Department of Conservation and Natural Resources
Victorian Fisheries Research Institute

Development of Methods to Age Commercially Important Dories and Oreos

Final Report
to
Fisheries Research & Development Corporation
Project 91/36

David C. Smith and Bryce D. Stewart

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MARINE SCIENCE LABORATORIES

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Summary

Four species of dories (Family: Zeidae) and five species of oreos (Family: Oreosomatidae) are caught in the South East Fishery (SEF). John dory and mirror dory are included in the SEF quota sytem with Total Allowable Catches (TACs), in 1993, of 240 t and 800 t, respectively. Oreos, originally a by-catch of the orange roughy fishery, have become an increasing component of the deep-water trawl fishery with estimated landings in excess of 2000 t in 1992. Assessment of these species proved difficult because methods to age them needed to be developed: basic life history parameters such as longevity and growth were unknown. In this report methods to age dories and oreos are described and preliminary growth curves presented.

Three species of dories were considered; John dory (*Zeus faber*), mirror dory (*Zenopsis nebulosus*) and king dory (*Cyttus traversi*). The fourth species, silver dory (*C. australis*), is a low value by-catch species. Four oreo species were considered; smooth (*Pseudocyttus maculatus*), black (*Allocyttus niger*), warty (*A. verrucosus*), and spiky (*Neocyttus rhomboidalis*). The fifth species, ox-eye oreo (*Oreosoma atlanticum*) is rarely caught.

A total of about 3,500 readings were made from 1700 pairs of sagittal otoliths. Otoliths were examined whole, using a variation of the "broken and burnt" method and in section. Otolith growth, for each species, was determined from measuring otolith morphometrics and otolith weight. This was also used in the evaluation of age estimates and identification of errors. Intra- and inter reader variability were examined using Beamish and Fournier's Index of Average Percent Error and regressions of age estimates were used to determine whether there was bias between readers. Von Bertalanffy growth curves were fitted to individual observations using non-linear least squares.

For John and mirror dory, ages were estimated from counting annuli on the surface of whole otoliths. King dory otoliths were examined whole for fish less than 20cm and in section for larger fish. For the oreos, tranverse sectioning and subsequent grinding to a thickness of approximately 0.2mm revealed annuli which provided age estimates for a range of fish sizes.

Partial validation was possible for some species. Age estimates for juvenile John dory and king dory were consistent with the available length-frequency data. However, age estimates for adults of these species and for adult and juvenile mirror dory require validation. Our estimates for warty oreo gave similar results to radiometric analysis of whole otoliths. The maximum age from otolith sections was 130 years for a female fish of 36.5 cm TL compared to maximum ages of 130-170 for fish of length 34-35 cm from radiometric analyses. Because the morphology and incremental structure of oreo otoliths is similar between species, these results suggest our interpretation of the other species is also correct. The first 4 to 5 annuli seen in sectioned oreo otoliths are very broad after which there is distinct transition to much narrower annuli. This appears to be consistent with the change from a pelagic to demersal habitat previously reported for oreos.

Age estimates for each species were highly repeatable. Intra- and inter- reader variablity was low and there was no significant bias between readers. The growth of all species was adequately described by the von Bertalanffy growth curve (Table 1). Results for each species are summarised in Table 1. John dory and mirror dory appear to be relatively short-lived and fast growing while king dory are more slow growing. Our results indicate that oreos are extremely slow growing and long-lived. Similar results, for oreos, have been reported recently from studies in New Zealand.

In summary, the main objectives of the project have been met and our results will be of considerable use to future assessments of these species. For the oreos, they have important implications for management of the fishery.

Table 1. Estimated age-at-maturity, maximum age and von Bertalanffy growth parameters for dories and oreos.

Species	Age at Maturity (yr)	Maximum Age (yr)	Von Bertalanffy parameters		
			K	Linf	to
Dories					
John	3-5	12	0.15	53.20	-1.00
Mirror	5	12	0.20	60.94	0.18
King	10-15	38	0.10	51.36	-0.83
Oreos					
Black	20	100	0.052	41.10	-10.30
Smooth	20-25	78	0.051	50.94	1.05
Warty	25-30	130	0.056	31.73	-3.40
Spiky	30-35	128	0.051	36.16	-1.69

Note: ages at maturity are estimated from reported lengths-at-maturity.

Introduction

Four species of dories (Family: Zeidae) and five species of oreos (Family: Oreosomatidae) are caught in the South East Fishery (SEF). John dory and mirror dory are included in the SEF quota sytem with Total Allowable Catches (TACs), in 1993, of 240 t and 800 t, respectively.

Oreos are caught in deepwater (> 600m). Originally a by-catch of orange roughy fishing, they are becoming an increasingly important component of the deepwater trawl fishery with estimated landings of over 3000 t in 1992. Five species of oreo are found in the SEF; smooth (*Pseudocyttus maculatus*), black (*Allocyttus niger*), warty (*A. verrucosus*), and spiky (*Neocyttus rhomboidalis*) are common. The fifth species, ox-eye oreo (*Oreosoma atlanticum*) is rarely caught.

Assessment of these species proved difficult because methods to age them needed to be developed. This was noted by the Demersal and Pelagic Fish Research Group at their meeting in Queenscliff in May 1990 (DPFRG 29). Basic life history parameters such as longevity and growth were unknown.

The *Development of Methods to Age Commercially Important Dories and Oreos* was an 18 month FIRDC funded research project. The original application is shown in Appendix 1.

The objectives of the project were:

1. To develop methods for ageing dories and oreos using hard parts.
2. To validate assigned ages of juveniles by analysing poly-modal length frequency distributions

In this report methods to age dories and oreos are described and preliminary growth curves presented. This report extends on the three previous progress reports (Stewart and Smith, 1992a and b, 1993), and summarises all results.

Methods

Species examined

Dories:

King dory, *Cyttus traversi*
Mirror dory, *Zenopsis nebulosus*
John dory, *Zeus faber*

Oreos:

Smooth oreo, *Pseudocyttus maculatus*
Black oreo, *Allocyttus niger*
Warty oreo, *Allocyttus verrucosus*
Spiky oreo, *Neocyttus rhomboidalis*

Sample collection

Sagittal otoliths were examined from all species. The majority of the John and mirror dory were sampled at the Sydney Fish Market. Additional John dory were supplied by CSIRO from samples taken during surveys of eastern Bass Strait. The remainder of the mirror dory, some of the smooth oreo and all of the spiky and warty oreo samples were taken during surveys of western Bass Strait, 1987-1990. The majority of the smooth oreo and all of the black oreo samples were sampled from commercial catches off southern Tasmania by the Tasmanian Department of Sea Fisheries.

Age determination

Whole Otoliths

Whole sagittal otoliths from all species were examined under a dissecting microscope using reflected light at magnifications from 6.4 to 50 times. All otoliths were immersed in water and viewed against a black background. Translucent zones were counted.

Breaking and Burning

Warty oreo and mirror dory otoliths were also examined using two variations of the "Breaking and Burning" technique (Christensen 1964). Initially, the right otoliths from five specimens of each species were cut in half transversely and then the cut face was baked on a hot plate until the otoliths were a light brown colour. Otoliths were then mounted in plasticine and viewed under immersion oil for the presence of increments. For comparison, the left otoliths were also baked whole and then mounted in resin (as for sectioning) before being cut in half and viewed for increments.

Sectioning

Otoliths from all species were sectioned transversely by mounting them in a block of clear polyester resin, generally lined up in two rows, with five otoliths in each row. After sufficient time for curing, sections were taken using a Gemmasta circular saw fitted with a diamond impregnated blade of 0.15 mm thickness. Using this procedure up to 5 otoliths were included in each section. Several sections were taken of each row to ensure the primordia of each otolith was included. Sections were then mounted on slides with polyester resin and ground down on wet and dry paper (400 grade followed by 800 grade) to a thickness of approximately 0.1-0.2 mm

Initially, sections containing all five otoliths were mounted and these were ground down as a whole. Best results were obtained, however, by cutting off each otolith from the section and then mounting it individually to grind it down. Once sections were judged to be of satisfactory quality a coverslip was mounted on the slide to produce a permanent preparation.

Otolith morphometrics

In many species, otoliths have been shown to cease growing in length and width in older, larger fish, but continue to grow in depth and weight. In these species, examination of whole otoliths only can lead to a significant underestimation of age. To determine the nature of otolith growth, otolith morphometrics were measured for each species. Otolith length, width and depth was measured to the nearest micrometre using a customised "Optimas" image analysis system and otolith weight was measured to the nearest microgram. Measurements were taken on both left and right otoliths if they were present and the mean was calculated. Otherwise, measurements were taken on whichever otolith was available.

Bias and Precision

To ensure age estimates were as objective as possible, otoliths were read without any reference to biological information i.e., the size or sex of the fish, and without any scale markings on the image to indicate the size of the otolith.

During the process of developing consistent interpretations of the incremental structure of otoliths, samples were read up to three times. Repeated readings were undertaken with no reference to previous ones.

A random sub-sample, chosen to cover a range of estimated ages and also difficulty of interpretation, was read twice by the primary reader and also by a secondary reader to enable estimates of inter- and intra-reader variability to be calculated. The average percent error was calculated (Beamish and Fournier 1981) to estimate precision and the slope of a linear regression between reader ages was compared to 1 to determine if there was any bias.

Validation

Validation is a critical component of age determination studies (Beamish and McFarlane 1983), yet the hardest to achieve. In this study only partial validation was possible.

The age estimates for juveniles of each species were compared to the available length frequency distributions to determine whether these were consistent. Warty oreo age estimates were validated by comparison with age determined by radiometric analysis (Stewart et al., in press).

Growth

Preliminary Von Bertalanffy growth curves were fitted to individual observations by standard nonlinear estimation procedures using the SAS System. Curves were fitted to combined sexes in all cases to maximise the sample size.

Results:

Overall, a total of about 3,500 individual readings were made from 1700 pairs of sagittal otoliths.

In the following description of results for each species, although increments are not fully validated, the term "age" is used for brevity.

Dories

1. King dory

King dory otoliths consist of an irregular ventral lobe separated by a narrow band, at the primordium, from a regular dorsal lobe (Figure 1.1). King dory otoliths were the easiest to read of all the species examined and generally only 1 or 2 interpretations of age were apparent from either whole or sectioned otoliths. All age estimates from whole otoliths were based on increments counted from the primordium along the dorsal lobe. Of the 236 whole otoliths examined, age estimates could be determined from 189. Assigned ages ranged from 1 year for an immature fish of 10.0 cm total length (TL) to 32 years for a female fish of 53.6 cm.

Age estimates from sections, on the other hand, were based on increments counted from the primordium to the medial edge (Figure 1.2). Of the 236 sections prepared, age estimates could be obtained from 167. Age estimates ranged from 4 years for a male fish of 17.5 cm to 38 years for a female fish of 48.4 cm.

Whole otoliths were generally clearer for smaller, younger fish, while sectioned otoliths were clearer for larger, older fish. Sectioned otoliths from small fish were often impossible to interpret due to the presence of numerous fine rings, making it difficult to compare results directly. For large fish, age estimated from sectioned otoliths was generally slightly higher than that from whole otoliths. On the basis of these observations it was decided to use age estimates from whole otoliths for fish up to 20 cm TL and sectioned otoliths for larger fish.

The relationships between otolith length, width and depth, and fish length were fairly similar (Figure 1.3). For the size range of fish examined, otolith growth was linear with fish length.

The relationships between otolith length, width and depth, and age were also similar (Figure 1.4). For the first ten years otoliths grow more rapidly but then slow down considerably in length and width but not depth. Even in the oldest fish, however, otoliths continue growing slowly in all dimensions.

Otolith weight was plotted against fish length and sectioned age estimates (Figure 1.5). There is a curvilinear increase of otolith weight with fish length but a linear relationship (R^2=0.772) between otolith weight and age.

Overall, these results indicate that as king dory increase in size and age, otoliths continue to grow in weight, but growth in other dimensions slows. The reduction of growth in otolith length and width, however, is not sufficient to account for the differences in counts between preparations. This difference is due to the clarity of preparations because, for large fish, sectioned otoliths are easier to interpret than whole otoliths, particularly at the margin.

Beamish and Fournier's (1981) method gave low intra- and inter-reader variability of 3.7%. The slope of the regression between the two readers was not significantly different from 1 (t=0.37, df=48, ns).

The smallest size of fish taken by trawlers off south-eastern Australia is 8-10cm (Smith and Stewart in prep). In fish of this size only one increment is visible.

The relationship between fish length and age by sex is shown in Figure 1.6 and all fish combined in Figure 1.7. Females grow substantially faster than males and reach a greater maximum size. The von Bertalanffy growth parameters for all fish were:

L_{inf}=51.36; K=0.10; t_o=-0.83

Smith and Stewart (in prep) show that king dory reach sexual maturity between 35 cm and 40 cm in length. From our results this corresponds to between 10 and 15 years of age.

