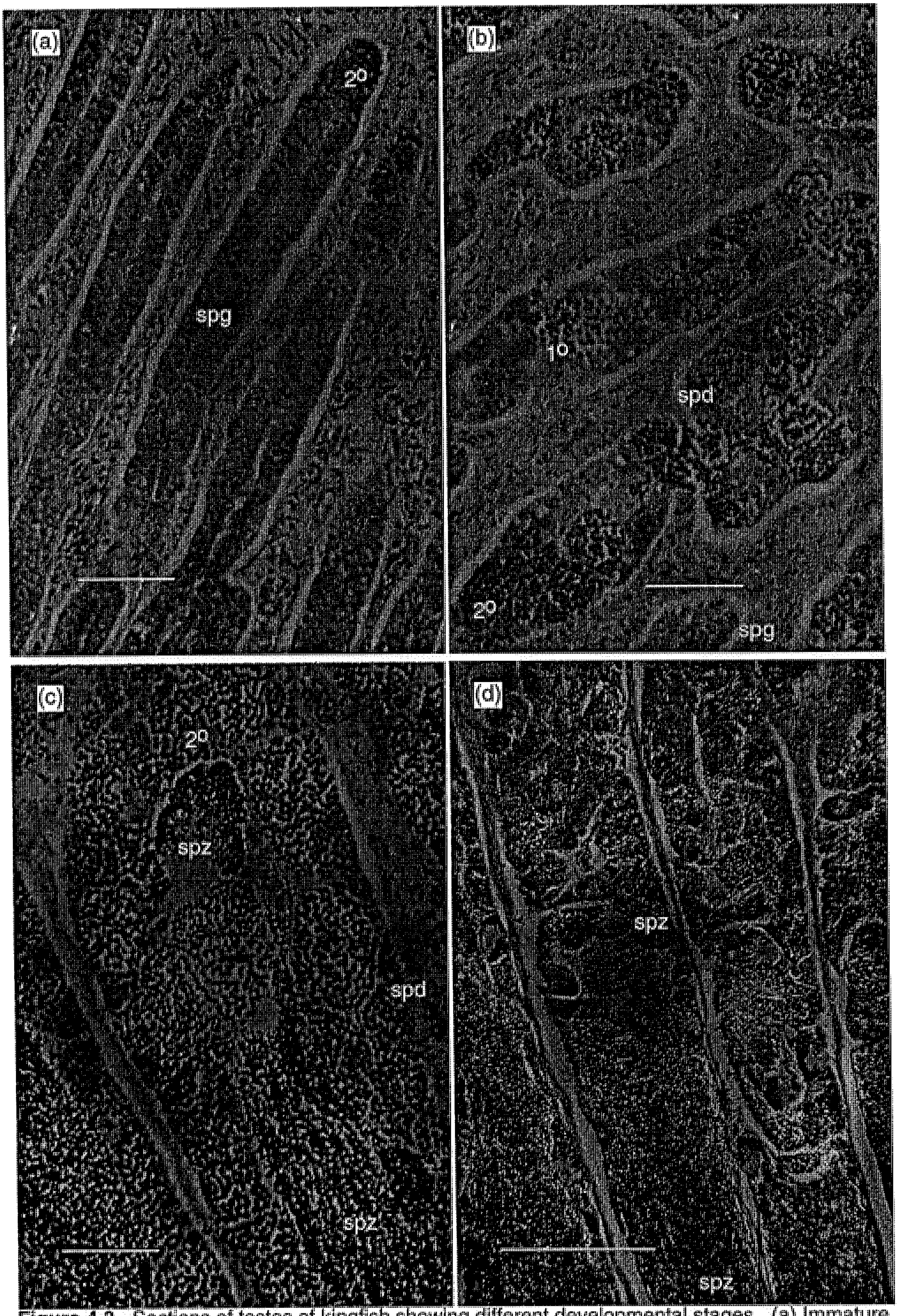

**Figure 4.3.** Sections of testes of kingfish showing different developmental stages. (a) Immature (705 mm FL), (b) Developing (550 mm FL), (c) Mature (785 mm FL), and (d) Ripe (773 mm FL). Scale bar for (a) - (c) is 100μm, for (d) 200μm; spg - spermatogonia, 1o primary spermatocytes, 2o - secondary spermatocytes, spd - spermatids and spz - spermatozoa.

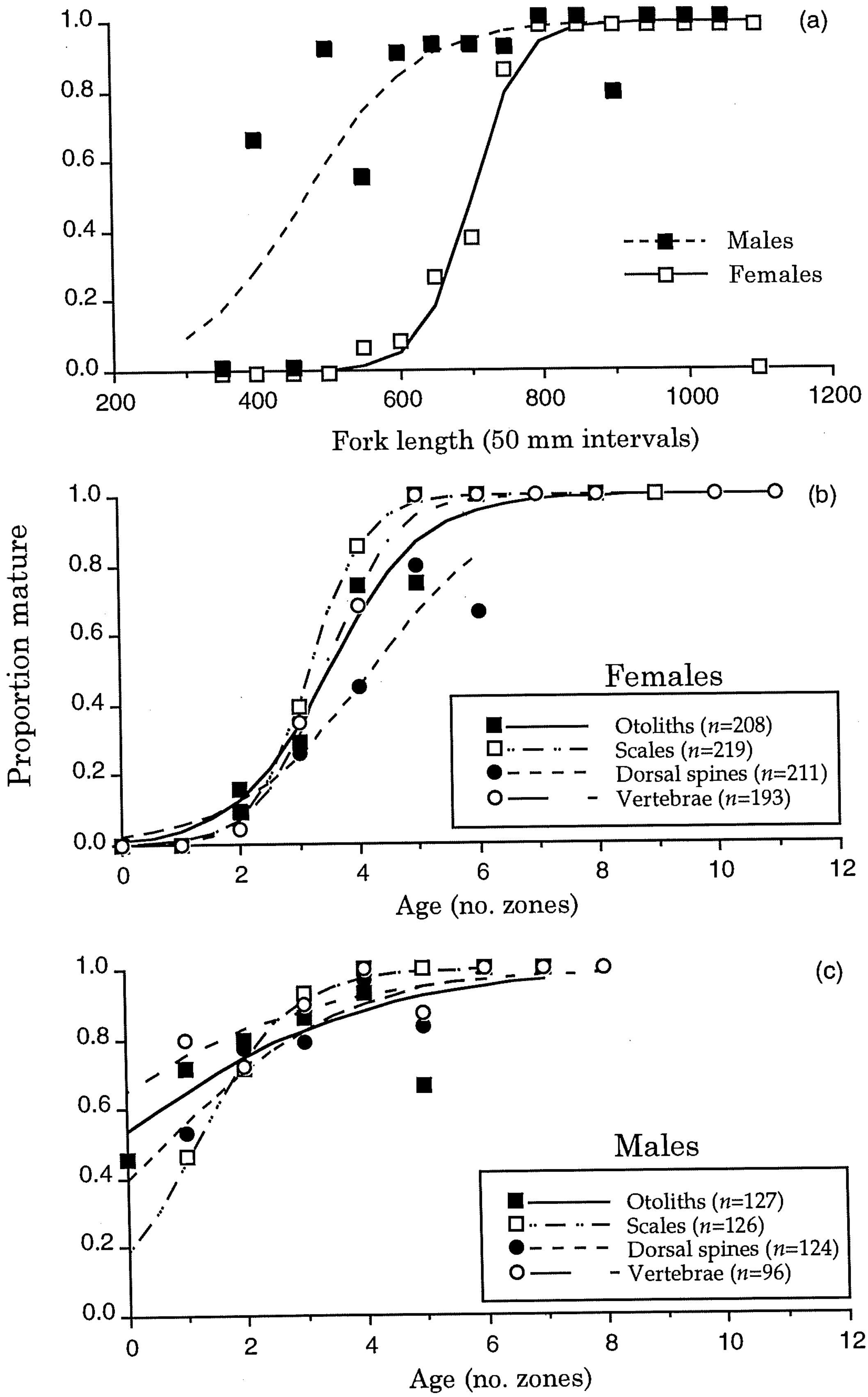

**Fig. 4.4.** Distribution of mature individuals of kingfish by (a) 50 mm fork length intervals (broken line and solid squares - males (*n*=154), solid line and open squares - females (*n*=244)), and age for (b) Females and (c) Males. Data were fitted to the logistic equation.

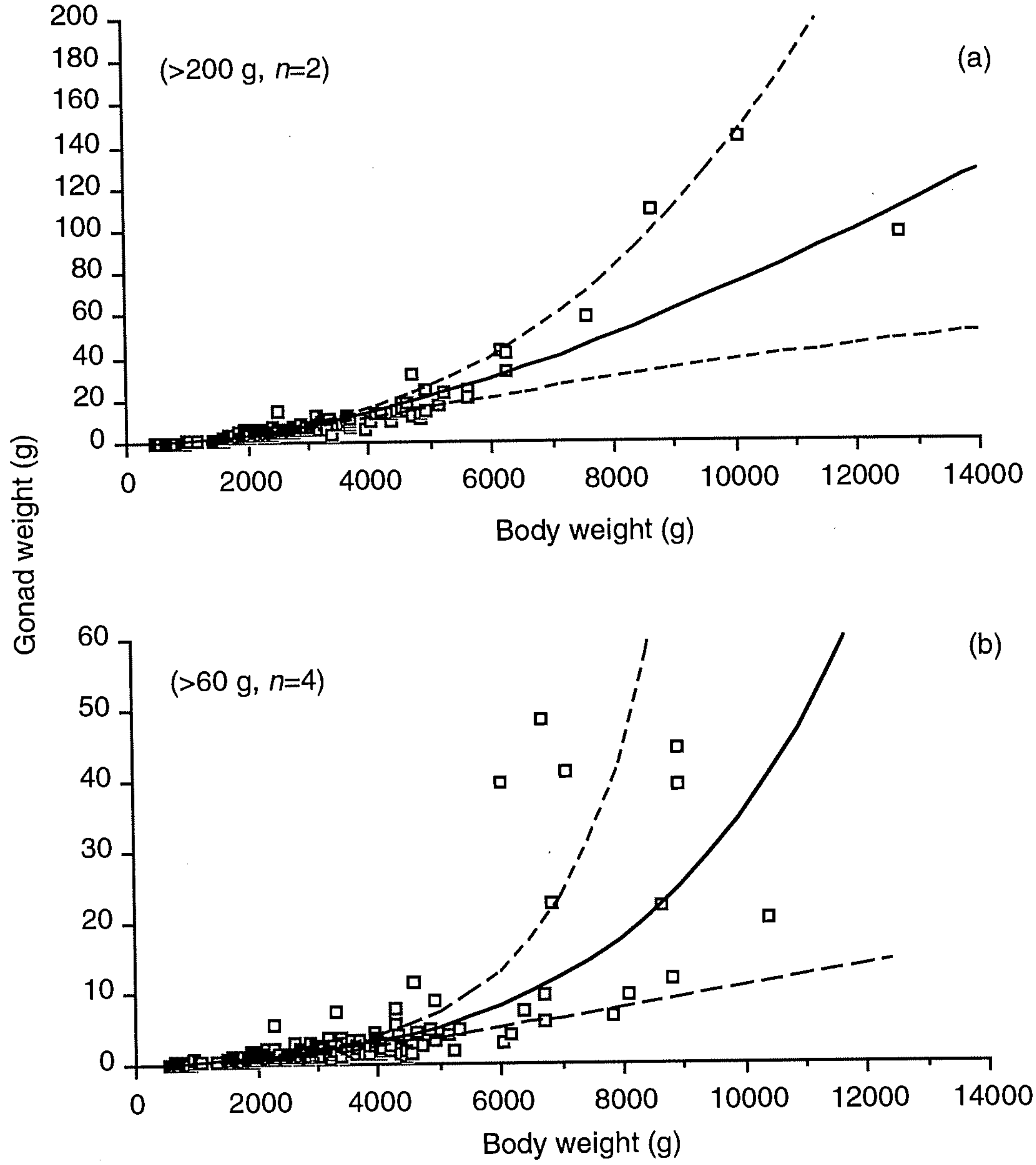

**Fig. 4.5.** Relationship between gonad weight and body weight for (a) female ($n$=175) and (b) male ($n$=213) kingfish. Shown are the predicted curves and 95% inference regions calculated using the methods of Richards and Schnute (1990).

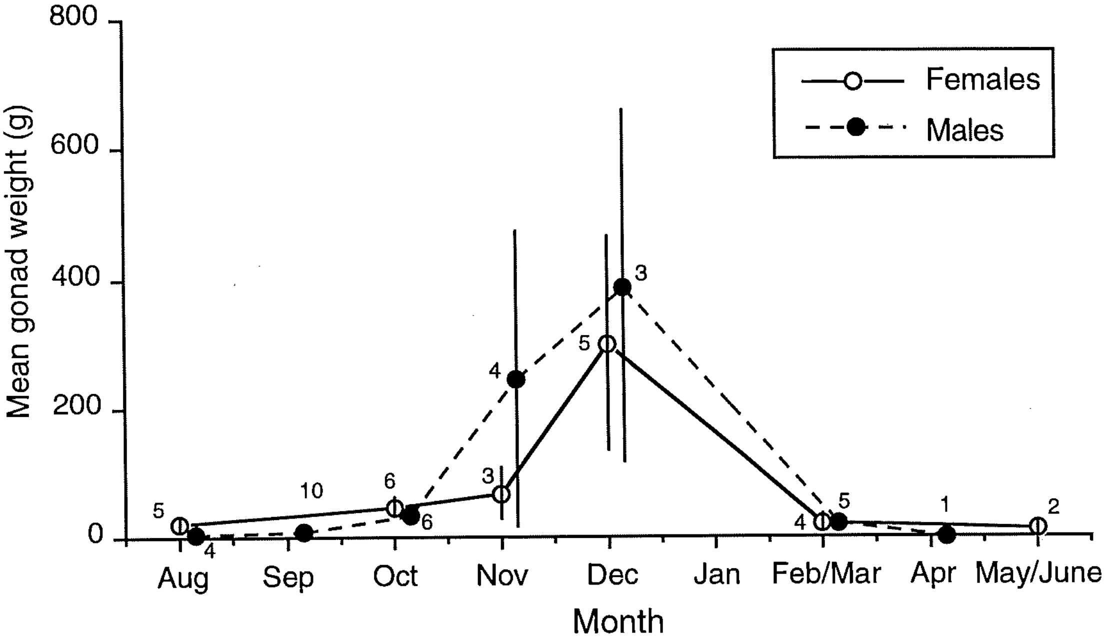

**Fig. 4.6.** Mean gonad weight (±SE) of female and male kingfish for monthly samples from along the coast of New South Wales. Only fish greater than 700 mm FL are included (sample sizes are shown).