2. John and Mirror dory

John and mirror dory otoliths are very small and propeller-like in shape, consisting of 3 distinct lobes: 2 smaller ventral lobes and 1 larger dorsal lobe (Figure 2.1). Otoliths from these species were the most difficult to intepret. Age estimates from whole otoliths were again taken along the dorsal lobe, although increments were often visible along the ventral lobes.

Whole otoliths from small John dory (< 25 cm) were difficult to age to the presence of numerous fine increments. Grouping of these increments was necessary to obtain realistic age estimates. In larger fish, however, the incremental pattern was clear throughout the otoliths.

Mirror dory otoliths were also examined in section but results were poor. There were a large number of increments visible in most sectioned otoliths, several interpretations were possible for each section and repeated counts varied considerably. The small size of otoliths also meant that sectioning and subsequent grinding required extreme care. In addition, neither variation of the "Breaking and burning" technique was successful in improving clarity.

For these reasons (and the pattern of otolith growth - see below) whole otoliths are regarded as more suitable for age determination than sectioned otoliths and whole otoliths were read for both species. Of the 195 whole John dory otoliths examined, age estimates could be determined from 167 and for mirror dory age estimates could be obtained from 155 of the 178 whole otoliths examined.

Age estimates for John dory ranged from less than 1 (ie no increments visible) for an immature fish of 9 cm to 12 years for a female fish 50.8 cm in length.. For mirror dory estimates ranged from 3 years for a male fish of 25.0 cm to 12 years for a female fish of 63.6 cm.

The pattern of otolith growth supports the of use whole otoliths for age determination in both species. There are linear relationships between otolith length, width and depth with fish length in both species (Figure 2.2 & 2.3). John dory otoliths grow very rapidly in length, width and depth during the first year and then growth slows down considerably, but still continues even the oldest fish (Figure 2.4). We could not obtain samples from very young mirror dory but otolith growth showed a similar pattern to John dory, particularly in otolith length and width (Figure 2.5).

For both species, growth in otolith weight is slightly curvilinear with fish length but linear with age (Figure 2.6 & 2.7). Again, based on these results it was decided whole otoliths were suitable for all age determination.

Precision estimates were 5.7% and 7.4% for John and mirror dory, respectively.

For John dory, the observed ages for the first three years are consistent with the modes in the length frequency distribution of juveniles (Figure 2.8).

Female John dory appear to grow slightly faster than males and reach a greater maximum size (Figure 2.9). Parameters of the von Bertalanffy growth curve (Figure 2.10a) for combined sexes are:

L_{inf}=53.20; K=0.15; t_o=-1.00

Only a low number of male mirror dory were sampled and thus a comparison of growth between the sexes was not possible. Similarly to John dory, the growth curve for mirror dory, derived from our samples (Figure 2.10b) does not reach an asymptote. Parameters of the von Bertalanffy growth curve for mirror dory are:

L_{inf}=60.94; K=0.20; t_o= 0.18

Hore (1982) reports that in New Zealand 50% of female John dory are sexually mature at 31.5 cm while males mature between 23 cm and 28 cm in length. From our results this corresponds to an age of 4 to 5 years for females and 3 years for males.

Off the southern Australian coast, female mirror dory reach sexual maturity at 40 cm and males at 34 cm (Rowling, unpubl. data). This corresponds to an age of approximately 5 years.

Oreos

Oreo otoliths are similar in shape to king dory otoliths and morphology is consistent for all four species. Age estimates from whole oreo otoliths were generally only possible from fish below 25 cm in length and confidence in these estimates was low. Whole otoliths from larger fish were normally only clear at the edge and it was often difficult to distinguish between what at this stage were presumed to be annual increments, and other structures. Breaking and burning of warty oreo otoliths was also of limited use as although numerous fine increments became visible at the edge of otoliths, the centres were impossible to interpret. It was concluded that examination of either whole or broken and burnt sagittal otoliths was not suitable for age determination. Consequently, all oreo age estimates were based on sectioned otoliths. Increments were counted from the primordium to the medial edge, or in some cases, along the dorsal lobe .

3 Warty Oreo

Age determination of warty oreo and validation by radiometric analyses are described by Stewart et al. (In press). The abstract is given below and the paper appended (Appendix 2).

Stewart, B.D., G.E., Fenton, Smith, D.C. and S.A. Short. Validation of otolith increment age estimates for a deepwater fish species, warty oreo, *Allocyttus verrucosus*, by radiometric analysis. Marine Biology (In press)

Otolith increment age estimates for a deepwater species, warty oreo, *Allocyttus verrucosus*, were validated by comparison with the results from ^{210}Pb / ^{226}Ra radiometric analysis. Transverse sectioning and subsequent grinding of otoliths to a thickness of approximately 0.2 mm revealed increments which provided age estimates for a range of fish sizes. Age estimates ranged from 7 years for an immature fish of 15.2 cm TL to 130 years for a female fish of 36.5 cm TL. Age at maturity was estimated at 24 years for males and 28 years for females. In comparison, radiometric analysis of whole otoliths, using a linear otolith mass growth rate, calculated maximum ages of 130-170 years for fish of length 34-35 cm. Radiometric ages were also calculated using a two-stage otolith mass growth rate model in which the growth rate was assumed to slow after maturity to 90 % of the pre-maturity rate. This reduces the maximum age to 118 years for a mean fish length of 34.5 cm. Age at maturity for females was estimated at 34.3 years. The similarity between age estimates from otolith increment counts and radiometric analysis strongly supports the accuracy of results

from both methods and encourages further use of such comparisons as an alternative validation technique.

4. Smooth oreo

Smooth oreo otoliths are smaller than other oreo otoliths and gave the lowest maximum age. The first 5 to 6 increments visible in sectioned otoliths are quite broad and these gradually narrow, in old fish, to very fine regular increments at the edge. (Figure 4.1). Of 276 sectioned smooth oreo otoliths prepared, age estimates could be obtained from 131. Failure to gain age estimates was due mainly to a large number of unsuccessful preparations. Assigned ages ranged from 7 years for a male fish of 18.1 cm to 78 years for a female fish of 54.0 cm.

There were linear relationships between otolith length, width and depth, and fish length for smooth oreo (Figure 4.2). The pattern of otolith growth with age, however, depends on the dimensions measured (Figure 4.3). Otolith length grows rapidly for the first 10 years and then slows down, but does not cease completely. Growth in otolith width, on the other hand, follows an asymptotic pattern and virtually stops in fish older than 50 years. Growth in otolith depth is rapid initially and then slows, but continues linearly. Otolith weight is a curvilinear function of fish length and there is a linear relationship between otolith weight and age (Figure 4.4).

The average percent error (Beamish and Fournier 1981) method for within and between readers was 4.18% and 3.80% respectively. The slope of the regression between the two readers was not significantly different from 1 (t=1.215, df=45, ns).

Females grow more quickly and reach a greater maximum size and age than males (Figure 4.5). The relationship between fish length and sectioned age the sexes combined is given in Figure 4.6. Parameters of the von Bertalanffy growth curve are:

L_{inf}=50.94; K=0.051; t_0=-1.05

Lyle et al (1992) reports that in Tasmanian waters female smooth oreo mature at about 41 cm and males at 32 cm. From our age estimates this corresponds to ages of approximately 25 and 20 years respectively.

5. Black oreo

In black oreo otoliths the first 4 to 5 increments are very broad and distinct and these are followed by a rapid transition to narrower increments (Figure 5.1). Of the 174 sectioned otoliths prepared, age estimates could be obtained from 127. Assigned ages ranged from 8 years for a female fish of 28.1 cm to 100 years for a female fish of 43.5 cm.

There were linear relationships between otolith length and width with fish length (Figure 5.2). However, the relationship between otolith depth and fish length is curvilinear. Growth of otolith length and width with age is also curvilinear (Figure

5.3), while there is a linear relationship between otolith depth and age. Otolith weight is a curvilinear function of fish length but linear with sectioned age (Figure 5.4). Black oreo otoliths appear to grow predominantly in depth and weight in old fish.

Beamish and Fournier's (1981) method gave low intra- and inter-reader variability of 4.41 and 4.43, respectively. The slope of the regression between the two readers was not significantly different from 1 ($t=1.251$, $df=48$, ns).

The relationship between fish length and sectioned age is shown by sex in Figure 5.5 and all fish combined in Figure 5.6. Black oreo appear to grow very quickly for the first 10 years and then slow down dramatically. There is no noticeable difference between the growth rates of males and females. Parameters of the von Bertalanffy growth curve for the sexes combined are:

$L_{inf}=41.10$; $K=0.052$; $t_o=-10.03$

Lyle et al. (1992), states that male black oreo mature at approximately 33 cm and females at 36 cm. From our age estimates this corresponds to an age of approximately 20 years.

6. Spiky oreo

Sectioned spiky oreo otoliths were the clearest of all the oreo species examined. The pattern of increment deposition was very similar to that of warty oreo (Figure 6.1). Of the 154 sectioned otoliths prepared, age estimates could be gained from 106. Age estimates ranged from 4 years for an immature fish of 9.9 cm to 128 years for a female fish of 40.1 cm.

Otolith growth followed the typical pattern for oreos. There is a linear relationship between otolith length and width, with fish length and a curvilinear relationship between otolith depth and fish length (Figure 6.2). The relationship between otolith length and width is asymptotic with age, while growth in otolith depth is very rapid for the first 5 years after which it changes to a slower, more constant rate (Figure 6.3). There is a striking increase in otolith weight in fish greater than about 35 cm TL but there is a linear relationship between otolith weight and sectioned age (Figure 6.4).

Beamish and Fournier's (1981) method gave low intra- and inter-reader variability of 3.69% and 3.65% respectively. However, the slope (0.95, SE 0.018) of the regression between the two readers was significantly different from 1 ($t=2.889$, $df=48$, $p<0.05$). The second reader aged younger fish slightly higher than the primary reader.

Females appear to grow slightly faster than males and to reach a greater size (Figure 7.5). Parameters of the von Bertalanffy growth curve for combined sexes (Figure 7.6) are:

$L_{inf}=36.16$; $K=0.051$; $t_o=-1.69$

Lyle and Smith (in prep) found greater than 50% of male spiky oreos were sexually mature at 29 cm, and greater than 50 % of females at 34 cm. From our results, this corresponds to ages of approximately 30 to 35 years.

Discussion

Overall, the project has been successful. Methods have been developed to age all the dory and oreo species in Australian waters of significant commercially importance or potential. In addition, otolith growth has been examined and preliminary growth curves have been constructed. For the oreo species, in particular, this was previously thought to be impossible. Partial validation was possible for some species. Age estimates for juvenile John dory and king dory were consistent with the available length-frequency data. However, age estimates for adults of these species and and for adult and juvenile mirror dory require validation. Our estimates for warty oreo gave similar results to radiometric analysis of whole otoliths (Stewart et al., in press). Now that methods for age estimation have been developed, specific sampling of juvenile fish could be carried out to enable further validation via length frequency and marginal increment analysis.

No previous studies have been undertaken to determine age and growth of king dory. A survey by the Tasmanian Department of Sea Fisheries (Lyle, unpubl. data) found that off southern Australia there appears to be an influx of juvenile king dory (8 to 10 cm) in catches during winter. Our observations indicate that the first increment visible in king dory otoliths appears at a fish length of approximately 10 cm. As king dory spawn during late-summer and autumn (Smith and Stewart in prep) this supports our interpretation that the first increment corresponds to the first year.

There has only been one previous study, (Parin et al. 1988), investigating age and growth of mirror dory. Although sample sizes was very small (only six fish were examined), their results were similar to ours, indicating a maximum life-span of at least 13 years for a female fish of 48 cm, with individuals growing 13 to 14 cm in the first year and 2 to 4 cm per year in subsequent years.

There has also only been one previous study (Hore 1982), examining the age and growth of John dory. Age estimates were also based on whole otoliths and indicated that in New Zealand waters John dory grow rapidly and are short lived. Maximum ages recorded were 9 years for females and 7 years for males. Length frequencies were examined and marginal increment analysis was carried out to validate age estimates for juveniles. These age estimates are very similar to our results which also indicated rapid growth and a maximum age of 12 years for females and 7 years for males. The small differences between the studies could be due to either real differences between populations or different interpretation of increments. It is possible that John dory live longer than our study recorded as they are known to reach a maximum length of at least 75 cm (Hutchins and Swainston 1986), considerably longer than the largest fish we obtained (51 cm TL).

There have been relatively few age and growth studies on the oreo species. Davies et al. (1988), investigated the suitability of otoliths from smooth and black oreos by examining whole, thinly sectioned (about 20 um) otoliths and by using acetate peels under scanning electron microscopy. They were unable to determine ages, a fact they attributed to the complexity of the crystal morphology of the otoliths. This is in stark contrast to our study which successfully obtained age estimates for both of the above species from sectioned otoliths. Our sections were considerably thicker, ranging from 100 to 200 um, so it appears that either incremental detail is lost in thinner sections or very high magnifications are inappropriate for age determination.

More recently, however, Annala (1992) reported that preliminary, unvalidated age estimates from sectioned otoliths suggest that smooth and black oreo from New Zealand are long-lived, slow growing species. For smooth oreo age at maturity was stated as 20 to 30 years, very similar to our estimates, and maximum age at greater than 40 years. For black oreo age at maturity was given as 15 to 20 years, again very similar to our estimates and maximum age again in excess of 40 years. The greater maximum ages we observed may be due to either differences in interpretation of increments or real differences between populations. In New Zealand a major trawl fishery has existed for smooth and black oreos since the late 1970s and catches have remained fairly constant over this time at around 20 000 tonnes per year (Lyle et al. 1992). This prolonged utilisation may have removed many of the older fish from the New Zealand populations.

Annala (1992) also reported a pelagic juvenile phase of 4 to 5 years for both smooth and black oreo. Examination of the otolith sections from all the oreo species in our study revealed a distinct change in increment width and appearance after the first 4 to 5 years. This appears to correlate with the transition from the pelagic juvenile phase to the demersal adult phase which occurs in all oreo species at a fish length of approximately 10 cm (James et al. 1988). Fish are also known to undergo a substantial change in body form during this transition. Several other studies have also reported changes in otolith increment width and appearance with transitions in life history (Victor 1982, 1986; Fowler 1989; May and Jenkins 1992), and environment (Campana 1984; Nielson and Geen 1985).

Several previous studies have attempted to age warty oreo. The first study by Mel'nikov (1982), estimated age using growth zones on the scales since the zones were claimed to be more clearly defined than on otoliths. The maximum age stated was 15 years for females and 14 years for males. The second study by Carter (1990), attempted to use vertebrae to age warty oreos and claimed a maximum age of approximately 25 years. The age estimates were not validated in either study.

Validation of age estimates for deep-water fish species has been difficult in the past as standard validation techniques such as comparison with tagged individuals (Francis et al. 1992) and mark re-capture experiments (Fowler and Doherty 1992) are not applicable. Comparison with radiometric analysis is therefore a valuable alternative. Such a comparison has also been used to validate otolith increment age estimates for the splitnose rockfish, *Sebastes diploproa*, (Bennett et al. 1982), and more recently, orange roughy, *Hoplostethus atlanticus*, (Smith et al. in press). As the incremental structure of oreo otoliths is similar between species, the results for warty oreo

(Stewart et al in press) suggest that our interpretation of otoliths from the other oreos is also correct. Further radiometric ageing is under way for smooth, black and spiky oreos which should provide confirmation of our results in the near future.

Sectioning of the oreo otoliths and examination of otolith growth revealed that as fish increase in age their otoliths continue to thicken after growth in otolith and fish length has virtually ceased. Numerous studies in recent years have reported similar patterns of otolith growth in long lived species (Bennett et al. 1982; Kenchington and Augustine 1987; Anderson et al. 1993; Smith et al. in press), and all emphasise the need for sectioning to reveal the full incremental structure of otoliths and hence obtain accurate age estimates.

In summary, John and mirror dory appear to be relatively short lived and fast growing, while king dory are more slow growing. There is little doubt the oreo species are extremely long lived and slow growing. Smooth and black oreo are known to have low fecundity (Conroy and Pankhurst 1989), and it is likely that warty and spiky oreo would be similar. If this is the case, the combination of low fecundity, high age at maturity and longevity would make the oreos particularly susceptible to exploitation. Our results therefore have important implications for the future management of both the dory and oreo fisheries.

Acknowledgments

We gratefully acknowledge Dr Jeremy Lyle (Division of Sea Fisheries, Tasmania), Dr Nick Bax (CSIRO Fisheries) and Kevin Rowling (Fisheries Research Institute, NSW) for providing otolith samples and size distribution data. Thanks also go to numerous people at the Marine Science Laboratories who provided assistance. Ken Smith co-ordinated the collection of otoliths during Western Bass Strait Trawl Fishery Assessment Program, Simon Robertson customised the Optimas software used for measurement of otolith morphometrics and Sandy Morison commented on the manuscript and assisted in interpretation of results.

References:

ANDERSON, J. R., A. K. MORISON AND D. J. RAY. (1992). Age and growth of the Murray cod, *Maccullochella peelii* (Perciformes: Percichthyidae), in the lower Murray-Darling basin, Australia, from thin-sectioned otoliths. *In* Age determination and growth in fish and other aquatic animals. (Ed. D. C. Smith) *Aust. J. Mar. Freshwater Res.* **43**: 983-1013.

ANNALA, J. H. (1992). Oreos. In. Report from the fishery assessment plenary, May 1992: stock assessments and yield estimates. MAF Fisheries, Auckland, 155-159.

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

BEAMISH, R.J. AND MCFARLANE, G.A. (1983). The forgotten requirement for age validation in fisheries biology. *Trans. Am. Fish. Soc.* **112**, 735-743.

BENNETT, J. T., BOEHLERT, G. W., AND K. K. TUREKIAN. (1982). Confirmation of the longevity in *Sebastes diploproa* (Pisces: Scorpaenidae) from $^{210}Pb/^{226}Ra$ measurements in otoliths. *Mar. Biol.* **71**: 209-215.

CAMPANA, S. E. (1984). Microstructural growth patterns in the otoliths of larval and juvenile starry flounder, *Platichthys stellatus*. *Can. J. Zool.* **62**: 1507-1512.

CARTER, D. L. (1990). Development of a suitable method of age determination of Allocyttus verrucosus (warty oreo). M.Sc. preliminary thesis, (Department of Biological Sciences: Deakin University, Australia). 42p.

CHRISTENSEN, J. M. (1964). Burning of otoliths, a technique for age determination of soles and other fish. *J. Cons. int. Explor. Mer.* **26**: 73-81.

CONROY, A.M. AND PANKHURST, N.W. (1989). Size-fecundity estimates in the smooth oreo, *Pseudocyttus maculatus*, and the black oreo, *Allocyttus niger* (Pisces: Oreosomatidae). *NZ J. Mar. Freshwater Res.* **23**: 525-527.

DAVIES, N.M., GAULDIE, R.W., CRANE, S.A. AND THOMPSON, R.K. (1988). Otolith ultrastructure of smooth oreo, *Pseudocyttus maculatus*, and black oreo, *Allocyttus sp.*, species. *Fishery Bulletin* **86**, 499-515.

FOWLER, A. J. (1989). Description, interpretation and use of the microstructure of the otoliths from juvenile butterfly fishes (family: Chaetodontidae). *Mar. Biol.* **102**: 167-181.

FOWLER, A. J. AND P. J. DOHERTY. (1992). Validation of annual growth increments in the otoliths of two species of damselfish from the southern Great Barrier Reef. *In* Age determination and growth in fish and other aquatic animals. (Ed. D. C. Smith) *Aust. J. Mar. Freshwater Res.* **43**: 1057-1068.

FRANCIS, R. I. C. C., L. J. PAUL AND K. P. MULLIGAN. (1992). Ageing of adult snapper (*Pagrus auratus*) from otolith annual ring counts: validation by tagging and oxytetracycline injection. *In* Age determination and growth in fish and other aquatic animals. (Ed. D. C. Smith) *Aust. J. Mar. Freshwater Res.* **43**: 1069-89.

HORE, A. J. (1982). Age, growth and reproduction of the John dory, *Zeus faber* (Linnaeus). Unpublished Master of Science Thesis (Department of Zoology: University of Auckland). 86 pp.

HUTCHINS, B. AND SWAINSTON, R. (1986). Sea Fishes of Southern Australia. (Swainston Publishing: Perth). 180 pp.

JAMES, G. D., INADA, T. AND I. NAKAMURA. (1988). Revision of the oreosomatid fishes (family Oreosomatidae) from the southern oceans, with a description of a new species. *New Zealand, J. Zool.* **15**: 291-326.

KENCHINGTON, T. J. AND O. AUGUSTINE. (1987). Age and growth of the blue grenadier, *Macruronus novaezelandiae* (Hector), in south-eastern Australian waters. *Aust. J. Mar. Freshwater Res.* **38**: 625-646.

LYLE, J. M., RILEY, S. P. AND KITCHENER, J. A. (1992). Oreos, an under utilised resource. Australian Fisheries. 51 (4): 12-15.

LYLE, J. M., AND SMITH, D.C. (In prep) Abundance and biology of warty oreo, *Allocyttus verrucosus,* (Gilchrist) and spiky oreo *Neocyttus rhomboidalis* (Gilchrist) (Oreosomatidae) from south-eastern Australia. (to be submitted to Marine Biology)

MAY, H. M. A. AND G. P. JENKINS. (1992). Patterns of settlement and growth of juvenile flounder, *Rhombosolea taparina*, determined from otolith microstructure. *Mar. Ecol. Prog. Ser.* 79: 203-214.

MEL'NIKOV, YU. S. (1982). Size-age composition and growth pattern of *Allocyttus verrucosus* (Oreosomatidae). *Ichthyology* (English translation Vopr. Ikhtiol.) **21**. 178-184.

NEILSON, J. D. AND G. H. GEEN. (1985). Effects of feeding regimes and deil temperature cycles on the otolith increment formation in juvenile chinook salmon, *Oncorhynchus tshawytscha. Fish. Bull.* **83**: 91-101.

PARIN, N.V., PAVLOV, YU. P. AND ANDRIANOV, D. P. (1988). Ecology of the mirror dory, *Zenopsis nebulosus*, of the Submarine Nasca Ridge. *Journal of Ichthyology* **28**, 707-716.

SMITH, D. C., G. E. FENTON, S. G. ROBERTSON, AND S. A. SHORT (in press). Age determination and growth of orange roughy (*Hoplostethus atlanticus)*: A comparison of increment counts with radiometric ageing. *Can. J. Fish. Aquat. Sci.*

SMITH, D. C. AND STEWART, B. D (in prep). The population biology of king dory *(Cyttus traversi)* in south-eastern Australian waters. Prepared for AJMFR

STEWART, B. D. AND SMITH, D. C. (1992a). Development of methods to age commercially important dories and oreos: Progress Report No. 1 - June 1992. (Department of Conservation and Environment, Marine Science Laboratories Internal Report No. 195). 6 pp.

STEWART, B. D. AND SMITH, D. C. (1992b). Development of methods to age commercially important dories and oreos: Progress Report No. 2 - October 1992. (Department of Conservation and Natural Resources, Marine Science Laboratories Internal Report No. 198). 12 pp.

STEWART, B. D. AND D. C. SMITH. (1993). Development of methods to age commercially important dories and oreos. Progress report no. 3 (Department of Conservation and Natural Resources, Marine Science Laboratories internal report no. 206). 23 pp.

STEWART, B. D., G. E FENTON, D. C. SMITH, D. C. AND SHORT (in press). Validation of otolith increment age estimates for a deepwater fish species, warty oreo, *Allocyttus verrucosus*, by radiometric analysis. *Marine Biology*

VICTOR, B. C. (1982). Daily otolith increments and recruitment in two coral-reef wrasses, *Thalassoma bifasciatum* and *Halichoeres bivattus*. *Mar. Biol.* **71**: 203-208.

VICTOR, B. C. (1986). Delayed metamorphosis with reduced larval growth in a coral reef fish (*Thalassoma bifasciatum*). *Can. J. Fish. Aquat. Sci.* **43**: 1208-1213.