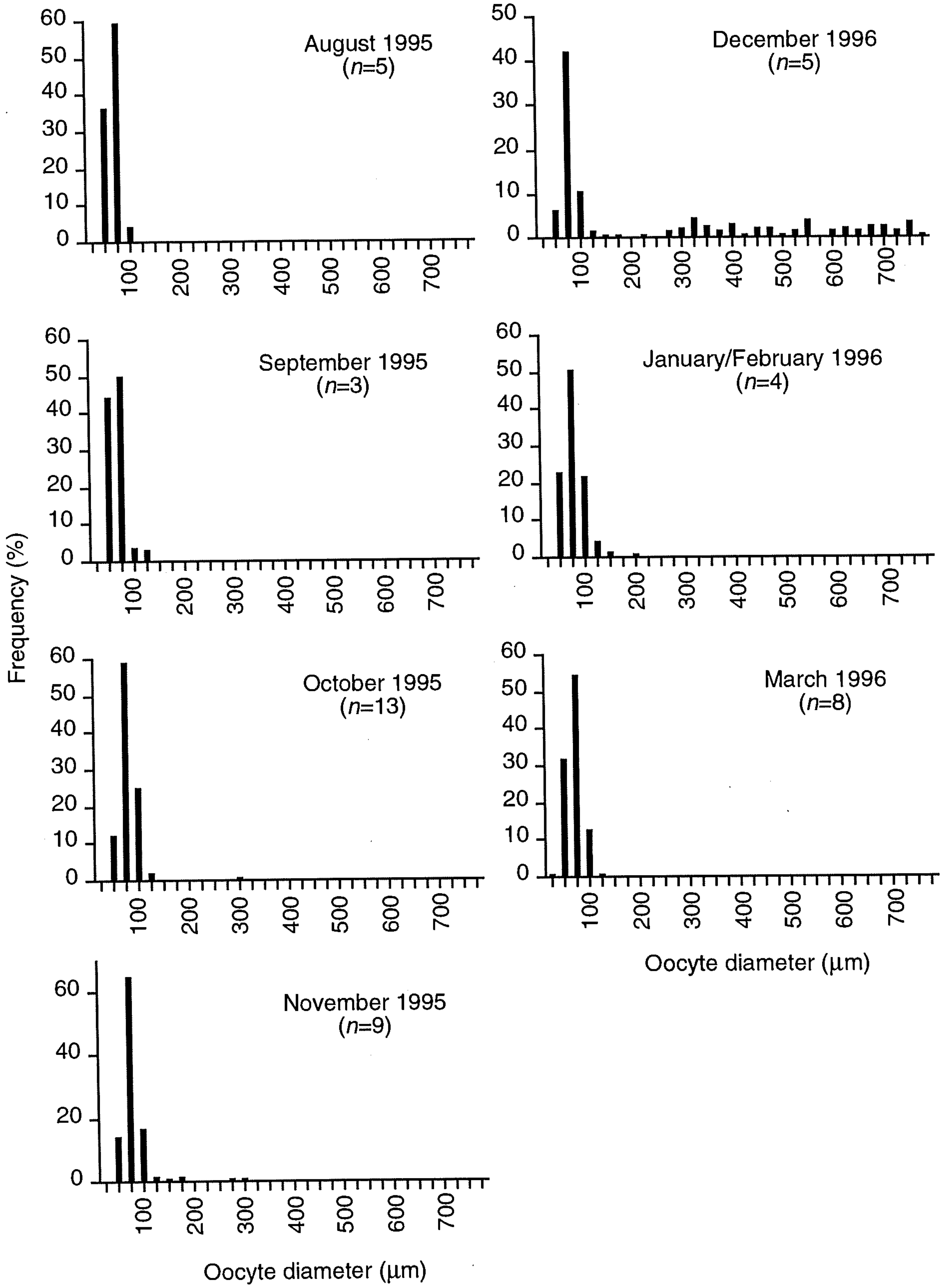

**Fig. 4.7.** Size-frequency distribution of oocytes in ovaries of kingfish showing change in size versus time. Sample sizes are also shown.

## 4.4. Discussion

### 4.4.1. *Development*

Histological examination appears to be a more reliable method to stage both female and male maturity than macroscopic observations, because there was some overlap in descriptions of visual appearance of gonads between different stages of maturity. In particular, colour of gonads did not appear to be a good descriptor for stage of maturity. Macroscopic staging of female gonads also provided inconclusive results in Baxter's (1960) study of *Seriola lalandi* (ex *dorsalis*) and histological observations were viewed as the only sensitive method to assess female maturity of *S. dumerili* (Marino *et al.* 1995). Marino *et al.* (1995), however, found that visual examination was reliable in staging of testes.

The absence of ripe oocytes in our collections and the small number of vittelogenic fish in general, precluded any inference about spawning mode in *S. lalandi.* Marino *et al.* (1995) determined that *S. dumerili* was a batch spawner, releasing eggs several times throughout the reproductive season.

### 4.4.2. *Size and age at maturity*

The majority of studies on size and age of *S. lalandi* at sexual maturity have focused on females. Female *S. lalandi* from New South Wales matured from 525 mm FL and 2 years, although 50% maturity was not attained until ≈700 mm FL and 3 years. These figures are in agreement with previous published studies on female *Seriola* spp. where size at maturity ranges from 500 to 750 mm FL and age at maturity ranges from 1 to 5 years (Baxter 1960; Garratt 1988; Micale *et al.* 1993; Tachihara *et al.* 1993; Marino *et al.* 1995; McGregor 1995*a,c*).

Males matured at smaller sizes and ages than females, which is consistent with previous studies on *S. dumerili* (e.g. Tachihara *et al.* 1993; Marino *et al.* 1995). We can find no other published information on size/age at maturity for male *S. lalandi*. Male *S. lalandi* mature at sizes approximately 200 mm smaller and 2 years younger than their female counterparts. Relatively small males had large amounts of spermatozoa in the sperm duct, but these fish are likely to be less fecund than large males. Although maturing earlier than females, only males above 6 kg body weight have the potential to show a huge increase in gonad weight (see Fig. 4.5).

### 4.4.3. *Seasonal patterns*

All *Seriola* spp. studied to date appear to be spring-summer spawners, although there have been few detailed studies. *Seriola lalandi* from NSW also appears to fit this pattern. Peak gonad activity was observed in December (summer) for both males and females. Penney (A.J. Penney, Sea Fisheries Research Institute, South Africa, pers. comm.) noted that *S. lalandi* from South Africa had a wide spawning season, with some gonad activity occurring year-round, although peak spawning occurred in summer (November-February). *Seriola lalandi* in NSW showed little gonad activity outside the summer months. It is not known whether the timing of spawning is uniform along the coast of NSW. Unfortunately, too few fish were obtained in the current study to determine time of spawning by site of collection. In a previous study on *S. lalandi* from NSW, fish from Coffs Harbour (northern NSW) had elevated gonad indices in February and March, when fish from Narooma (southern NSW) did not (Smith 1987). Smith's (1987) collections of fish were, however, limited to three collections of fish from Coffs Harbour (in February, March and August) and one each from Narooma (in March) and Greenwell Point (in October) and therefore there was probably insufficient temporal sampling to comment on timing of spawning. Another study on *S. lalandi* (ex *dorsalis*) from the northern hemisphere found that the time of spawning was fairly uniform over the known range of the species because ripe fish were found in different parts of the species range at the same time (Baxter 1960).

The NSW Kingfish fishery is presently managed by a range of input controls, including a minimum size limit and effort restrictions. The size composition of harvested fish is not known, but if fish available for the current study (mostly smaller than 700 mm FL) are representative of the fishery then very few harvested fish may be reproductively mature. Moreover, although some females are maturing at a smaller size than the current size limit (600 mm TL), many fish may be harvested prior to first reproduction. The impact of these factors on the stock remains unclear, as the species is both highly fecund and mobile (see Chapter 5). If all kingfish are available to the fishery, then the current minimum size limit may impact on total reproductive output. Alternatively, information supplied by fishers indicates that there may be very large and highly fecund fish that are not available to the fishery. If this was correct and these fish supply recruits to the fishery, then the minimum size limit in the NSW fishery may have limited impact on the total reproductive output.

# 5. Movement of yellowtail kingfish based on tag-recapture data

## 5.1. Introduction

Yellowtail kingfish, *Seriola lalandi*, is a circumglobal species restricted to subtropical and temperate waters (Smith-Vaniz 1984; Paxton *et al.* 1989). It consists of a series of apparently disjunct populations, many of which until recently were considered separate species (Smith-Vaniz 1984). Kingfish are generally thought to be highly mobile, although there has been little research conducted. Most information on their movements is in the form of maps showing where fish were tagged and recaptured (e.g. Baxter 1960; Pepperell 1985; Smith *et al.* 1991; Saul and Holdsworth 1992) and there have been few quantitative analyses (but see Holdsworth 1994). In one study (Smith *et al.* 1991), patterns of movement of kingfish were used to assess stock structure leading to the suggestion that the NSW fishery be treated as a single unit.

Most tagging studies of kingfish have involved cooperative tagging programs, in which government agencies supply tags and equipment to volunteer anglers to mark a range of fish species. Such programs are thought to be a cost-effective method of studying fish populations especially for less abundant species. There are a number of reasons why such tagging programs are initiated, many of which are primarily socially-oriented (Kearney 1988). Of the scientific reasons for tagging, Kearney (1988) has listed five attributes as the primary targets of tagging programs. These are (i) migration and investigations of stock structure, (ii) estimates of growth, (iii) mortality, (iv) determination of stock size, and (v) stocking success. Although a number of assumptions underlie the interpretation of results from such studies, few studies have investigated the impact of violating the underlying assumptions. Data for kingfish obtained from an amateur tag-recapture program were therefore used to assess the usefulness of such data for obtaining information about movement and life history parameters.

The objectives of this study were to (1) investigate patterns of tagging and recaptures to determine whether they were uniform in distribution among fishing zones, seasons and years, (2) investigate size of fish at tagging and recapture to determine the size range of the population that was being sampled, (3) determine whether recapture rates vary between experienced and inexperienced taggers and therefore whether differences in rates of tag loss or tagging mortality between fishers are likely, and (4) investigate patterns of movement in relation to days at large, size of fish and season of recapture.

## 5.2. Materials and Methods

### 5.2.1. *Tagging program*

Kingfish were tagged as part of the NSW Fisheries Gamefish Tagging program, which has been in operation since 1974. Initially, this program was restricted to a few anglers in New South Wales, but the program now services the Indo-west Pacific region (Pepperell 1985) and has the cooperation of over 190 angling clubs (Matthews and Deguara 1994). Kingfish, however, have only been tagged as part of this program in Australian (99.9%) and New Zealand (0.1%) waters. The majority of fish (99.6%) were tagged along the eastern coast of Australia from Queensland to Victoria.

### 5.2.2. *Tagging methods*

Kits of tagging equipment, including instructions on tagging procedures, are supplied to anglers (usually through clubs). A tagging kit contains 5, 10 or 20 tags (each attached to a reply paid card), depending on the type of tag. Three types of tags were used for tagging kingfish: nylon-headed single-barbed spaghetti tag (type A), stainless steel-headed spaghetti tag (type S) and T-bar anchor tags (type M; see Pepperell 1990 for further details). The majority of releases were made with the nylon-headed spaghetti tag (91%).

Anglers were asked to insert tags of type A and M behind the dorsal pterygiophores and to place type S tags in the anterior dorsal musculature, but according to Pepperell (1990) tags were commonly placed elsewhere. After each release, anglers were requested to complete a tag card with information on the species, length and weight of the fish (and whether these measurements were actual or estimated), location of release, date of tagging, as well as information relating to the angler and the boat. Upon recapturing a fish, anglers were requested to supply the same information as taggers and to supply the tag number of the recaptured fish. All records of tagging and recapture were sent to NSW Fisheries.

### 5.2.3. *Distribution of tagging and recaptures by area, season and year*

The numbers of fish tagged and recaptured were described by season and area (in bands of 1° latitude). For example, the 1° band between 33° S and 34° S is referred to as the 33° band. Numbers of fish were separated by season (summer = Dec-Feb, autumn = Mar-May, winter = Jun-Aug and spring = Sep-Nov) in which they were tagged or recaptured. This definition of season is used throughout this chapter. Three areas (the 30°, 33° and 34° bands) that had the greatest numbers of fish tagged and recaptured were used to investigate numbers of fish tagged and recaptured by year.