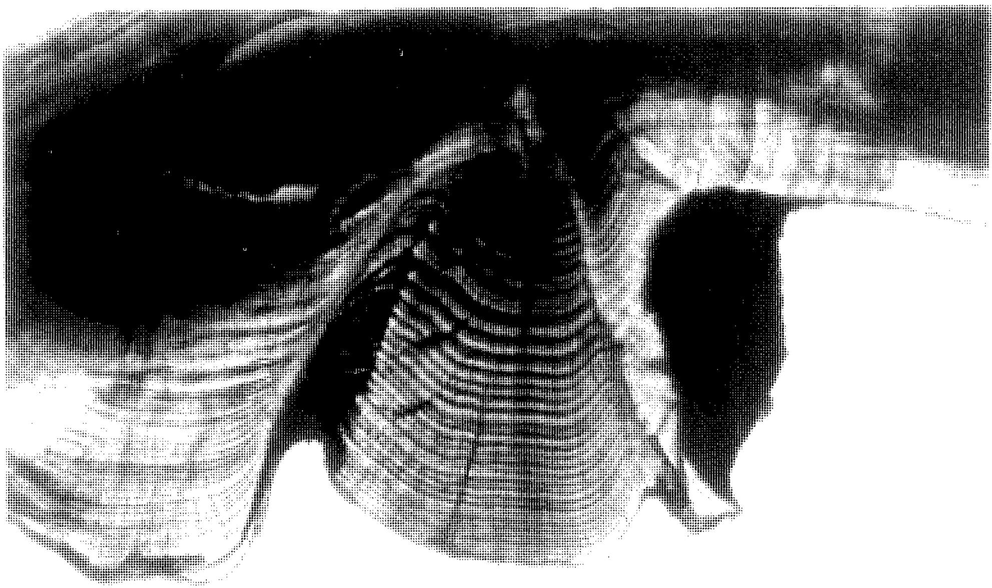
Figure 1.1 King dory otolith viewed with reflected light.
18.5 cm TL juvenile; 3 years (x 25 magnification)

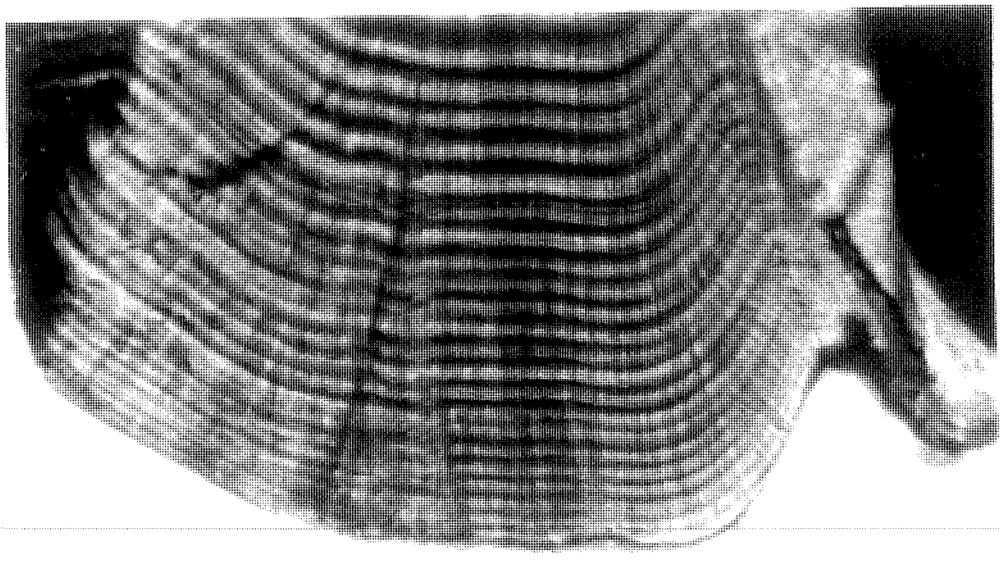
Figure 1.2 Sectioned king dory otoliths viewed with transmitted light.

a) 40.9 cm TL, M; 22 years (40x magnification)

b) 53.6 cm TL, F; 31 years (40x magnification)

c) Close-up of edge of b) (100x magnification)





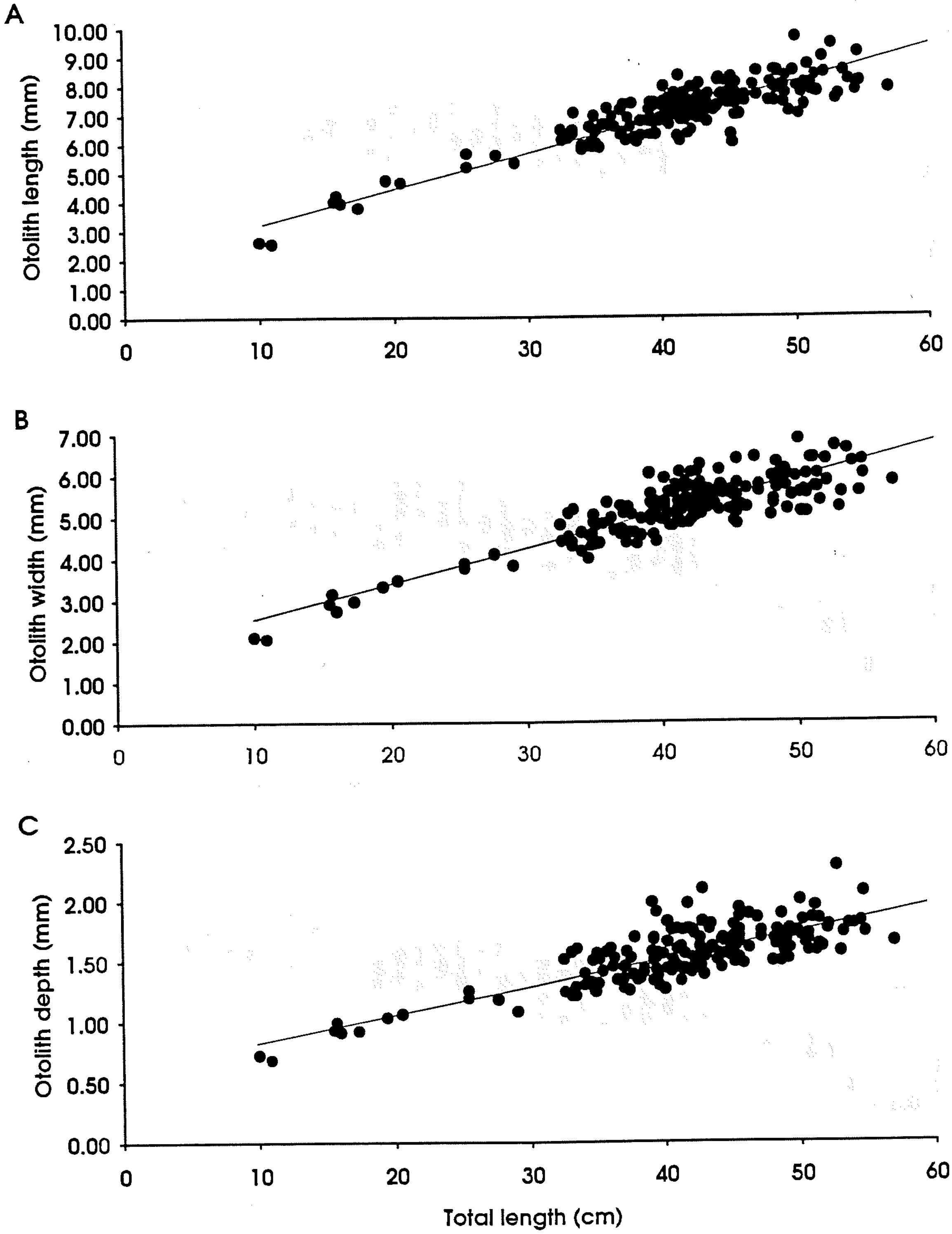


Figure 1.3. King dory (all fish combined) - relationship between:
A. Otolith length and fish length (OL=0.1145 FL+2.3308, R^2=0.78, n=172)
B. Otolith width and fish length (OW=0.0829 FL+1.7612, R^2=0.74, n=172)
C. Otolith depth and fish length (OD=0.0231 FL+0.5968, R^2=0.62, n=172)

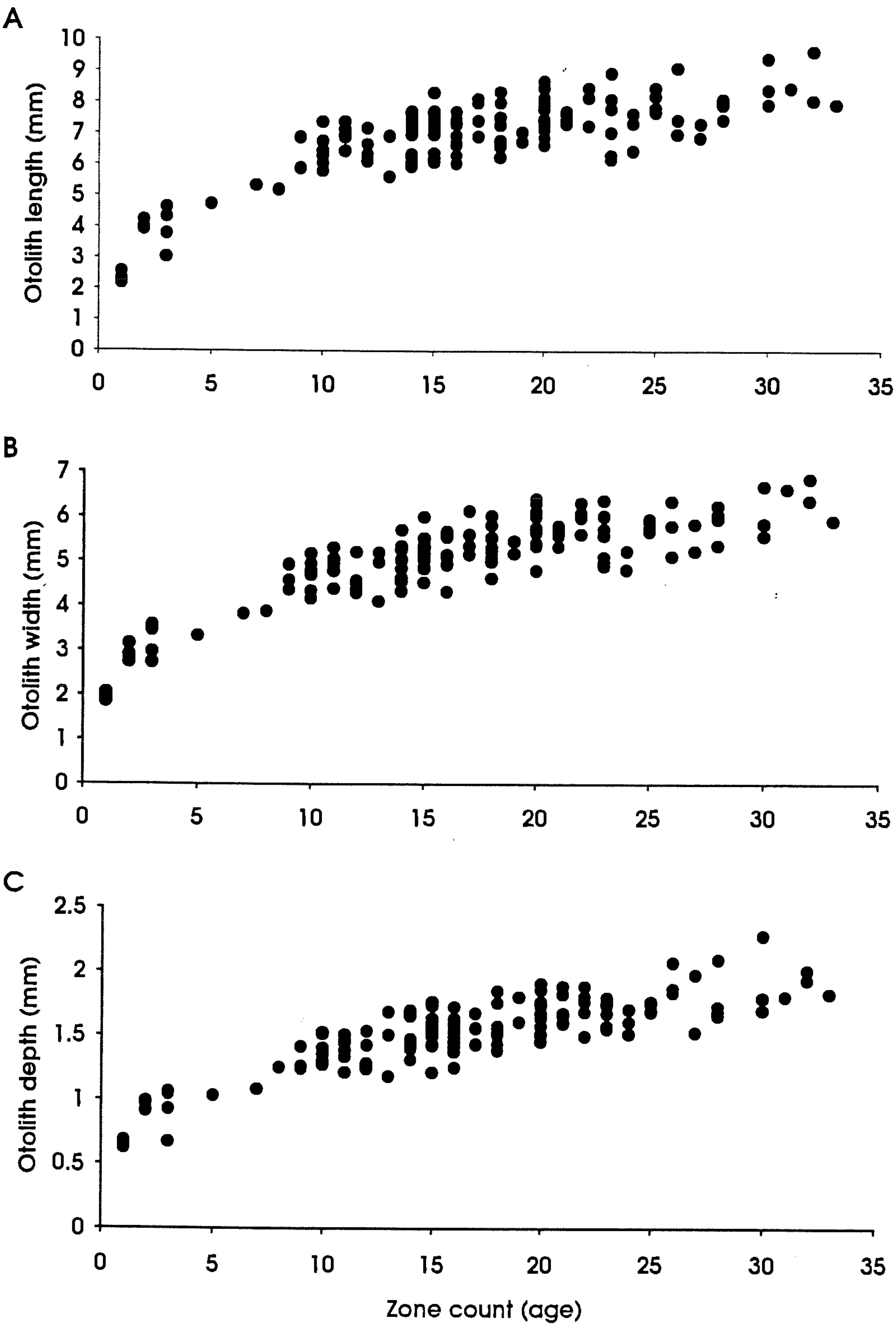
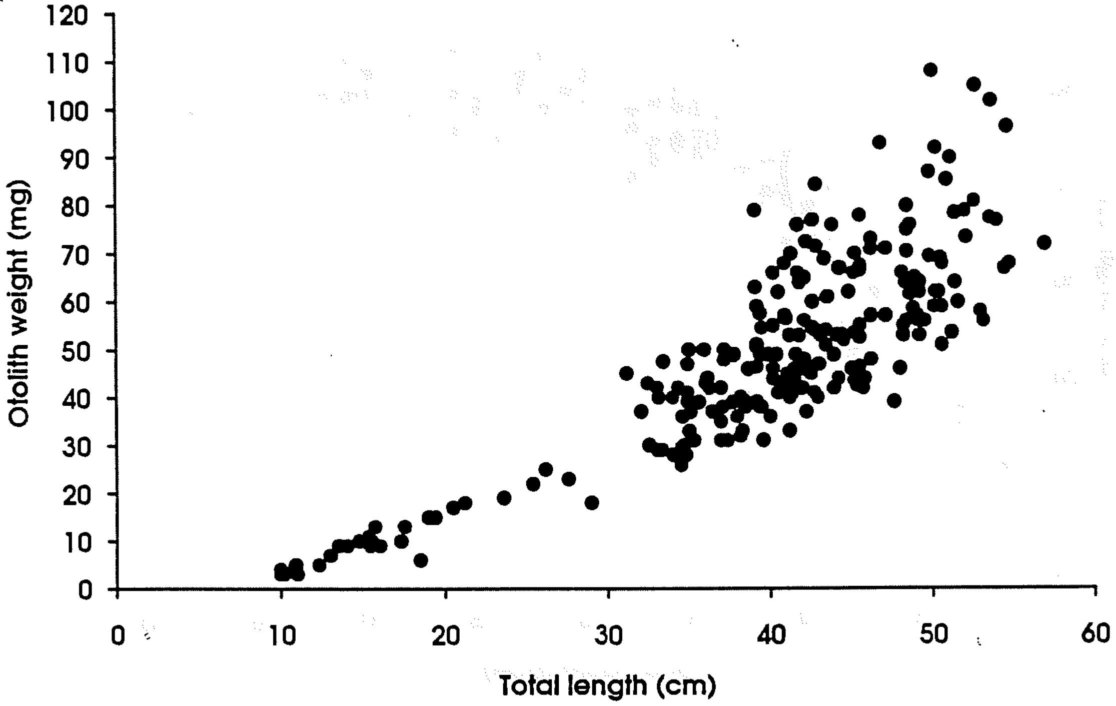