### 5.2.4. *Size at tagging and recapture*

The database only gives total length for size at tagging. Improbably-sized fish (e.g. < 20 cm and > 2 m) were deleted from the database. These fish accounted for < 1% of tagged fish. Both fork length (FL) and total length (TL) were given for size at recapture. For 9% of recaptures, FL only was reported. Where this occurred, FL was converted to TL using the equation [TL(cm)=1.122*FL(cm)+9.021]. This equation was calculated from fish (*n* ≈ 570) obtained for ageing as part of the present study, and in which both fork and total lengths were measured.

### 5.2.5. *Direction and movement of fish*

To evaluate the directional movement of kingfish, two methods were used: (1) maps illustrating release and recapture locations, and (2) number of recaptures in different angular intervals. Maps were only used to show recaptures of fish moving greater than 50 km. To determine whether fish may have been moving different directions by season, maps were separated by season in which fish were recaptured.

To determine the direction that recaptured fish had moved, the 360° compass was divided into 45° angular intervals with midpoints of 0°, 45°, 90°, 135°, 180°, 225°, 270°, and 315° (corresponding to N, NE, E, SE, S, SW, W and NW respectively). The compass heading for the direction that each recaptured fish had moved was calculated and assigned to one of these intervals. The principal direction(s) that fish moved ($\varphi_1$ and $\varphi_2$), the proportion of fish moving in direction $\varphi_1$ ($\lambda$), and the strength of a fish's tendency to move in each principal direction (concentration parameters $\kappa_1$ and $\kappa_2$, larger values indicate greater bimodality in the directions moved) were calculated following systematic likelihood methods outlined in Schnute and Groot (1992). These five parameters were combined into a model to determine the probability of obtaining the observed frequencies for each angular interval given specific values of the parameters. Measures of uncertainty on all parameter estimates were also computed (see Schnute and Groot 1992). Fish that had moved less than 1 km were excluded from these analyses.

Distances moved are expressed as the minimum distance travelled (in kilometres) between release and recapture.

## 5.3. Results

Approximately 17,190 tagged kingfish were released between 1974 and 1995. The number of fish tagged per year increased over the first 10 years of the program, but showed a general decline from 1983 (Fig. 5.1). A total of 1,376 recaptures were reported, although some recaptures (7.8%) contained little or no useful information because initial tagging data had not been returned. This equates to a recovery rate of 8%. The majority of tag returns were made by recreational fishers (56%), although in 8% of returns, the status (recreational or professional) of the fisher was unknown.

### 5.3.1. *Distribution of tagged/recaptured fish*

Most of the fish tagged and recaptured along the east coast of Australia were concentrated in New South Wales (Fig. 5.2). Within NSW, the greatest numbers of tagged and recaptured fish were obtained from the 30° band. Taggings and recaptures were not evenly distributed among seasons (Fig. 5.2). For each region, the greatest numbers of fish were generally tagged in summer (December-February), although the greatest number were tagged in Autumn (March-May) for the 36° band. Although more fish were recaptured in Summer from the 30° band, recaptures in both summer and autumn dominated the more southern NSW regions (Fig. 5.2). Within three main areas (the 30°, 33° and 34° bands), the number of fish tagged and recaptured varied among years (Fig. 5.3). About 2% of all kingfish were tagged around Lord Howe Island (31°30′, 159°00′) and the remainder were tagged relatively close to the coast of mainland Australia.

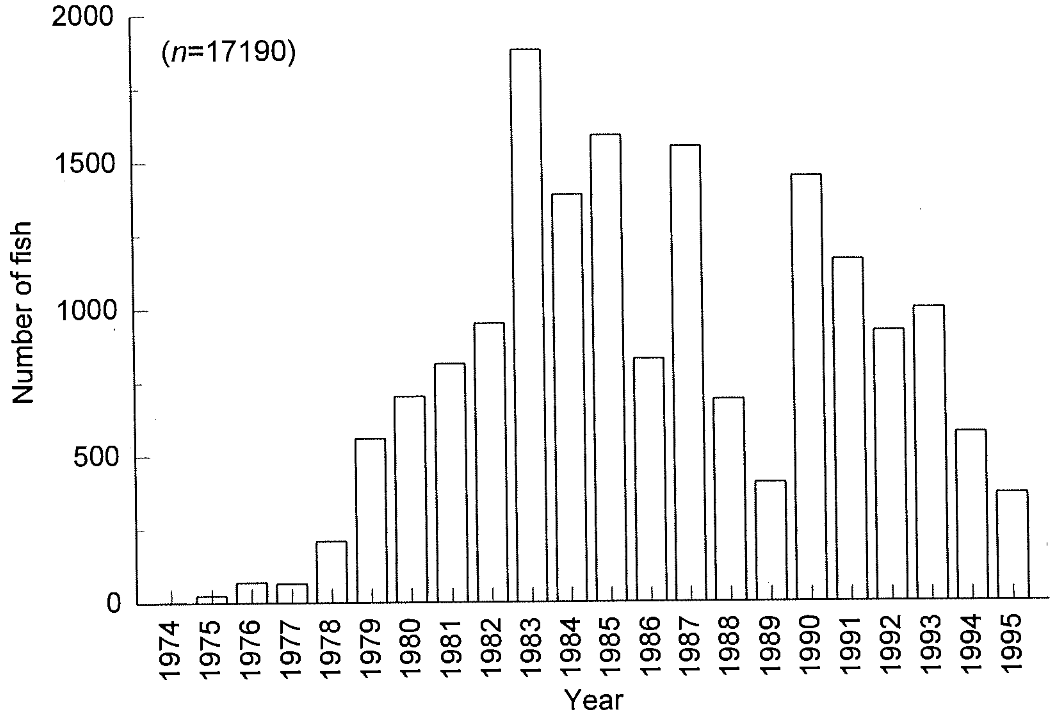

**Figure 5.1.** Number of kingfish tagged per year as part of the NSW Fisheries Gamefish programme.

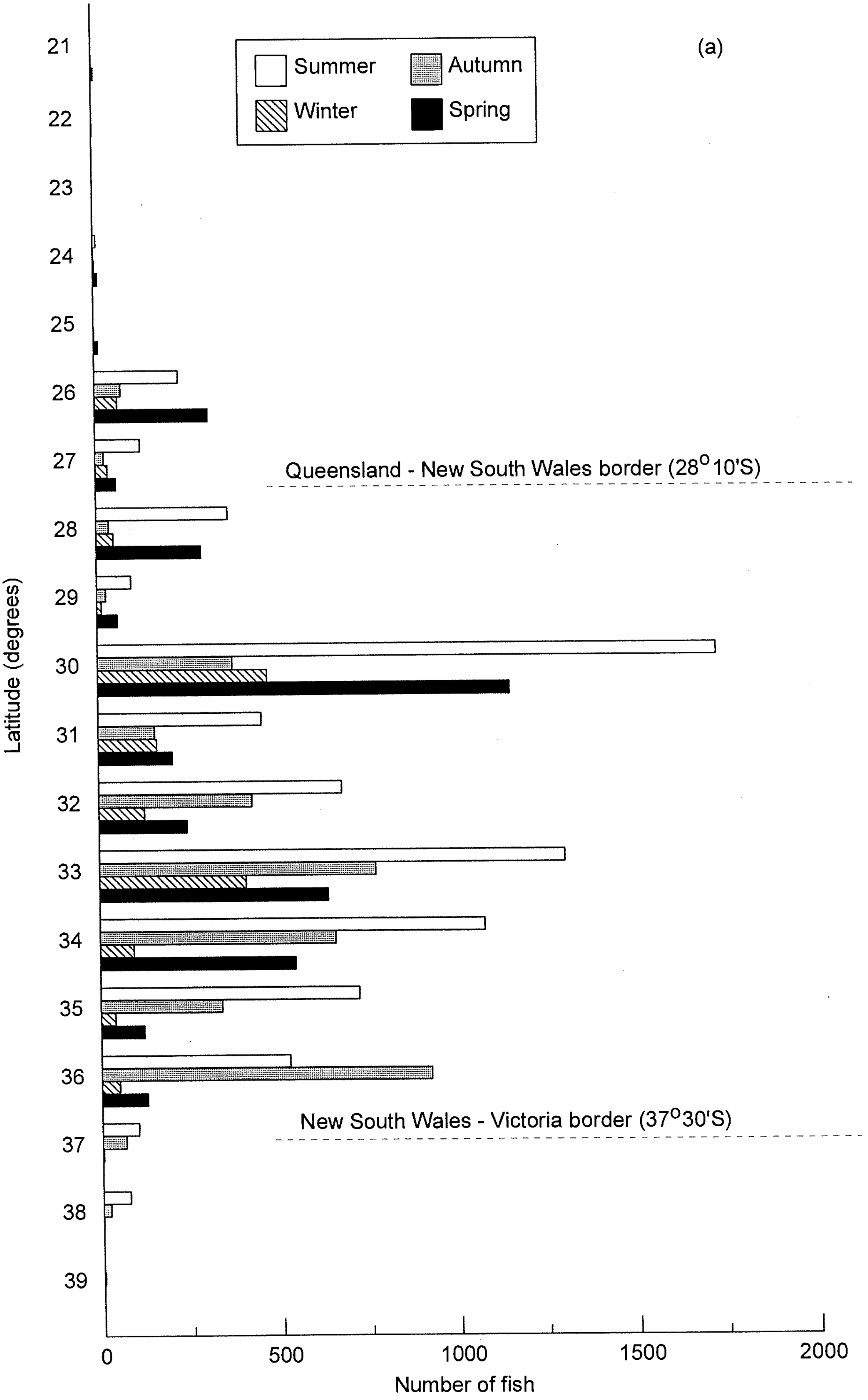

**Figure 5.2.** (a) Number of kingfish tagged each season along the east coast of Australia and (b) number of kingfish recaptured each season along the east coast of Australia.

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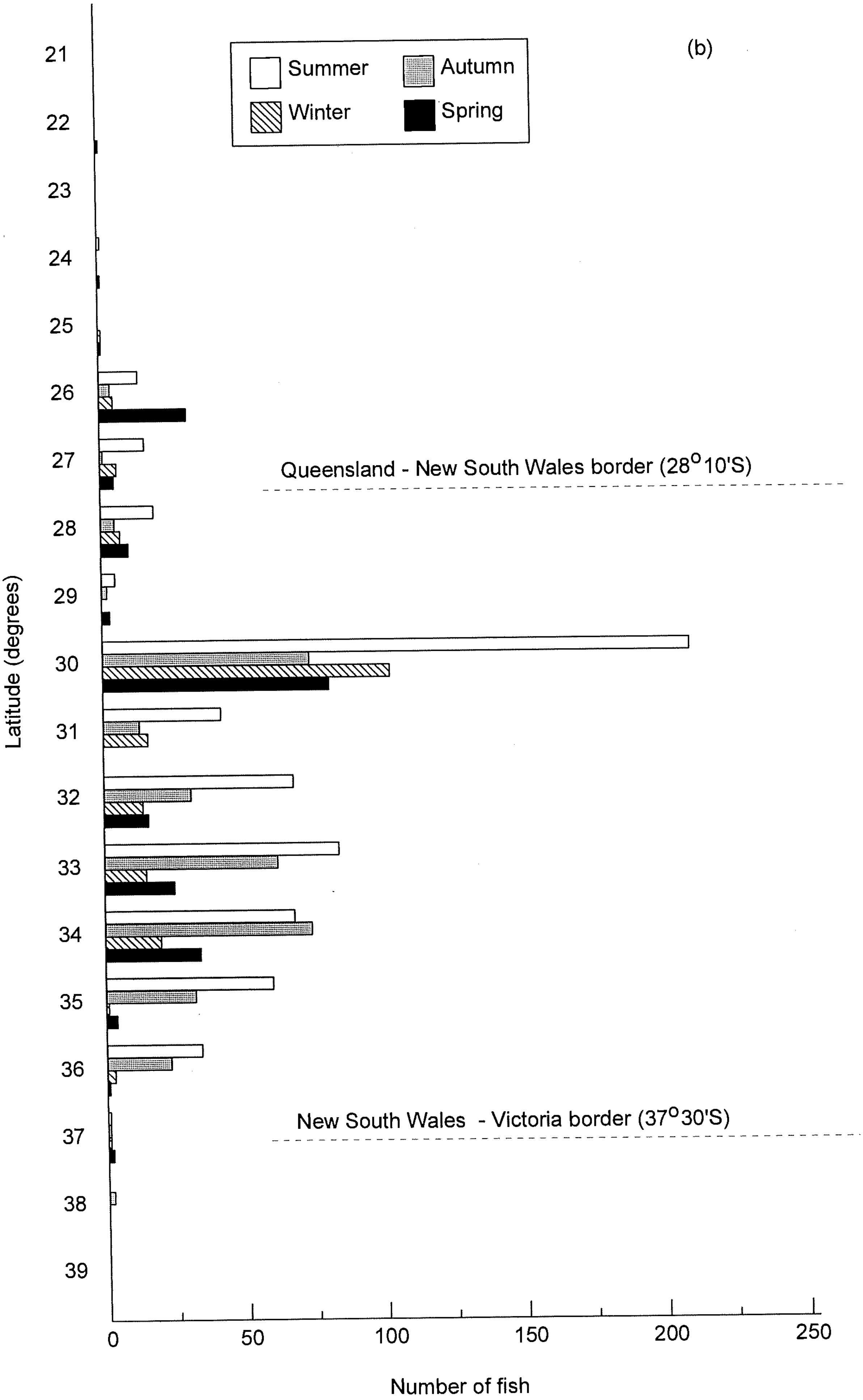