Figure 1.4. King dory (all fish combined) - relationship between:
A. Otolith length and age (n=143)
B. Otolith width and age (n=143)
C. Otolith depth and age (n=143)

A



B

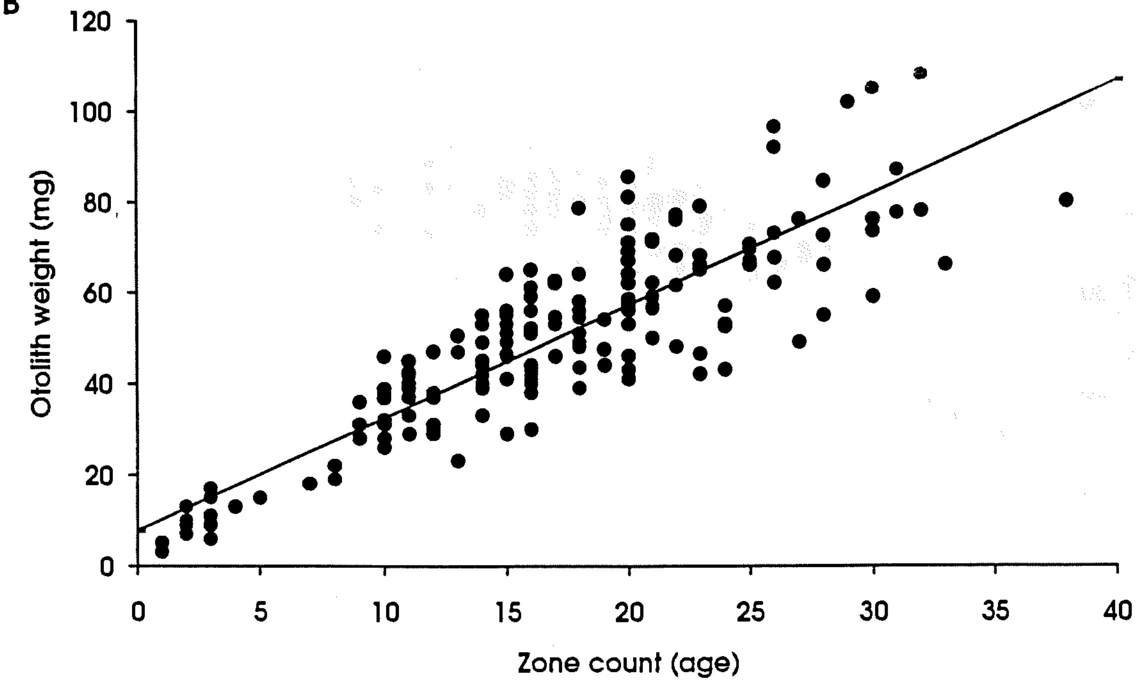


Figure 1.5. King dory (all fish combined) - relationship between:
A. Otolith weight and fish length (n=216)
B. Otolith weight and age (OW = 2.470SA + 7.871, R^2=0.772, n=181)

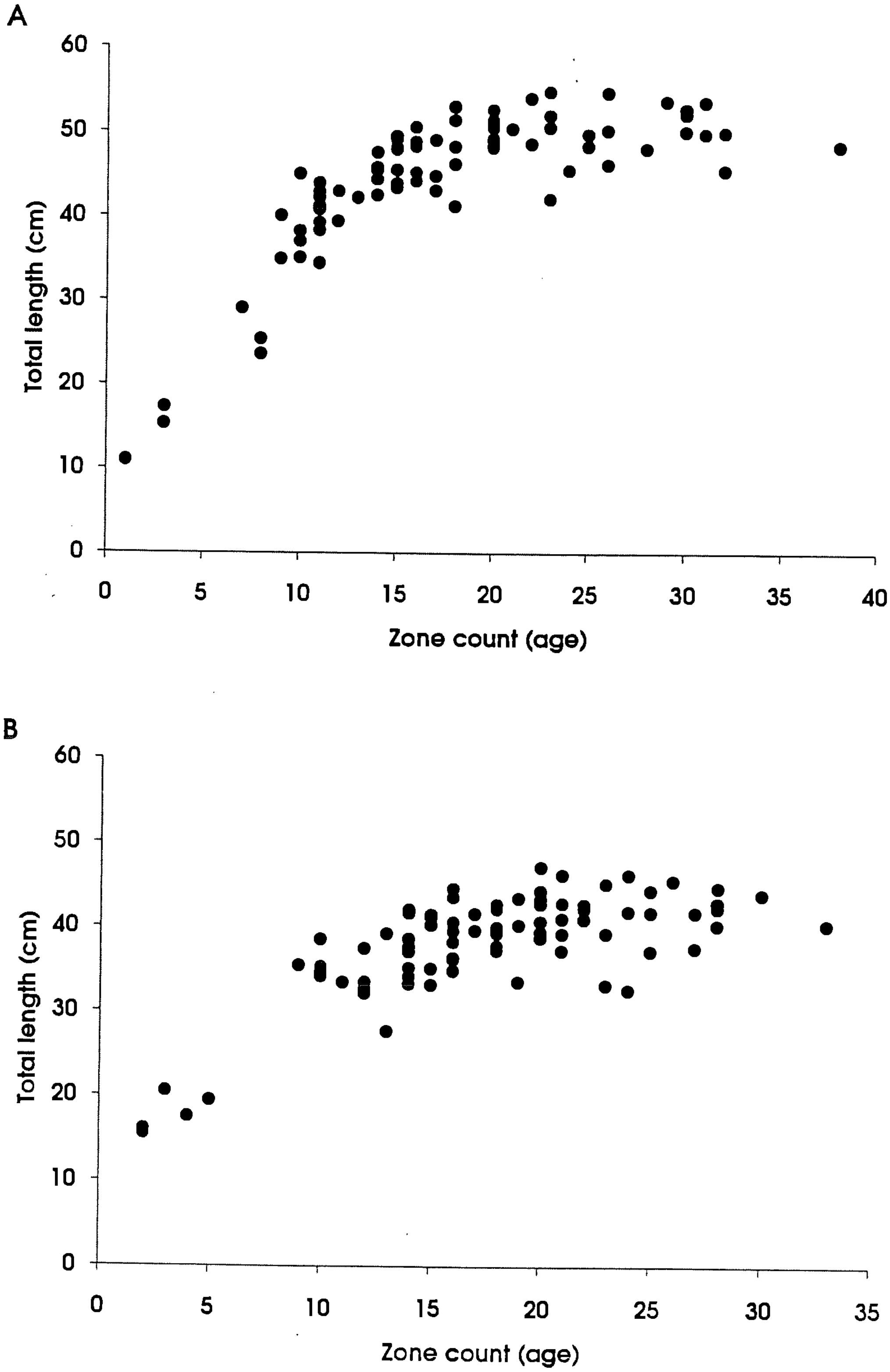


Figure 1.6. King dory - relationship between fish length and age
A. Females (n=86) B. Males (n=87)

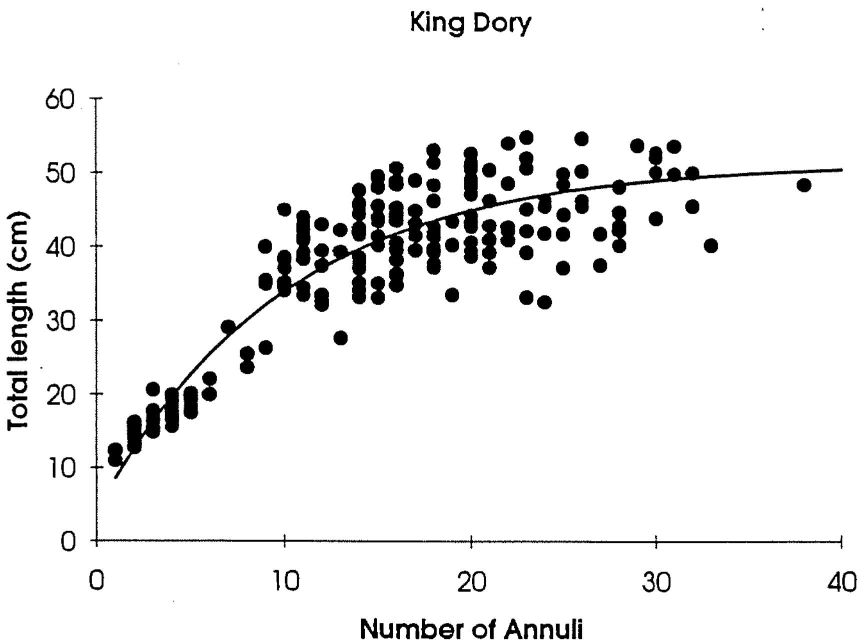
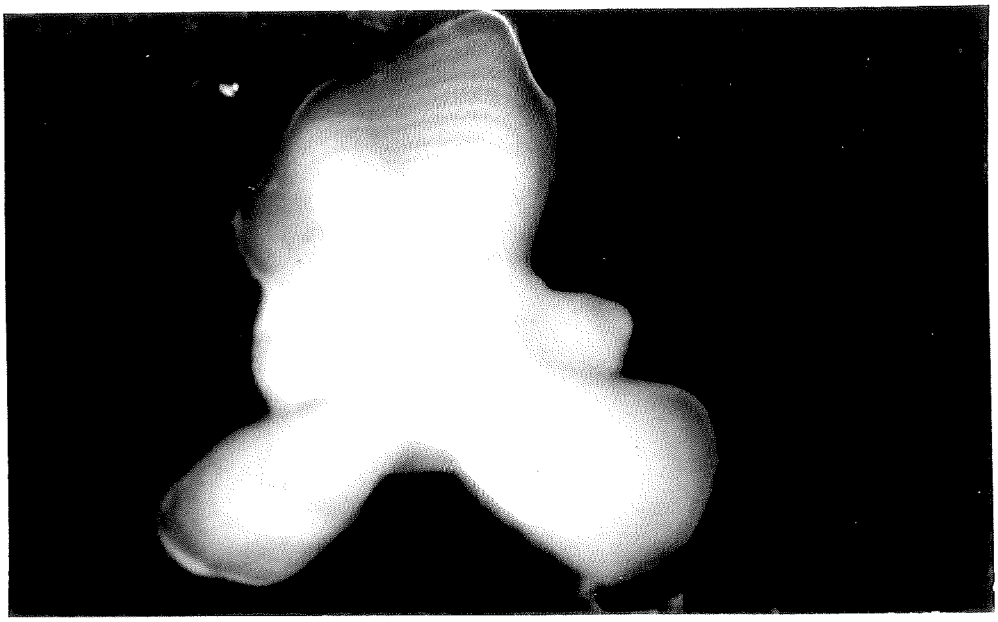


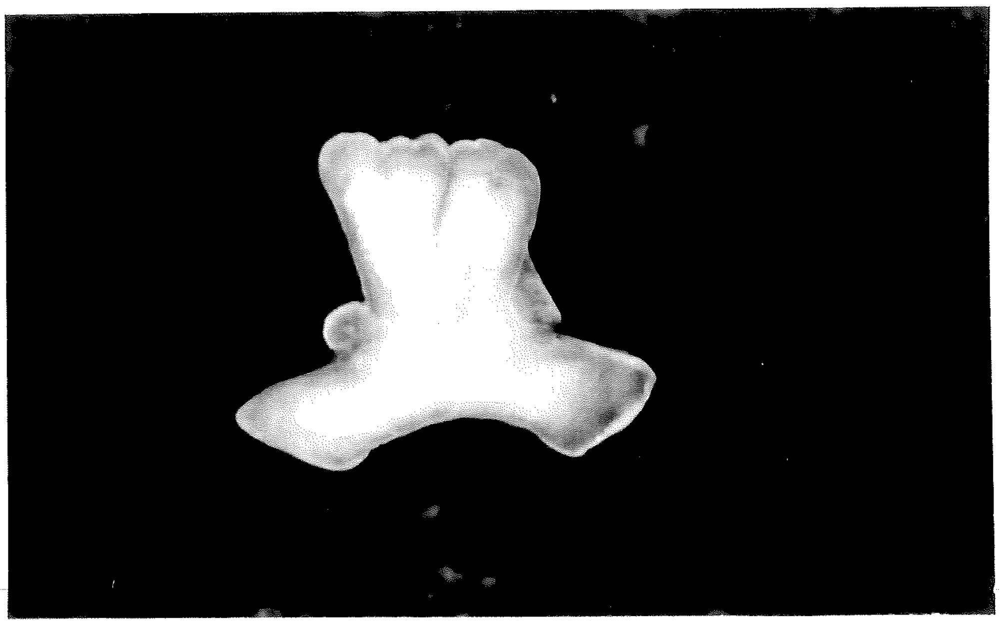
Figure 1.7 Von Bertalanffy growth curve for king dory.