**Figure 5.2.** continued

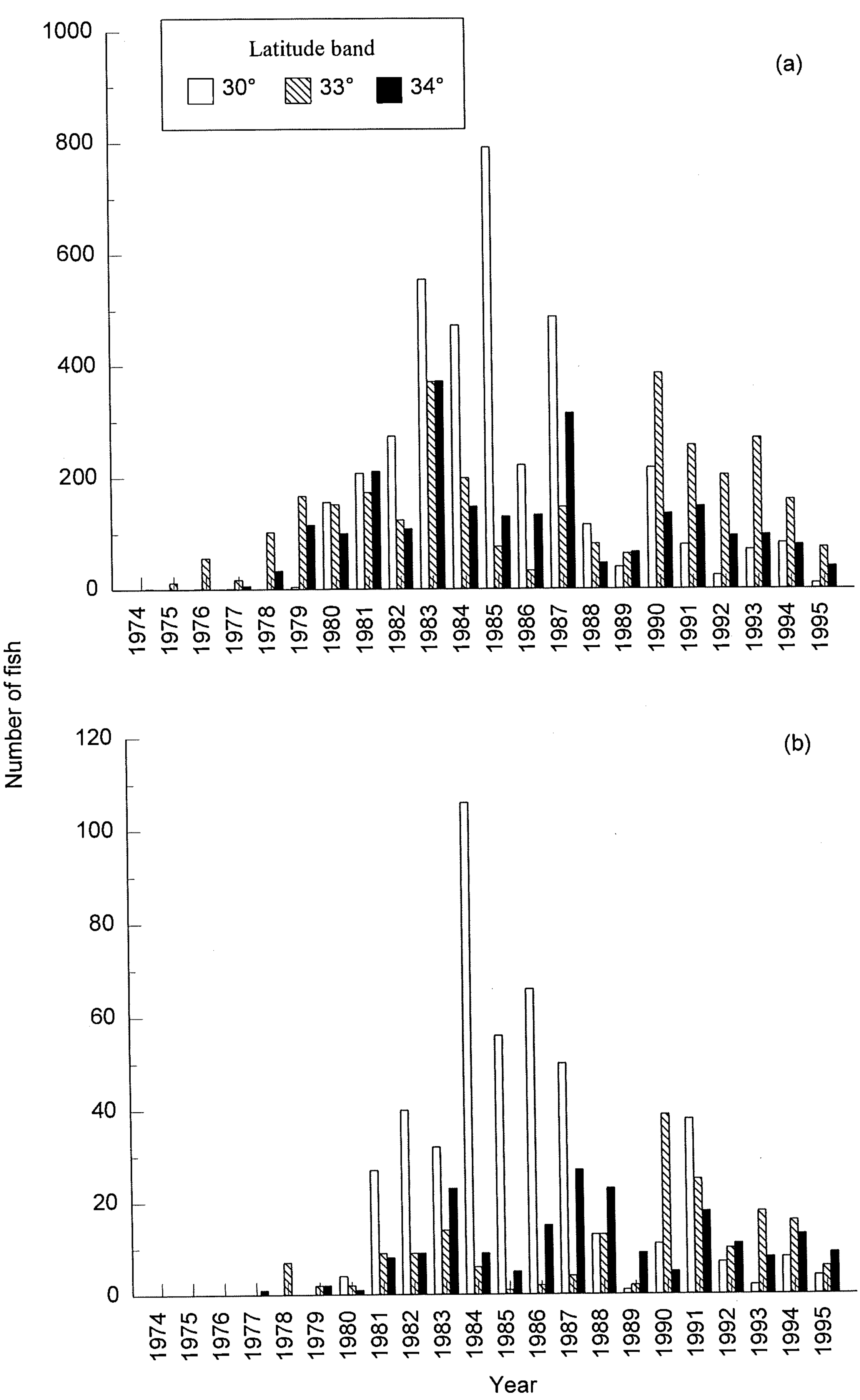

**Figure 5.3.** Distribution of kingfish (a) tagged each year and (b) recaptured each year for the three areas where most tagging occurs.

### 5.3.2. *Recapture rates*

Recapture rates for fish tagged in the different areas varied among areas (Table 5.1). The 30° band had the highest recapture rate (12%), whereas the 36° band had the lowest recapture rate (4.4%). The remaining areas had recapture rates between 5% and 8%.

Ninety three percent of recaptured fish were caught within 12 months of tagging. Although some fish were tagged up to 20 years ago, none of the recaptured fish were at large for more than 5 years. Numbers of recaptures per month at large decreased rapidly for the first six months and then showed a gradual decrease until approx. 30 months, after which few recaptures occurred (Fig. 5.4).

Of the more than 1525 fishers who have tagged kingfish, 30% tagged one fish (totaling 3% of all fish tagged) and 78% of fishers tagged less than 10 fish each (22% of all fish tagged) (Fig. 5.5). Six fishers have tagged more than 200 fish each and these were 14% of all fish tagged. Recapture rates for these six fishers varied, but on the whole were greater than the overall recapture rate (Table 5.2). The recapture rate of fishers tagging 1 to 4 fish is below that of the overall recapture rate (≈4.8% vs. 8%), whereas two-thirds of the top six fishers have recapture rates above the overall rate (Table 5.2).

### 5.3.3. *Size at tagging and recapture*

All fish tagged were between 200 and 1400 mm long; there was a tendency for fishers to round measurements to the nearest 50 and/or 100 mm (Fig. 5.6a). At recovery, fish ranged from 300 to 1400 mm long (Fig. 5.6b). The tendency to round measurements to the nearest 50 or 100 mm was not as pronounced in the recapture data as in the tagging data. There was no evidence of bias in measurements for fish at large < 30 days, for example taggers did not overestimate sizes of fish compared to recapturers (see Fig. 3.3a). The distribution of lengths at recovery had shifted to the right compared to the distribution of lengths at tagging (Fig. 5.6).

**Table 5.1.** Recapture rates of kingfish by area tagged. Each latitude band is the northern limit of a 1° band.

| **Latitude band** (°) | **% recaptured** |
|---|---|
| Queensland | 8.4 |
| 28 | 5.0 |
| 29 | 5.6 |
| 30 | 12.1 |
| 31 | 7.4 |
| 32 | 7.6 |
| 33 | 6.0 |
| 34 | 6.4 |
| 35 | 5.6 |
| 36 | 4.4 |
| 37 | 5.2 |
| South of 38 | 5.9 |

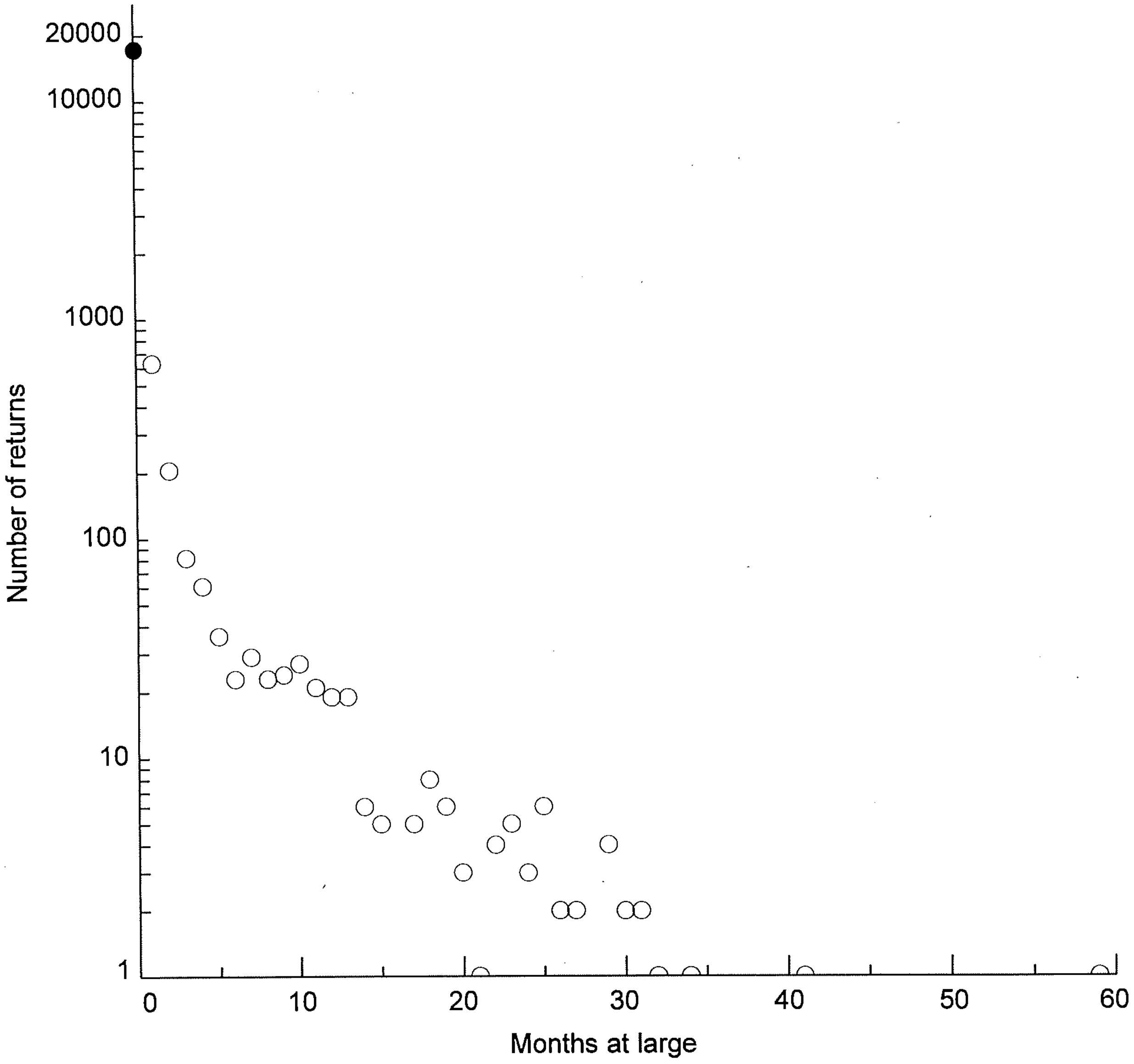

**Figure 5.4.** Numbers of kingfish tag recoveries versus months at large. The y-axis is a logarithmic scale. The solid circle is the number of fish tagged.

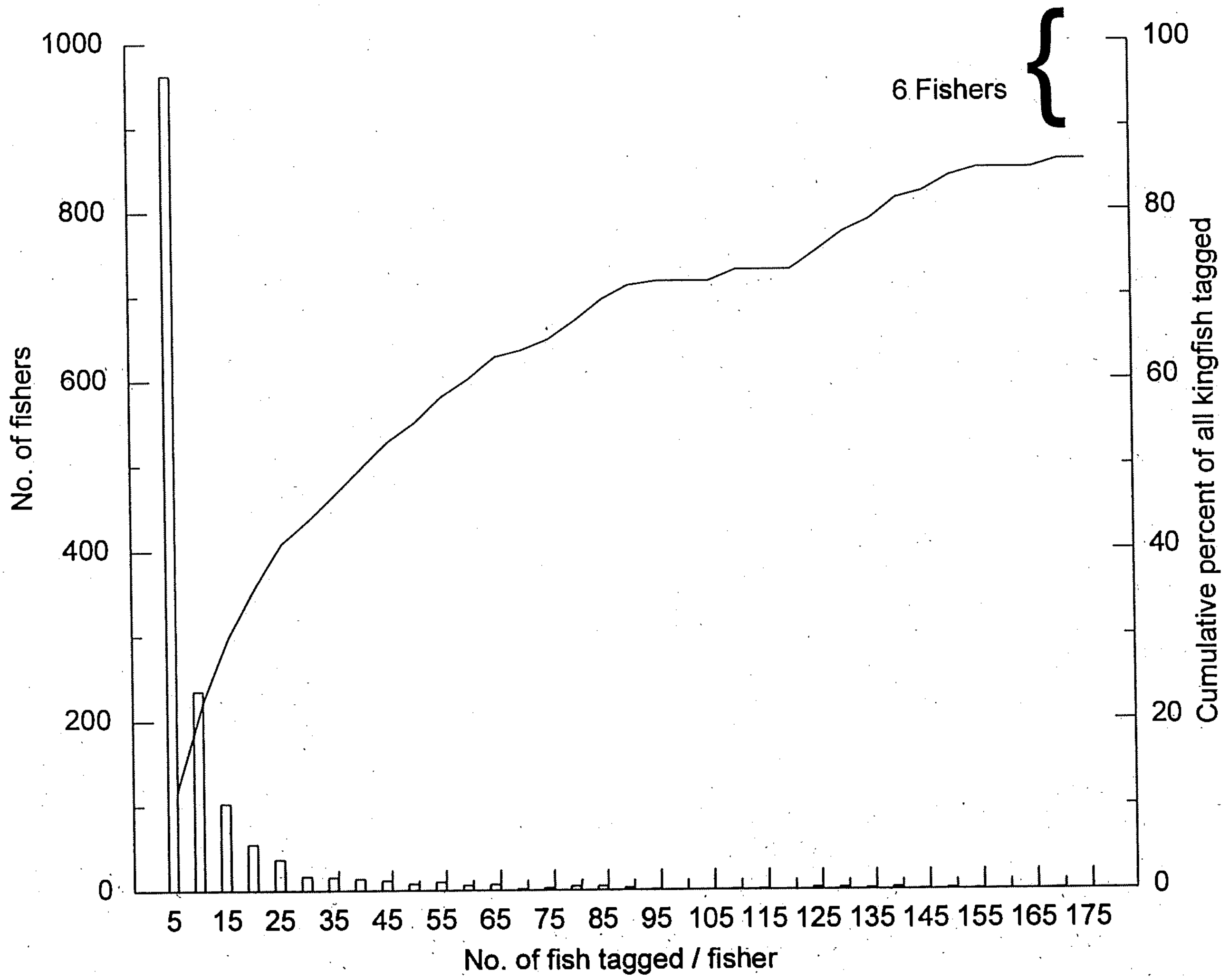

**Figure 5.5.** Frequency distribution showing number of kingfish tagged by individual fishers and line indicating how the distribution relates to the total number of kingfish tagged. Six fishers tagged greater than 175 fish which equates to 14% of all kingfish tagged (see Table 2).

**Table 5.2.** Recapture rates for fish tagged by (a) the top six fishers in terms of numbers of fish tagged, (b) fishers tagging ≈125 fish, (c) fishers tagging ≈50 fish, (d) fishers tagging 20 fish and (e) fishers tagging only 1 to 4 fish. * Three fishers tagged 20 fish and 2 fish were recaptured from each of these three fishers, likewise 6 fishers that tagged 20 fish had one fish recaptured from the 20 tagged. The overall recapture rate was 8%

| | No. Tagged | No. Recap. | Recap. rate |
|---|---|---|---|
| (a) Top ranked fishers | | | |
| 1 | 906 | 130 | 14.3 |
| 2 | 568 | 77 | 13.6 |
| 3 | 259 | 16 | 6.2 |
| 4 | 233 | 35 | 15.0 |
| 5 | 205 | 21 | 10.2 |
| 6 | 204 | 10 | 4.6 |
| (b) Fishers tagging ≈125 fish | | | |
| 1 | 129 | 8 | 6.2 |
| 2 | 126 | 12 | 9.5 |
| 3 | 124 | 13 | 10.5 |
| 4 | 124 | 10 | 8.1 |
| 5 | 124 | 2 | 1.6 |
| (c) Fishers tagging ≈50 fish | | | |
| 1 | 51 | 11 | 21.6 |
| 2 | 51 | 0 | 0.0 |
| 3 | 50 | 8 | 16.0 |
| 4 | 50 | 4 | 8.0 |
| 5 | 50 | 3 | 6.0 |
| (d) Fishers tagging 20 fish | | | |
| 1 | 20 | 3 | 15.0 |
| 2 | 20 | 2 (3 fishers*) | 10.0 |
| 3 | 20 | 1 (6 fishers) | 5.0 |
| 4 | 20 | 0 | 0.0 |
| (e) Fishers tagging 1-4 fish | | | |
| 1 | 460 (460 fishers) | 22 | 4.8 |
| 2 | 402 (201 fishers) | 19 | 4.7 |
| 3 | 393 (131 fishers) | 19 | 4.8 |
| 4 | 396 (99 fishers) | 19 | 4.8 |

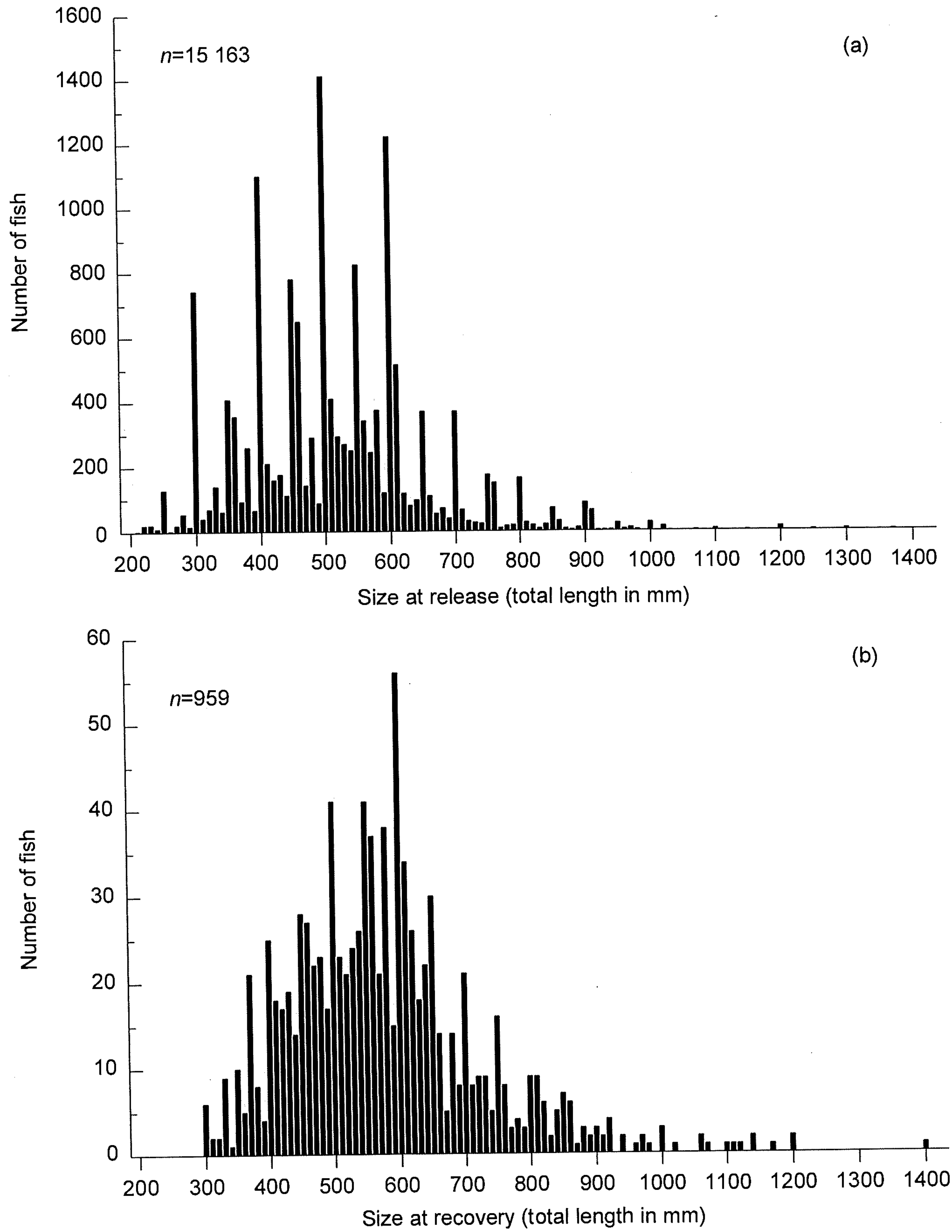

**Figure 5.6.** Length frequency histograms of kingfish (a) tagged (mean size 515 mm, 141 SD) and (b) recaptured (mean size 576 mm, 147 SD) between 1974 and 1996 as part of the NSW Fisheries Gamefish Tagging program.

### 5.3.4. *Movements of fish*

The majority of fish were recaptured within 50 km of the location where they were tagged (Table 5.3, Fig. 5.7), although there was evidence that fish at large for longer periods moved further (Fig. 5.7). There was also an indication that larger fish (>750 mm TL) moved greater distances than smaller fish (e.g. fish <600 mm TL; Fig. 5.8), although one fish 310 mm TL moved 678 km. Larger fish also showed greater variability in distance moved than smaller fish (Fig. 5.8), however few fish over 1000 mm TL were tagged.

Information for 119 fish which moved more than 50 km was separated by season of recapture (Fig. 5.9). There were few fish that moved long distances recaptured in winter and this presumably reflects a combination of fishing effort and abundance of fish (Fig. 5.9c). Similar numbers of fish moving long distances were found for the remaining three seasons. Three fish moved from NSW, Australia to northern New Zealand (>2000 km) and all were recaptured in Autumn (Fig. 5.9b). Seven other fish moved in excess of 500 km, including one fish moving from The Peak in NSW to Lord Howe Island and another moving from Whale Beach in NSW to Barren Island in Queensland (Fig. 5.9d). Movements along the coast of eastern Australia were much more frequent than offshore movements (e.g. to New Zealand or other islands in the Pacific), but this presumably also reflects fishing effort.

### 5.3.5. *Direction of movement of fish*

The predominant movements of kingfish were north-east ($\varphi_1$ /$\varphi_2$ between 23.5 and 40.6°) and south-west ($\varphi_1$ /$\varphi_2$ between 211 and 227°) along the eastern coast of Australia (Fig. 5.10). There were strong north-east movements of kingfish in all seasons ($\kappa$ 6.5±5.9 winter, 6.6±3.4 spring, 36.1±6.8 summer versus 2.5±1.5 winter, 2.6±1.2 spring, 1.5±0.4 summer) except autumn, which showed a stronger south-west ($\kappa$ 6.0±2.7) movement of kingfish and a weaker north-east ($\kappa$ 1.3±0.6) movement. The proportion of fish moving in the two principal directions was, however, similar ($\lambda$ between 0.45 and 0.54, error 0.1) with the exception of summer where approximately 75% of fish moved in a north-east direction (Fig. 5.10). Confidence regions around values of $\varphi$ and $\kappa$ for each principal direction showed that although fish were generally moving similar directions among seasons, the strength of the movements sometimes varied (Fig. 5.11). This was particularly true for spring and autumn where non-overlapping confidence regions were found and for summer which generally varied from all other seasons (Fig. 5.11). This analysis assumes uniform fishing effort in time and in space and therefore results should be treated with caution.

**Table 5.3.** Movement of tagged kingfish between areas. Shown are the percentage of fish recaptured in each latitude compared to the latitude of tagging. Sample sizes (*n*) are indicated.

| | | **Latitude band of recapture** | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Latitude band of tagging** | *n* | **26** | **27** | **28** | **29** | **30** | **31** | **32** | **33** | **34** | **35** | **36** | **37** | **38** |
| **26** | 49 | 100 | | | | | | | | | | | | |
| **27** | 28 | | 96 | 4 | | | | | | | | | | |
| **28** | 37 | | | 97 | | | | 3 | | | | | | |
| **29** | 11 | | | | 55 | 45 | | | | | | | | |
| **30** | 450 | | | | 1 | 96 | 1 | 1 | 1 | 1 | | | | |
| **31** | 73 | | | | | | 86 | 10 | 3 | 1 | | | | |
| **32** | 113 | | | | | | | 90 | 8 | 2 | | | | |
| **33** | 187 | | | 1 | | 2 | | 2 | 82 | 11 | 3 | | | |
| **34** | 152 | | | | | 1 | | 1 | 1 | 82 | 15 | 1 | | |
| **35** | 69 | | | | | | | | | 19 | 77 | 4 | | |
| **36** | 71 | | | | | | | | 4 | 10 | 11 | 69 | 4 | 1 |
| **37** | 9 | | | | | | | | 11 | 22 | 11 | 44 | 11 | |
| **38** | 6 | | | | | | | | | 50 | 17 | | 17 | 17 |

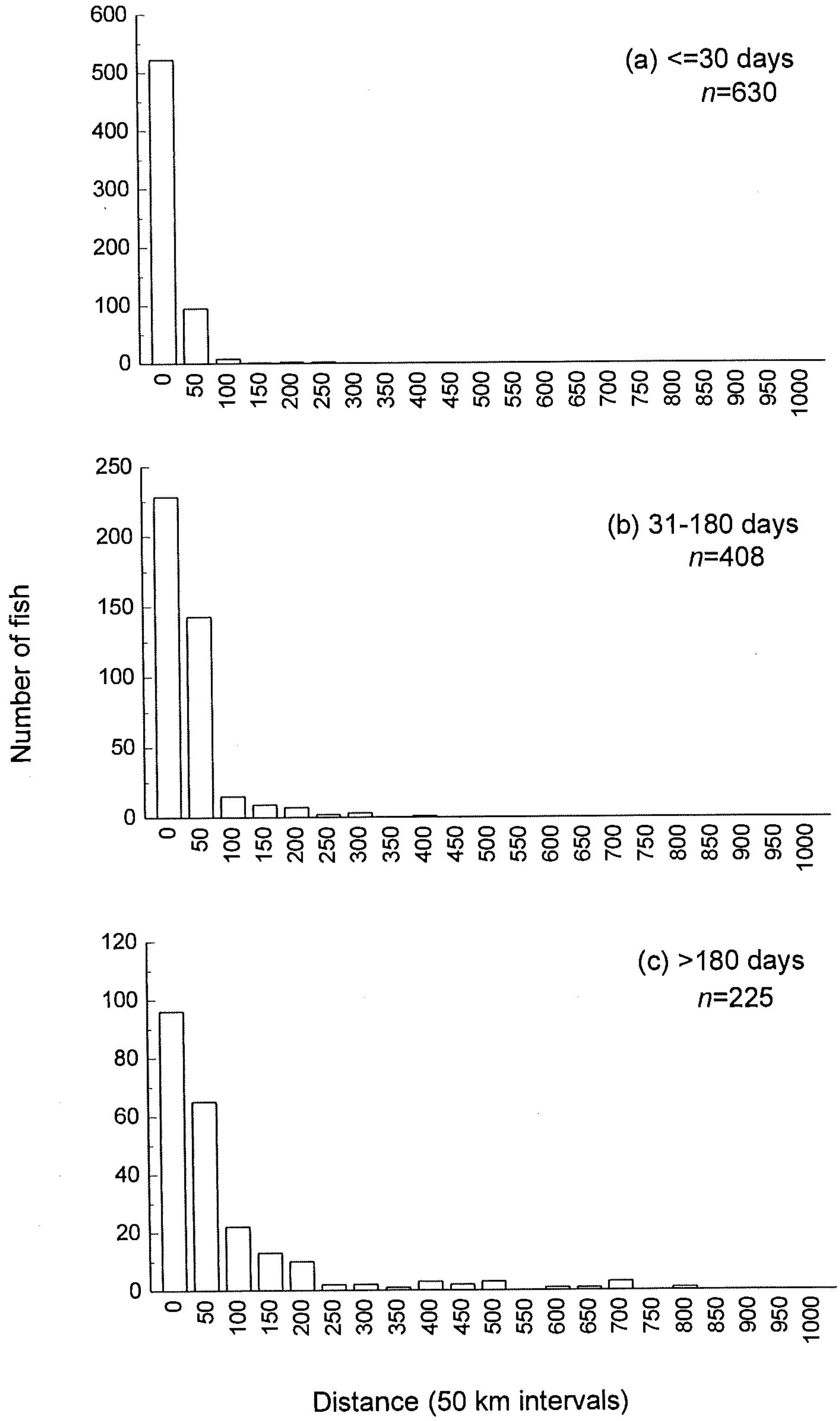

**Figure 5.7.** Frequency distribution of numbers of kingfish versus distance moved for fish at large (a) 30 days or less, (b) 31 to 180 days and (c) greater than 180 days. Note maximum y-value varies.