Figure 2.1a Mirror dory otolith viewed with reflected light.
56.6 cm TL, F; 11 years (25x magnification)

Figure 2.1b John dory otolith viewed with reflected light
37.9 cm TL, M; 7 years (25x magnification)

Figure 2.1c John dory otolith viewed with reflected light
16.0 cm TL, juv; 1 year (25x magnification)





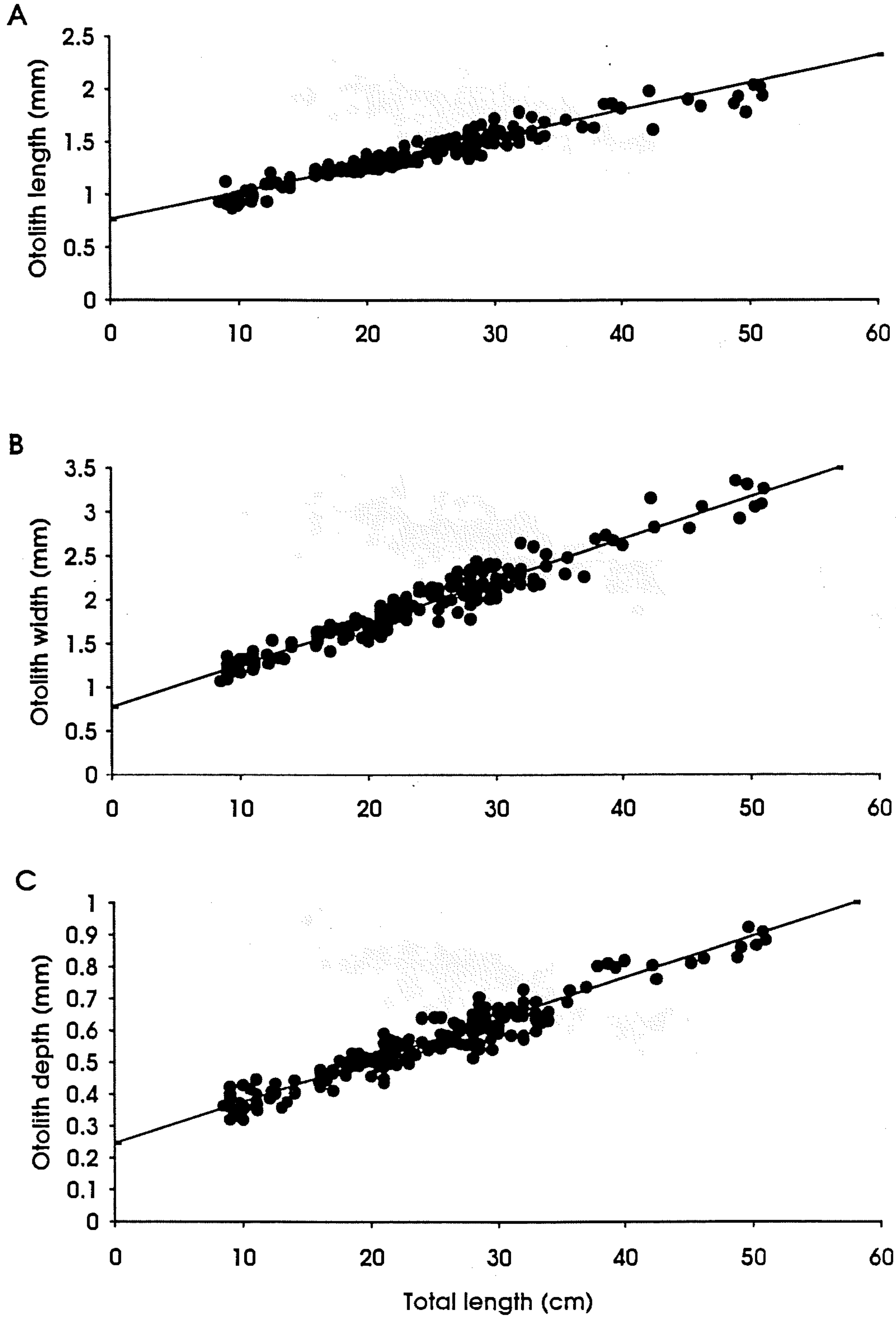


Figure 2.2. John dory (all fish combined) - relationship between:
A. Otolith length and fish length (OL = 0.026 FL + 0.767, R^2=0.912, n=169)
B. Otolith width and fish length (OWD = 0.048 FL + 0.780, R^2=0.932, n=166)
C. Otolith depth and fish length (OD = 0.013 FL + 0.247, R^2=0.920, n=169)

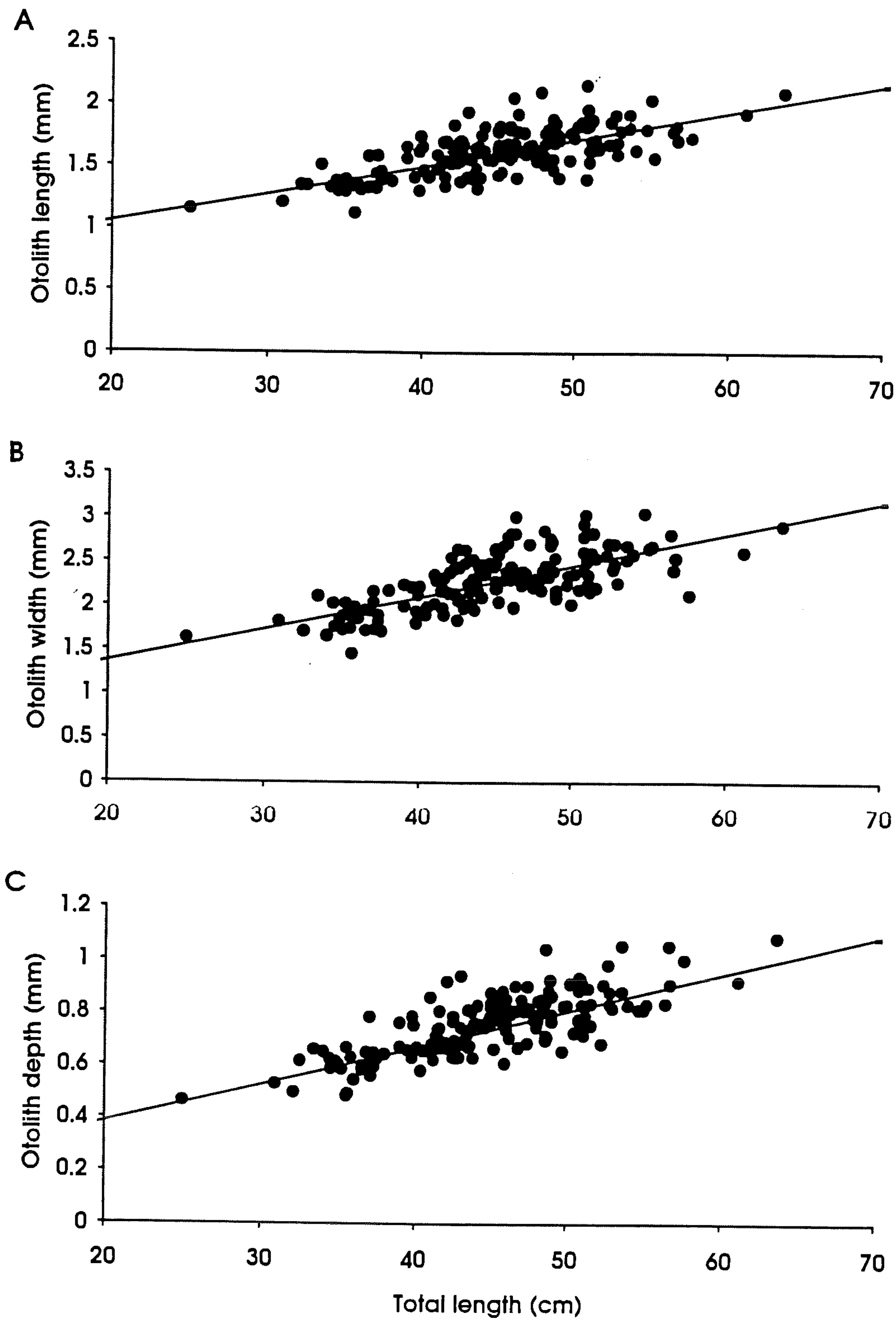


Figure 2.3. Mirror dory (all fish combined) - relationship between:
A. Otolith length and fish length (OL = 0.022 FL + 0.613, R^2=0.501, n=166)
B. Otolith width and fish length (OWD = 0.036 FL + 0.648, R^2=0.498, n=161
C. Otolith depth and fish length (OD = 0.014 FL + 0.104, R^2=0.593, n=166)

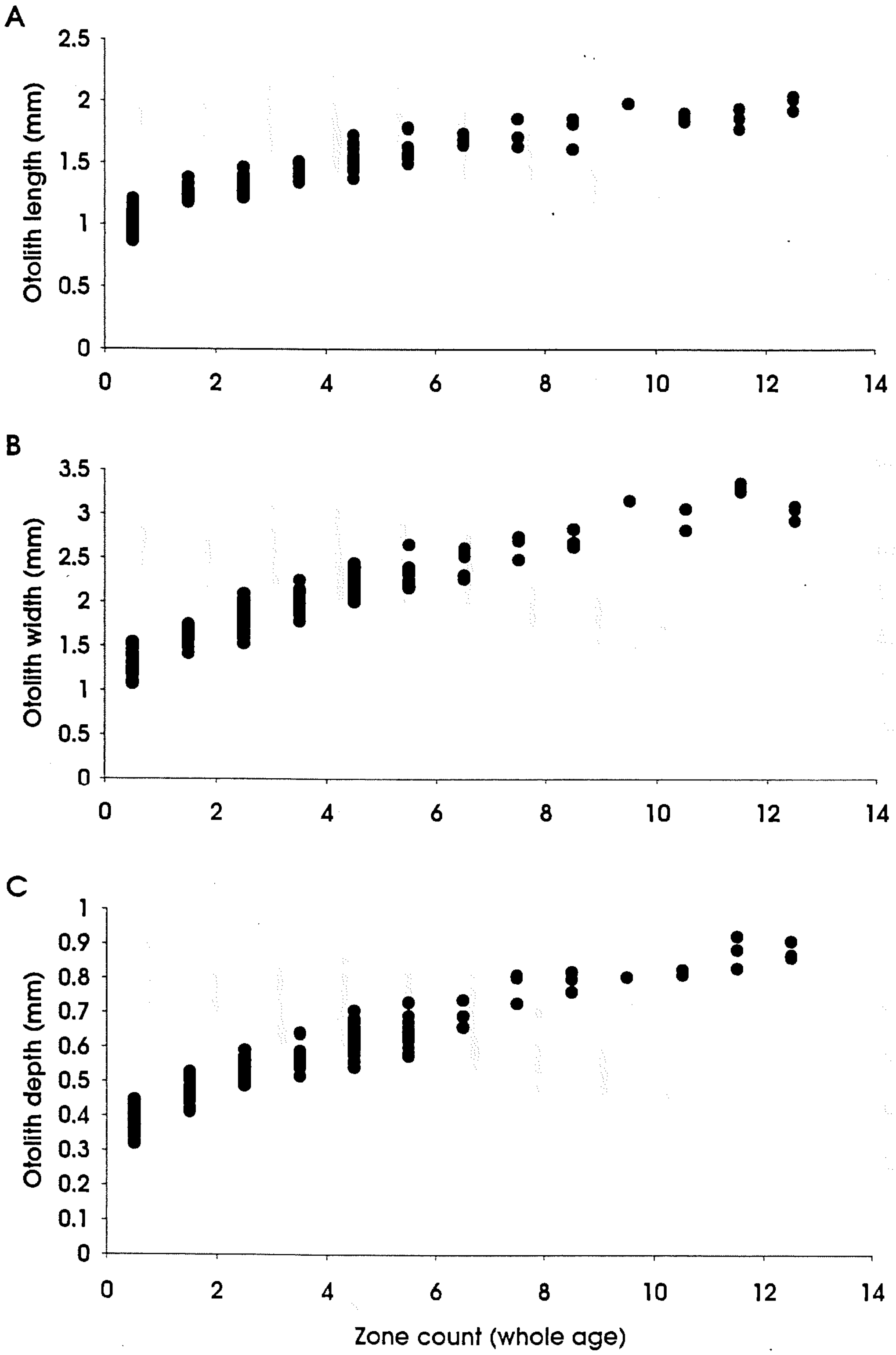


Figure 2.4. John dory (all fish combined) - relationship between:
A. Otolith length and whole age (n=163)
B. Otolith width and whole age (n=160)
C. Otolith depth and whole age (n=164)