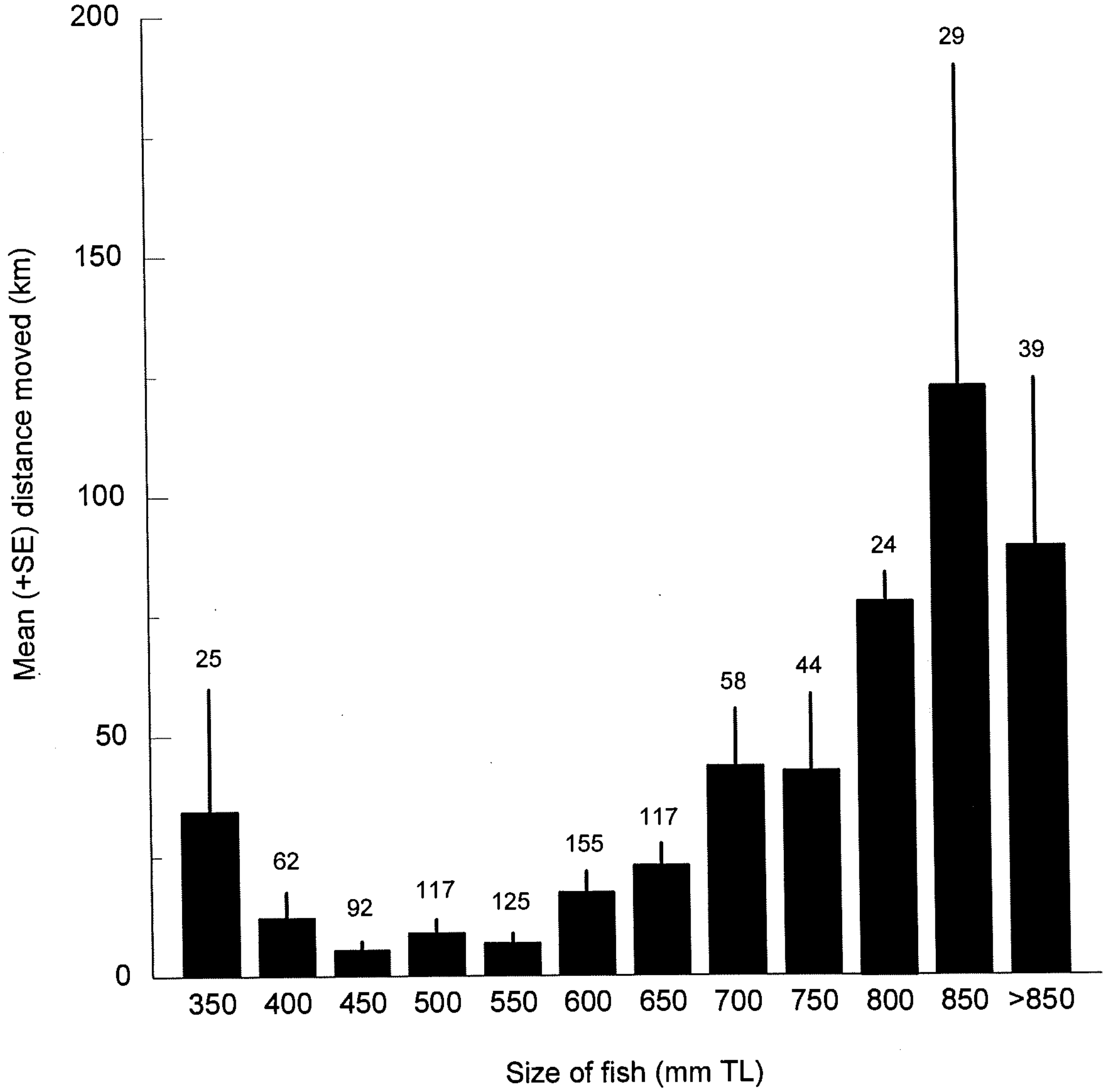

**Figure 5.8.** Mean distance (+ standard error) moved by different size classes of kingfish. Numbers above the error bars are sample sizes.

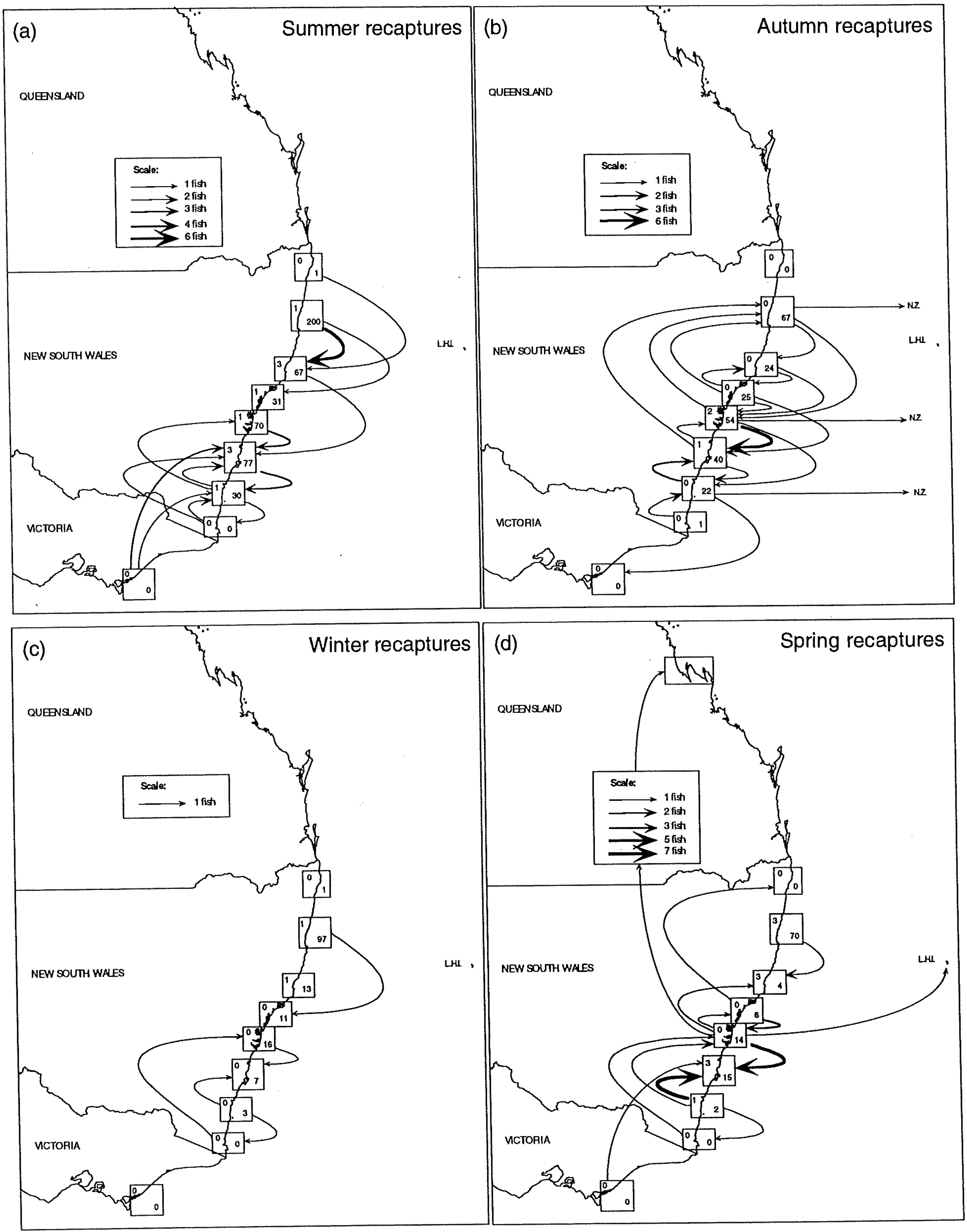

**Figure 5.9.** Movement of kingfish by season in which they were recaptured for fish moving greater than 50 km. Movements shown to the right of the coast are southerly movements, those to the left represent northwards movement of fish (with the exception of one fish moving to Lord Howe Island (L.H.I.) and three fish moving to New Zealand). Numbers shown in the left corner of the boxes are fish which moved > 50 km but which were recaptured in the same general area as they were tagged, numbers shown in the right corner are fish recaptured less than 50 km from their release point. The size of the arrows is proportional to the number of fish with the scale shown on each map.

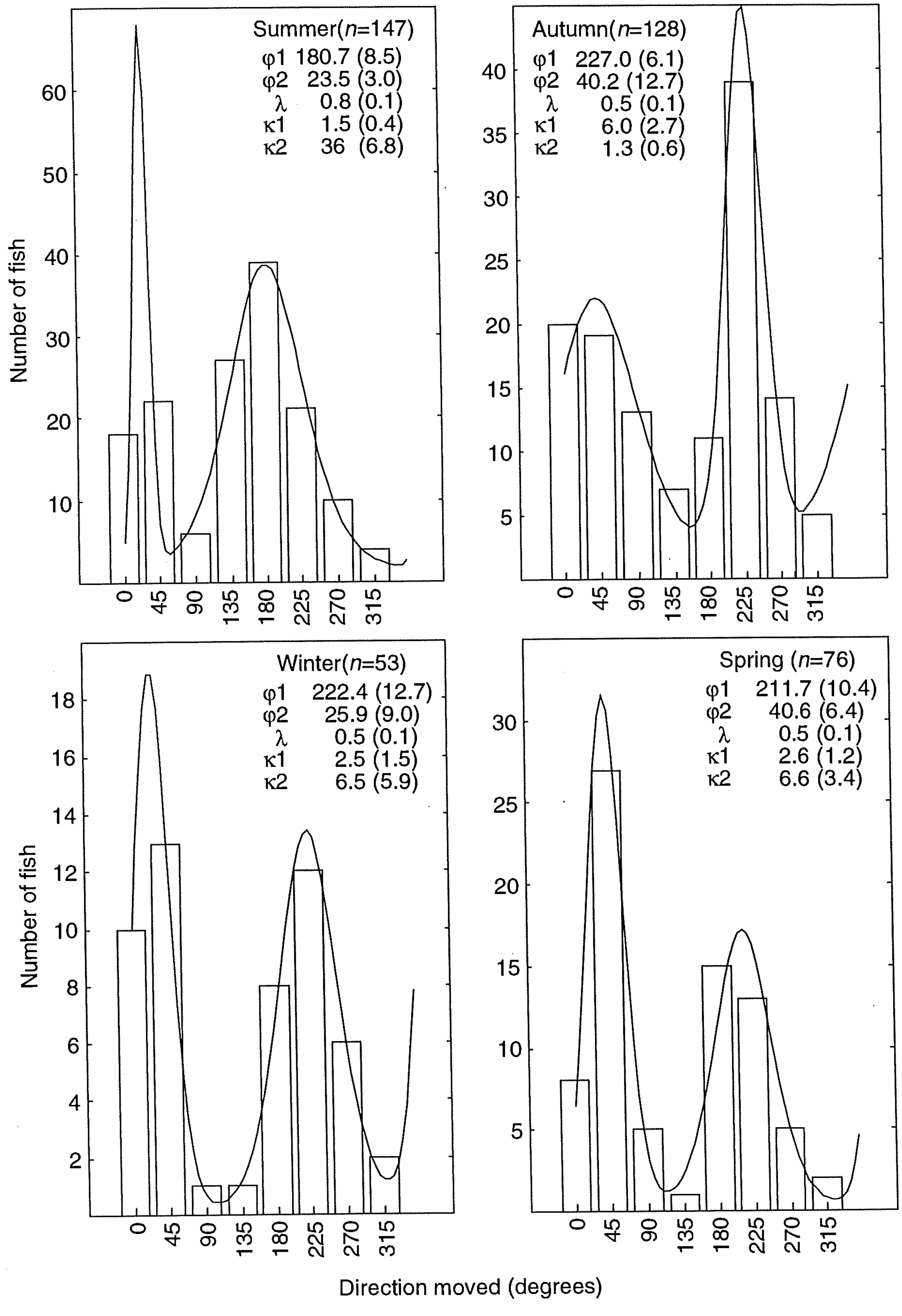

**Figure 5.10.** Histograms showing observed frequencies of kingfish moving different directions for different recapture seasons. The predicted frequencies according to the model developed from the methods of Schnute and Groot (1992) are shown by the curved lines. Parameter values (and standard errors) are also indicated.

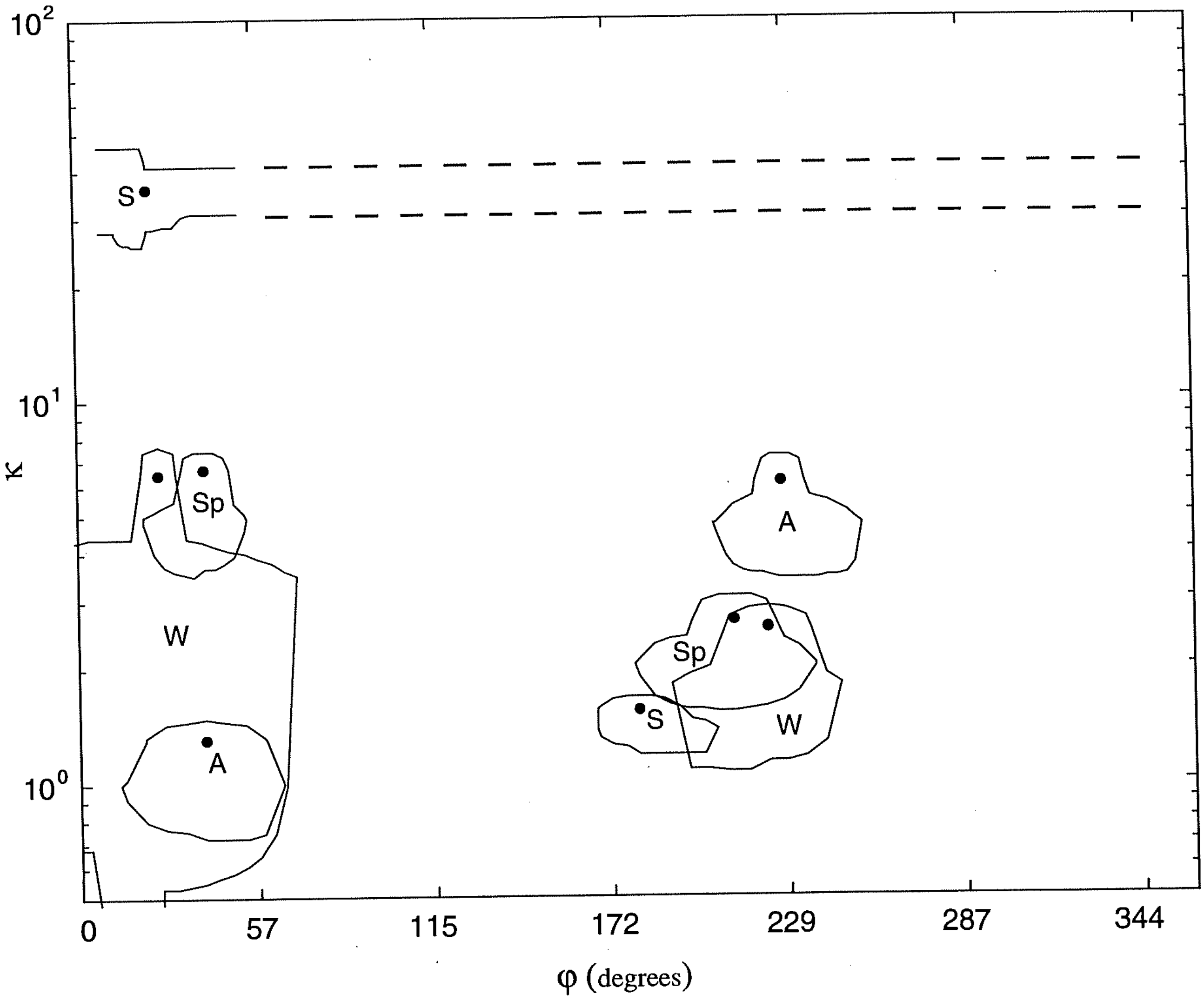

**Figure 5.11.** Confidence regions around parameter estimates of φ and κ (i.e. direction moved and strength of movement - see text for additional details) for movements in each season (S, summer, Sp, spring, A, autumn, W, winter) calculated using methods of Schnute and Groot (1992). Solid circles indicate the corresponding estimates (φ, κ) for each principal direction. 95% confidence regions are not symmetrical because a von Mises distribution was used and the y-axis is plotted on a log scale.

## 5.4. Discussion

### 5.4.1. *Distribution of tagged and recaptured fish*

The distribution of both tagged and recaptured fish varied along the east coast of Australia, by season and by year. Whether this reflects fishing effort or changes in abundance of fish is not known because no catch and effort information was collected and there are no estimates of abundance for this species. The distribution of tagged/recaptured fish along the coast of NSW did not reflect the catch of the commercial fishery, although the numbers of fish tagged and recaptured each season were similar to the proportion of the commercial catch taken in each season (Table 5.4). Without catch and effort data, tagging data can only be used to provide an indication of distance and direction travelled, but these parameters can not be expressed in more quantitative terms.

**Table 5.4**. Percentage of commercial catch compared with percentage of fish tagged and recaptured as part of NSW Fisheries Gamefish Tagging program in each 1° band and season.

| | Commercial fishery | NSW Fisheries Gamefish Tagging program | |
|---|---|---|---|
| Area/ season | % of catch | % tagged | % recaptured |
| 28 | 2 | 4 | 3 |
| 29 | 3 | 1 | 1 |
| 30 | 7 | 22 | 36 |
| 31 | 10 | 6 | 6 |
| 32 | 10 | 9 | 9 |
| 33 | 10 | 19 | 15 |
| 34 | 29 | 14 | 12 |
| 35 | 8 | 7 | 5 |
| 36 | 19 | 10 | 6 |
| 37 | 1 | 1 | 1 |
| Summer | 38 | 45 | 46 |
| Autumn | 21 | 23 | 24 |
| Winter | 12 | 9 | 14 |
| Spring | 29 | 23 | 16 |

### 5.4.2. *Size of fish*

The majority of fish tagged and recaptured were between 400 and 700 mm TL, yet this species reaches a maximum size of 2000 mm. Only 28% of tagged fish and 41% of recaptured fish were above the current NSW legal size of 600 mm TL, although this size limit was only implemented in early 1990. Few very large fish were tagged and therefore it is important to note that the observed movement patterns are only for a subset of fish and may not be representative of the entire population (see also Table 5.5).

Results from the current study suggest that small fish (<700 mm TL or ≈620 mm FL) showed less movement than larger fish, but few fish over 1000 mm TL were tagged. In another study on *S. lalandi* off the Californian coast, small (<600 mm FL) and large (>900 mm FL) fish showed very little movement, whereas medium size fish (610-900 mm FL) travelled the greatest distances (Baxter 1960). Clearly, if the size range of fish that are tagged is limited then extrapolating to the entire size range, may be misleading (Table 5.5). It may be of value if future tagging studies could target very large fish.

### 5.4.3. *Recapture rates*

Tag-recovery information has traditionally been used to describe movement of fish in a qualitative way, largely because unequal tag-recovery rates from different areas confounds migration rates with tag-recovery rates (Schwarz and Arnason 1990). Results of tag-recovery experiments will therefore be affected by non-uniform distribution of fishing effort. Spatial and temporal variations in fishing effort have been consistently ignored or overlooked as factors that may influence patterns of recapture of tagged organisms (Sheridan and Melendez 1990). Areas without fishing effort will obviously have no recaptures and therefore recoveries per unit of fishing effort are often used rather than total recoveries (Hilborn 1990). Although it has been acknowledged that seldom are fishing effort data good enough to enable appropriate corrections to be made (Kearney 1988), tagging studies should start to incorporate catch and effort statistics into the overall design (Hilborn 1990; Sheridan and Melendez 1990). Whether differential recovery of kingfish among areas is related to fishing effort is not known and highlights the need to obtain such statistics.

The current study on movement of kingfish found that some areas had different recovery rates. Recapture rates of kingfish among areas may also reflect differential rates of tag loss, mortality of fish due to tagging and non-reporting of tag recoveries. These parameters are difficult to calculate because they are often confounded with fishing mortality, natural mortality and movement (Hilborn 1990). Some attempt could, however, be made to estimate tag loss by double tagging fish, although in a cooperative tagging program this may not provide meaningful data because of differences in the ability of taggers rather than true differences

**Table 5.5.** Dedicated versus co-operative tagging programs: the table lists scientific reasons for undertaking tagging programs and their assumptions. Problems associated with each type of tagging study and their assumptions are then listed in order to highlight operational differences.

| **Reason for tagging study** | **Assumptions** | **Dedicated tagging program** | **Co-operative tagging program** |
|---|---|---|---|
| Migration (and investigations of stock structure) | -Behaviour of tagged fish same as untagged fish<br>-Tagged fish fully mixed with mainstream population<br>-Pattern of recoveries represents pattern of distribution of tagged individuals<br>-Tagging representative of age/size structure<br>-Low incidence of non-reporting | -Effort can be spread evenly over entire study area<br>-Catch and effort statistics can be incorporated into design<br>-Effort can be devoted to tagging entire size range<br>-Rates of tag loss/mortality can be more easily estimated and controlled<br>-Experienced taggers<br>-Expensive in terms of time and cost | -Tagging effort may be difficult to control and uneven in space and time<br>-Recapture patterns influenced by uneven distribution of tagging effort<br>-Catch and effort information difficult to get making some analyses difficult<br>-Size range of fish tagged difficult to control<br>-Rates of tag loss and mortality of fish due to tagging very difficult to estimate, but known to vary among taggers<br>-Relatively low cost<br>-Large numbers of fish can be tagged |
| Growth | -Behaviour of tagged fish same as untagged fish<br>-Tag no impediment to growth<br>-Recoveries not influenced by size of fish<br>-Measurement errors are accounted for<br>-Recovery rate not influenced by growth rate | -Although measurements more accurate, still possibility of human error<br>-Possible to tag complete size range<br>-Taggers and recapturers experienced and careful | -Estimated rather than measured sizes and many people measuring means that measurement error more difficult to control<br>-Measurement error can be dealt with in some analyses (e.g. GROTAG) and outliers can be deleted if sample sizes are large<br>-Size range of fish tagged difficult to control<br>-Generally less care taken when measuring and tagging |

**Table 5.5. continued**

| Reason for tagging study | Assumptions | Dedicated tagging program | Co-operative tagging program |
|---|---|---|---|
| Mortality | -Tagged individuals uniformly represent the total population<br>-Recovery effort similar among age/size classes<br>-Tagging mortality similar among any strata<br>-Uniform fishing mortality over large area<br>-Low non-reporting among fishers<br>-Tag loss known | -Rates of tag loss/mortality more easily estimated<br>-Tagging mortality can be minimised by set up of tagging vessel<br>-Possibly better recapture rates through rewards | -Taggers have highly variable rates of tag loss/mortality<br>-Less care in tagging may lead to uncontrolled mortality |
| Stock size | -Recovery effort uniform and covers total population<br>-Emigration/immigration constant or known<br>-Total catch known<br>-Percentage of tags returned from recaptured tagged fish known and unbiased | -Under reporting of recaptured fish may be a problem but use specialised tags where amateurs not involved | -Catch and effort data needed<br>-Under reporting of tagged or recaptured fish a problem<br>-Recovery effort may not be uniform |
| Validation of ageing through tetracycline | -Date of tagging and recapture known | -Relatively high costs | -Probability of long-term recovery may be enhanced by large numbers of tagged fish |

among areas. Tag loss may be significant in kingfish, as a previous study noted that the tubular body of the tag was worn as early as one week after tagging and abrasion increased over time until the tag was broken (Pepperell 1990). Because such abrasion was noted almost exclusively in kingfish, Pepperell (1990) suggested that this species may rub against hard surfaces in an attempt to dislodge the tag.

Failure to report tag recoveries is often highlighted as a major problem in many tagging studies (e.g. Crossland 1976; Hunter *et al.* 1986; Trumble *et al.* 1990; Shimada and Kimura 1994). In a study on halibut, non-reporting of tags changed with geographic area and over time as the fishery changed and therefore could not be corrected (Trumble *et al.* 1990). Non-reporting of tags was estimated to be as high as 50% in one study and along with tag mortality and tag loss to sum to 66% in another study (Trumble *et al.* 1990; Shimada and Kimura 1994). Non-reporting of kingfish tags is known from anecdotes, but the level of nonreporting is not known. It may, however, be quite significant if differences between recreational and commercial fishery catches and the contribution of each to recaptures are correct (see below).

Recent recreational boat ramp surveys suggested that the estimated harvests of kingfish from large access locations were 53.0 (5.6 SE) tonnes for September 1993 to August 1994 and 35.8 (3.3 SE) tonnes for a similar period in 1994/95 (Steffe *et al.* 1996). By comparison, the commercial catch for NSW for the 1993/94 and 1994/95 financial years was 346 tonnes and 292 tonnes respectively. Our results suggested that 56% of kingfish were recaptured by recreational fishers and 36% by professionals. This suggests that a disproportionate number of tagged fish are recovered by recreational fishers. This discrepancy may be explained by a range of factors, including geographic differences in effort between commercial and recreational fishers, and/or non-reporting of tagged fist. A number of studies are now investigating the use of internal tags as an alternative to external tags in order to prevent the need to rely on voluntary returns and eliminate problems of non-reporting (Trumble *et al.* 1990). Internal tags must be put in by trained taggers and the catch must be surveyed. This is only likely to be feasible for commercial operations and relatively abundant species, therefore estimates of catch by recreational fishers will be unlikely.

Different taggers also had different recovery rates, which may be due to the effects of different tagging procedures among taggers. Poor tagging procedures are known to dramatically increase subsequent mortality (Schwarz and Arnason 1990). In one area (the 30° band), three of the most active taggers (recapture rates between 10 and 15% versus overall average of 8%)

tagged ≈50% of the recaptures from this area and therefore the recapture rate (12%) in this area may in part be a reflection of the influence of these few taggers.

Another factor contributing to both differences in recapture rate among areas and among fishers may be types of tag used. Ninety one percent of kingfish were tagged with the type A tag (nylon-headed spaghetti tag), but this tag has had various models, each of which had different recapture rates (Pepperell 1990). Although Pepperell (1990) lists factors that may confound comparisons among different types of tags, differences in recapture rate among types of tags may result from differences in tag loss and tagging-induced mortality.