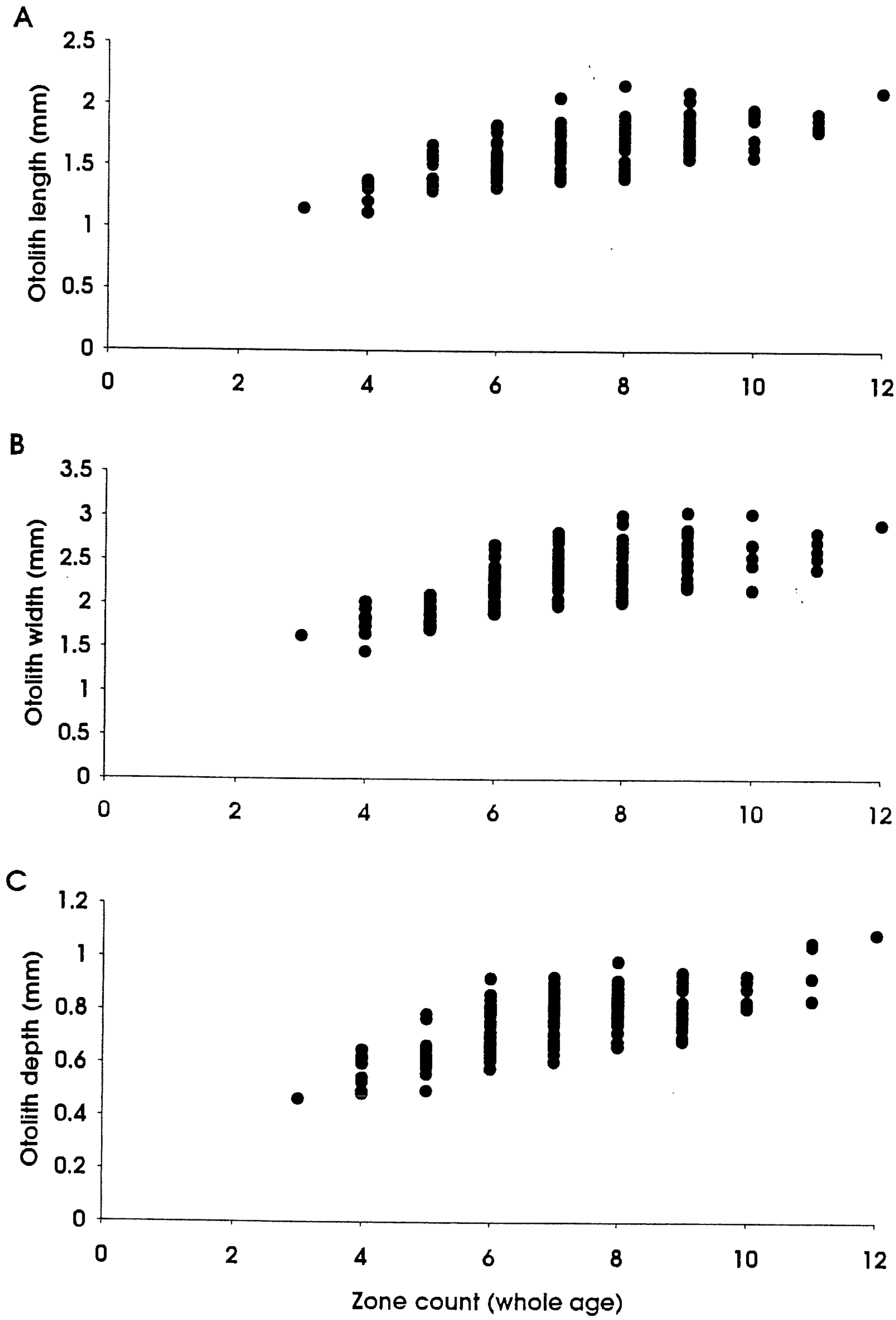
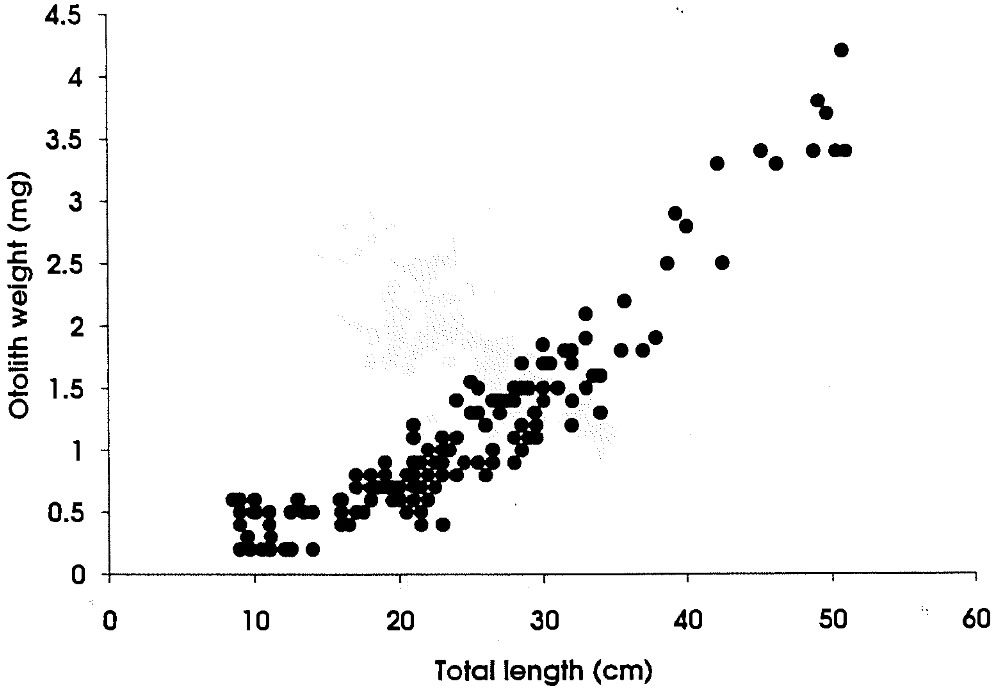


Figure 2.5. Mirror dory (all fish combined) - relationship between:
A. Otolith length and whole age (n=151)
B. Otolith width and whole age (n=147)
C. Otolith depth and whole age (n=151)



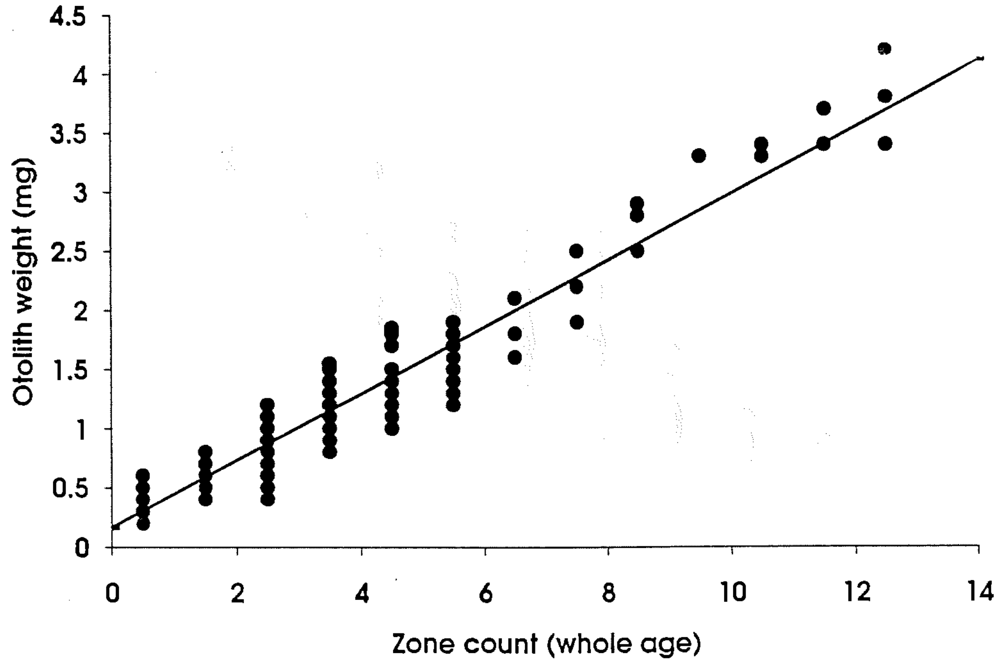
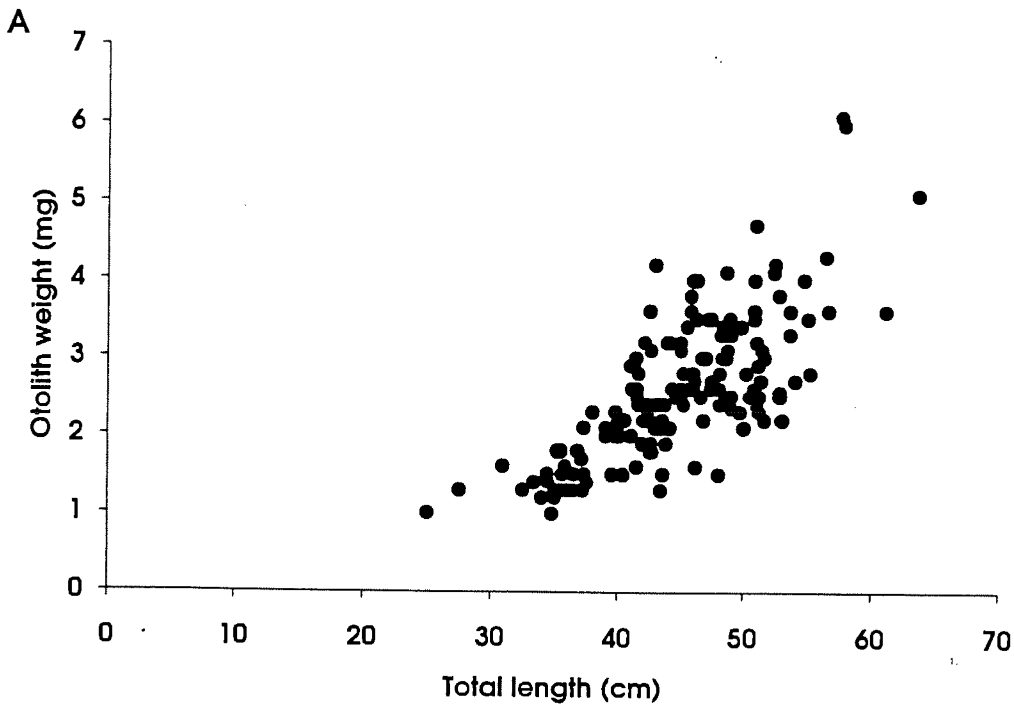


Figure 2.6. John dory (all fish combined) - relationship between:
A. Otolith weight and fish length (n=150)
B. Otolith weight and whole age (OW = 0.282 WA + 0.168, R^2=0.928, n=148)



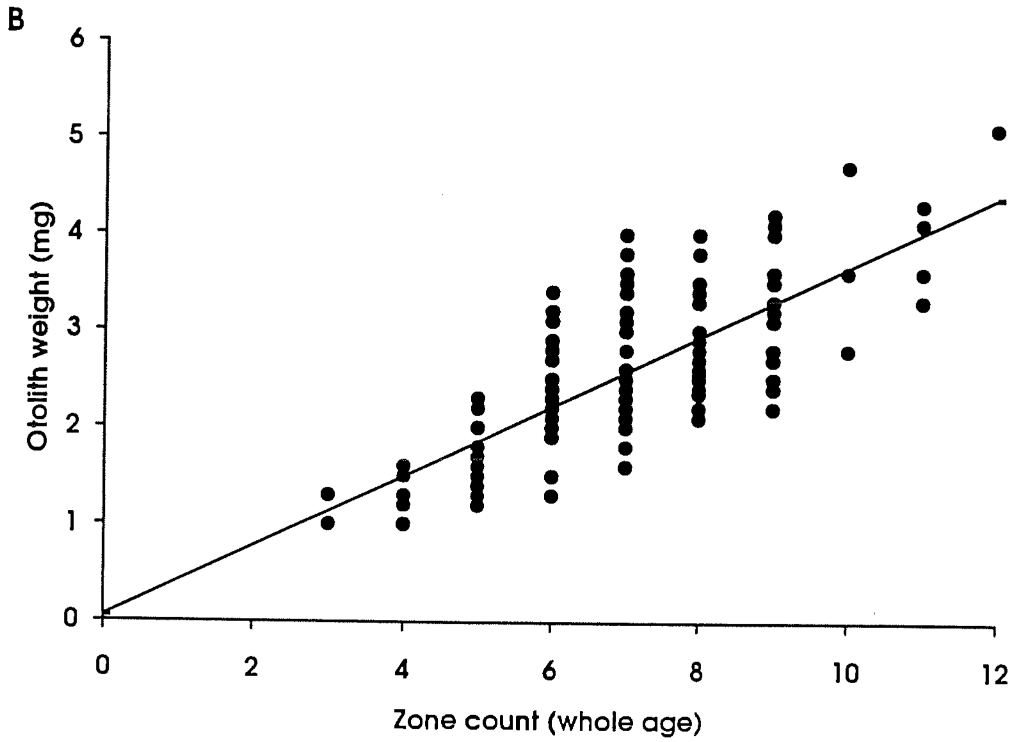


Figure 2.7. Mirror dory (all fish combined) - relationship between:
A. Otolith weight and fish length (n=157)
B. Otolith weight and whole age (OW = 0.360 WA + 0.057, R^2=0.569, n=143)