Recovery rates vary among areas, among fishers and among types of tags used. All these factors may influence analyses of life history parameters and need to be accounted for. Without estimates of fishing effort, tag-related mortality and tag-loss, more quantitative analyses were not possible. These factors are not only likely to vary along the coast but may also vary among taggers, therefore it seems that cooperative tagging programs will not provide useful information for calculations of mortality etc. (Table 5.5).

### 5.4.4. *Missing tag information*

In 5.8% of recaptures (*n*=80), there was no original tagging information available because taggers had not returned tag cards. Assuming that these fish have similar recapture rates to other fish, this may equate to at least 1000 kingfish which were tagged and the tagging information was not returned. Similar problems have previously been reported (e.g. Crossland 1976; Saul and Holdsworth 1992). This incidence of non-return of tag cards was higher than that found in the New Zealand cooperative tagging program, where non-return of tag reports was 1.7% of recoveries (*n*=9; Saul and Holdsworth 1992).

### 5.4.5. *Movement of kingfish*

Long distance movements in either direction along the coast of NSW show the kingfish population is likely to be well mixed and that it is unlikely that more than one stock exists. A previous genetic study of kingfish from NSW suggested that there may be some subpopulation structuring but that this did not relate to different stocks along the coast (Smith *et al.* 1991). Further questions relating to stock separation may need to focus on other methods (e.g. otolith microchemistry, DNA analysis).

Some mixing of fish between Australian and New Zealand kingfish was found. Three fish tagged in NSW were recaptured in New Zealand and one fish tagged in New Zealand was recaptured in Australia (Saul and Holdsworth 1992). Interstate movements (between NSW and Queensland, and NSW and Victoria) also occur. Although one kingfish moved to Lord Howe Island, movements of fish to other island states in the Pacific have not been observed. This is may to reflect a lack of fishing effort in these areas. Results from a tagging study of a wide-ranging fish where fish are mostly tagged within Australia may bias overall patterns of movement. If tagging also occurred throughout the Pacific, movement along the coast of Australia may not be the predominant pattern. For example, when only skipjack tuna tag and recovery data collected by Japan were analysed, patterns of movement were defined differently than when data from two other data sets (South Pacific Commission and Inter-American Tropical Tuna Commission) were also included (Hunter *et al.* 1986). However, less common movements, such as the three fish moving to New Zealand, may not be detected unless large numbers of fish are tagged over many years. In such instances cooperative tagging programs may be the only way to detect these fish.

### 5.4.6. *Cooperative versus dedicated tagging programs*

The NSW Gamefish Tagging Program has tagged, on average, more than 500 kingfish per year for 20 years. Recovered kingfish from this program have provided information on movement and growth. There are, however, limits to the type of information that can further be derived from the program without changes in emphasis. For example, in the absence of effort data, the program will not allow analyses to be done on the relative proportions of kingfish that move to and from areas of particular interest. In the analyses presented in the present study, the observed patterns of movement may better reflect patterns of fishing effort than the movement of kingfish.

Periodic reviews of programs are necessary to ensure that they remain cost effective and maximise the amount of information recovered. The present program may be enhanced by such a review, particularly with respect to focusing on the spatial and temporal distribution of fishing effort by recreational taggers. Further gains may be made by focusing on tagging/measuring techniques (see Table 5.5). Cooperative tagging programs have relatively low costs and offer the prospect of movement and growth data across a wide range of species. Dedicated tagging programs by research institutions are more expensive but offer greater prospect of more accurate size estimates and a clearer focus on the questions to be asked of the program, and the capacity of the data collection scheme to provide those answers. The relative merits and cost-benefits of cooperative vs. dedicated tagging programs may be worthy of more study.

# 6. Recommendations and implications

## 6.1. Benefits

Estimation of the reliability of ageing methods is critical to any subsequent stock assessment. This project has identified potentially useful structures for ageing kingfish and eliminated a structure that is not useful. The reliability of estimates of ages will need to be validated. The recognition of structures that may be used in ageing will benefit all states and countries that have kingfish fisheries. In NSW, this project will provide information for an assessment of appropriate management actions.

## 6.2. Intellectual property and valuable information

There is no economic value arising from this project. The information is however relevant to other researchers studying kingfish.

## 6.3. Further development

Before the ageing methods can be fully utilised additional research is needed to validate all age classes and to better determine the position of the first increment. Further should focus on improving our understanding of the size and age composition of the harvest by all sectors of the fishery. A proposal to address some of these issues is currently under consideration by FRDC.

## 6.4. Staff

| | |
|---|---|
| Bronwyn Gillanders | Senior Technical Officer |
| Doug Ferrell | Principal Investigator |
| Neil Andrew | Principal Investigator |
| Norm Lenehan | Temporary Assistant (Cronulla) |
| Martin Tucker | Temporary Assistant (Forster) |

## 6.5. Final cost

| FRDC | |
|---|---|
| Salaries | $58,619 |
| Operations | $8,769 |
| Capital | nil |
| **Total** | **$67,388** |

| NSW Fisheries | |
|---|---|
| Salaries | $9,079 |
| Operations | $6,000 |
| Capital | $54,000 |
| **Total** | **$69,079** |

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# Appendix A. Tetracycline validation of kingfish kept in aquaria

## Introduction

Assessing accuracy of age determination methods is important in fisheries science because incorrect age estimates can lead to errors in mortality and longevity resulting in over/under harvesting of fish stocks (Beamish and McFarlane 1983). A number of methods exist for assessing accuracy including examining fish of known age, mark-recapture techniques, analysis of length frequency modes, monitoring of strong year classes, examination of the edge of a structure, comparison of back-calculated lengths with observed lengths of the corresponding age groups, growth analysis, and comparisons among different techniques (Beamish and McFarlane 1983). Many of these methods are, however, only suitable for the period of initial faster growth.

Two methods were used to assess the accuracy of estimates of age in kingfish. The first method attempted to determine when zones were formed by measuring marginal increments and has been reported in Chapter 3. Fish were also marked with tetracycline, which is metabolised and deposited on the growing surface of bone, thus forming a time-marker within the structure. By allowing the fish to remain at large in a tetracycline-free environment, the new growth can be interpreted relative to the time of year of treatment and recapture and the period between these events (Fowler and Doherty 1992). Whilst this latter method can be used to validate the ages of older fish, only one size class of fish were used in the present study.

## Materials and Methods

Fish were obtained from a fish trap in the Sydney region, measured (FL, TL), injected with tetracycline (equivalent to 50 mg kg$^{-1}$ body weight) and tagged with a numbered dart tag. The concentration of tetracycline was 50 mg tetracycline mL$^{-1}$ sterile saline. All fish were transported to the Sydney Harbour Aquarium where they were held in an outdoor 7000 litre tank for between 2 and 10 months. All structures were processed as described in Chapter 3.

With the exception of otoliths (see below), all structures were first read under a compound microscope using reflected light. The distance from the focus or centre of the structure to each zone and to the edge of the structure was measured from video images on a computer screen using image processing software. Structures from experimental fish were mixed with approximately 30 fish of similar size so that it was not known whether the structure being viewed was from one of the experimental fish (but see below). Structures from experimental fish were then viewed under a microscope with ultraviolet light and the position of the tetracycline mark noted; the distance from the mark to the edge of the structure was also measured along the same axis as measurements under reflected light. Comparison of fluorescent and light microscope images, therefore, enabled the position of the tetracycline mark to be related to the position of opaque and translucent zones. Otoliths were viewed under ultraviolet light and then under reflected light because burning destroys the tetracycline mark (see McFarlane and Beamish 1995). Because a similar alignment between ultraviolet light and reflected light images was needed, otoliths could not be read blind. For vertebrae, the tetracycline could not easily be seen after staining and therefore the unstained half of the vertebrae was used to determine the position of the tetracycline. It should also be noted that for dorsal spines of all tetracyclined fish, the position of the tetracycline mark could easily be seen under reflected light.

## Results

Fish ranged in size from 490 to 540 mm FL at tagging (*n*=15). Fish in captivity for two months were similar in size to those at tagging (range 488 to 535 mm FL, *n*=6). Otoliths and dorsal spines showed a tetracycline mark close to the edge of the structure indicating that tetracycline had been successfully incorporated. In vertebrae, the tetracycline had been incorporated into the whole structure and not just the edge. A tetracycline mark could not be seen in scales of fish collected after two months.

Fish in captivity for 10 months ranged in size from 650 to 725 mm FL indicating growth of between 145 and 200 mm (*n*=5). Tetracycline marks were seen in dorsal spines, otoliths and scales. Because the tetracycline was incorporated into all the vertebrae that existed at the time of injection, the position of the tetracycline mark was taken as the outermost part in which tetracycline existed.

With the exception of dorsal spines, structures from most fish showed that one zone was laid down per year (Fig. 1). Scales of one fish and vertebrae from one fish suggested that no zone had formed since tetracycline incorporation and for otoliths of one fish there was a zone immediately outside the tetracycline mark and another zone further towards the edge of the otolith. The position of zones for dorsal spines did not appear to be related to annuli with three fish showing two zones outside the tetracycline mark (Fig. 1).

## Discussion

Our findings suggest that for otoliths, scales and vertebrae it is most probable that zones form once a year and therefore can be considered as annuli. This interpretation does not appear possible for dorsal spines. It should, however, be noted that only one size/age class of fish was investigated and therefore before the methods can be considered validated all size classes of fish should be investigated (Beamish and McFarlane 1983). Initial results from tetracycline incorporation add further evidence to suggest that ageing is possible in kingfish.

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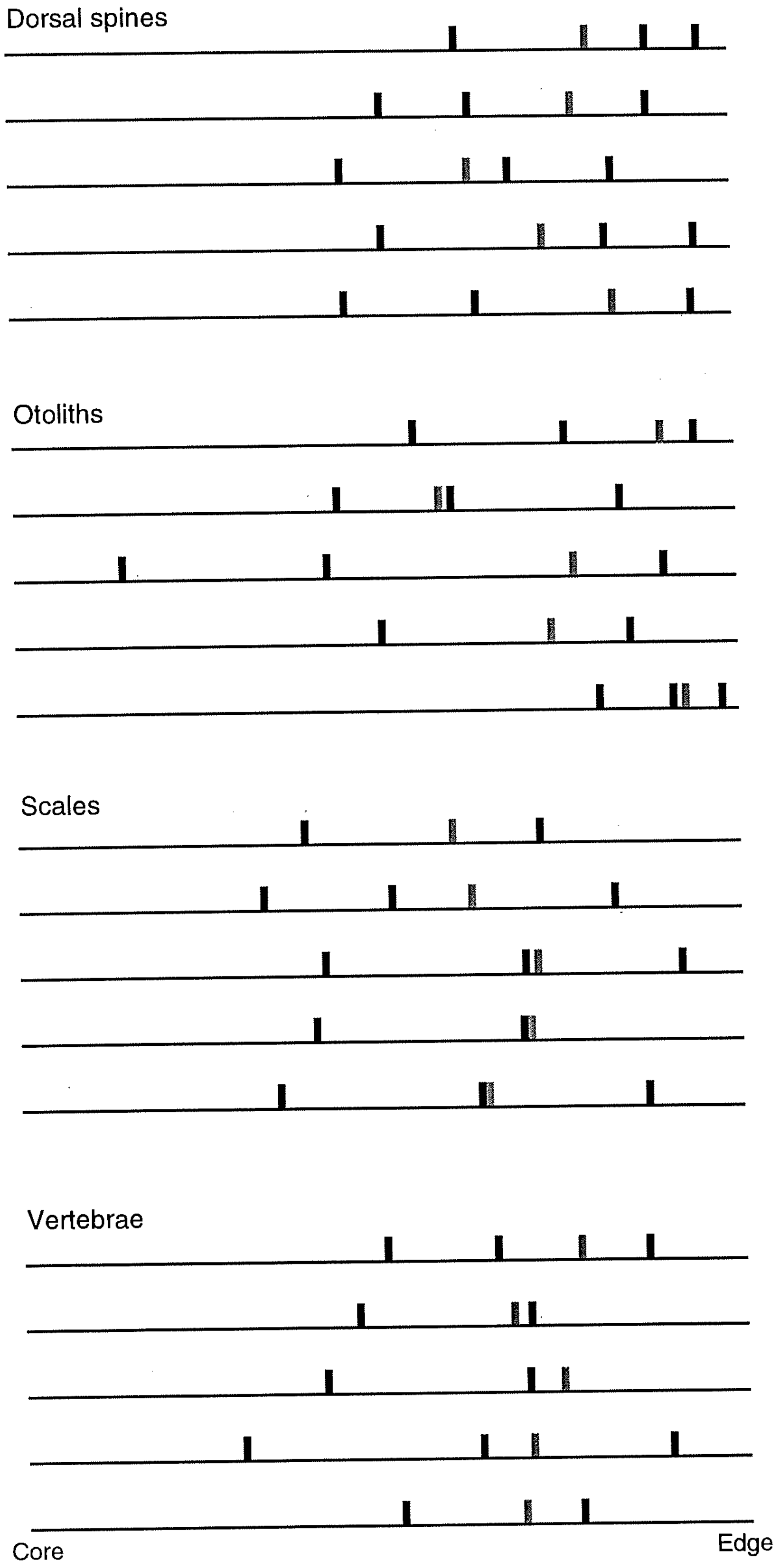

**Figure 1.** Relative position of each growth zone (solid bars) and of the tetracycline mark (hatched bars) for each structure used for ageing kingfish. Fish were at large 10 months. Horizontal bars represent individual fish (*n*=5); the order of fish is the same for each structure.