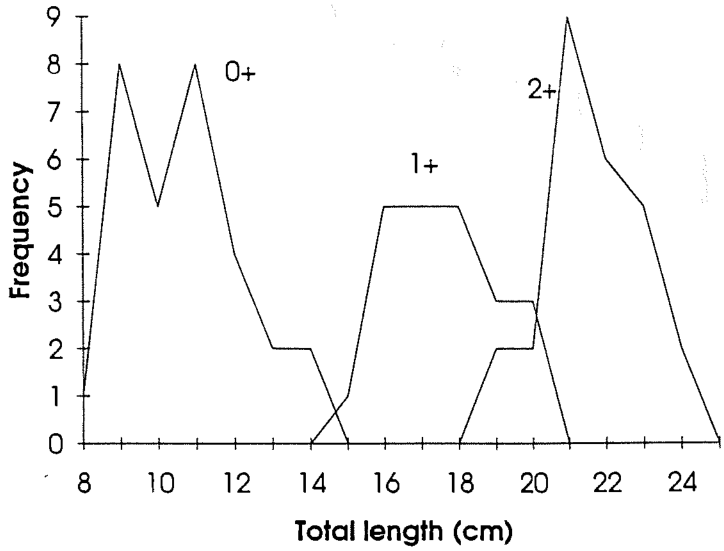


Figure 2.8 Age frequency by length for 0+,1+ and 2+ John dory

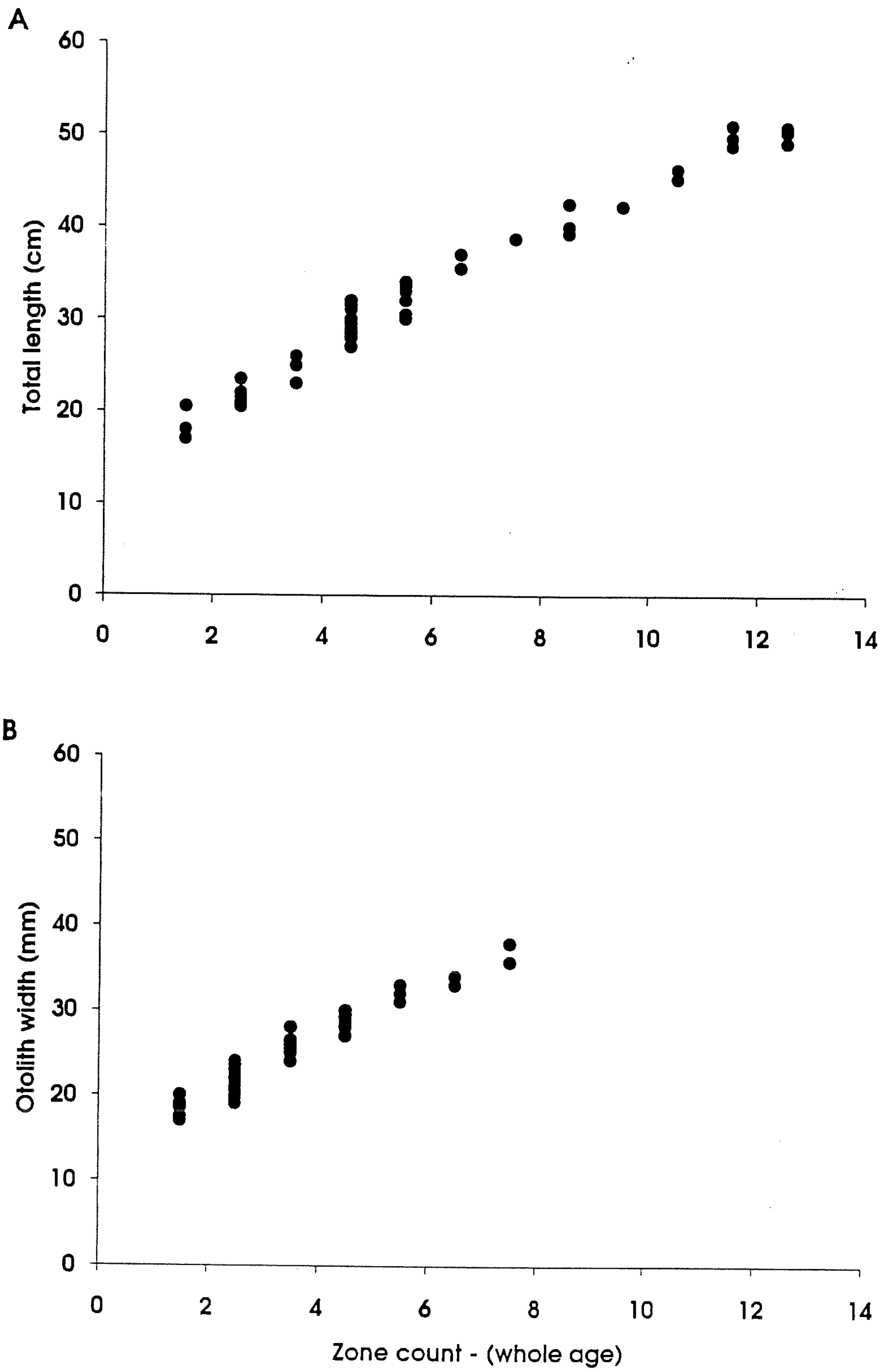


Figure 2.9. John dory - relationship between fish length and whole age
A. Females (n=55) B. Males (n=55)

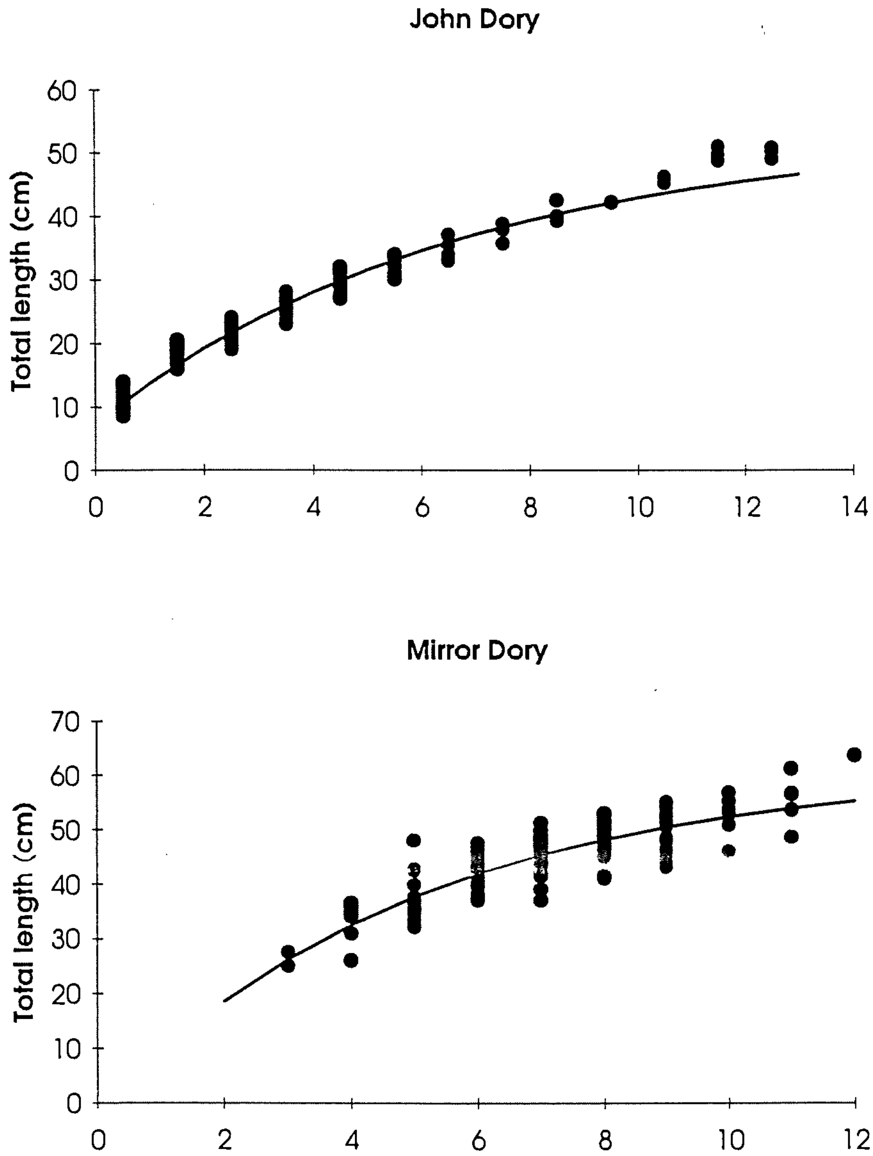


Figure 2.10 Von Bertalanffy growth curves for A) John dory and B) Mirror d

Figure 4.1a Sectioned smooth oreo otolith viewed with transmitted light.

19.2 cm TL, M; 8 years (40x magnification)

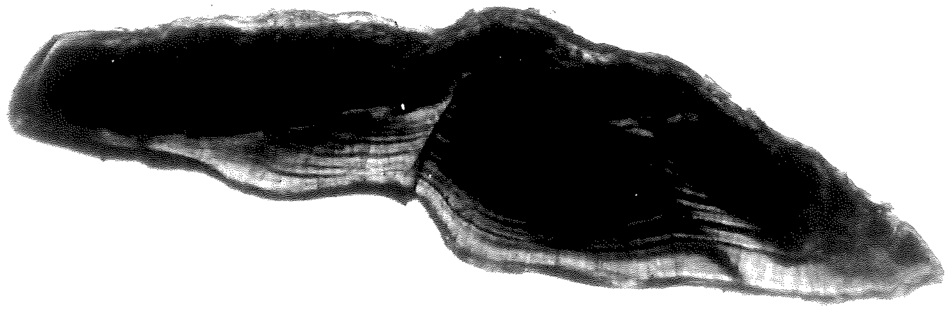
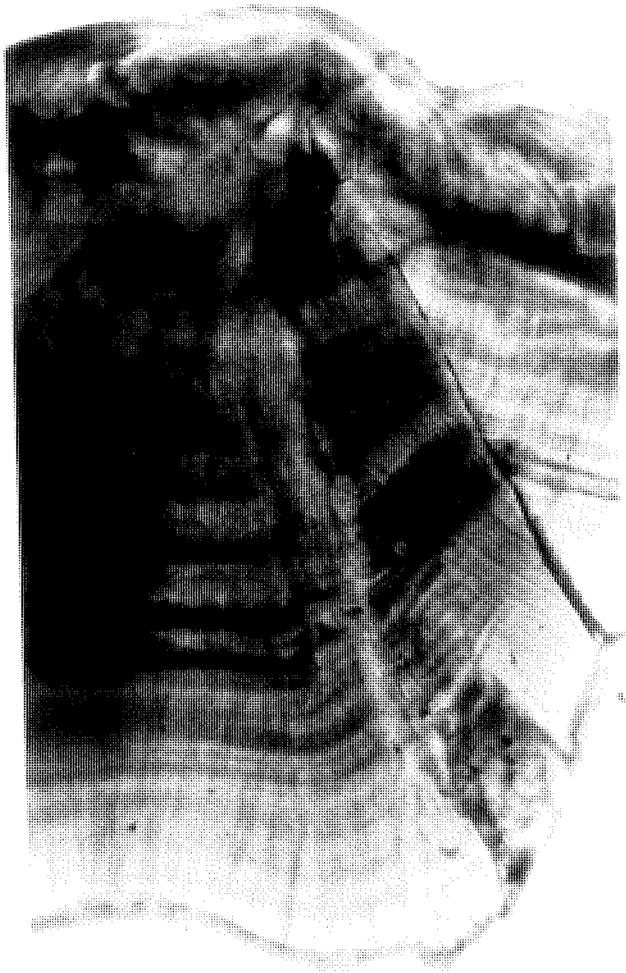


Figure 4.1 Sectioned smooth oreo otoliths viewed with transmitted light.

b) 26.0 cm TL, M; 13 years (100x)

c) 44.5 cm TL, M; 52 years (40x)



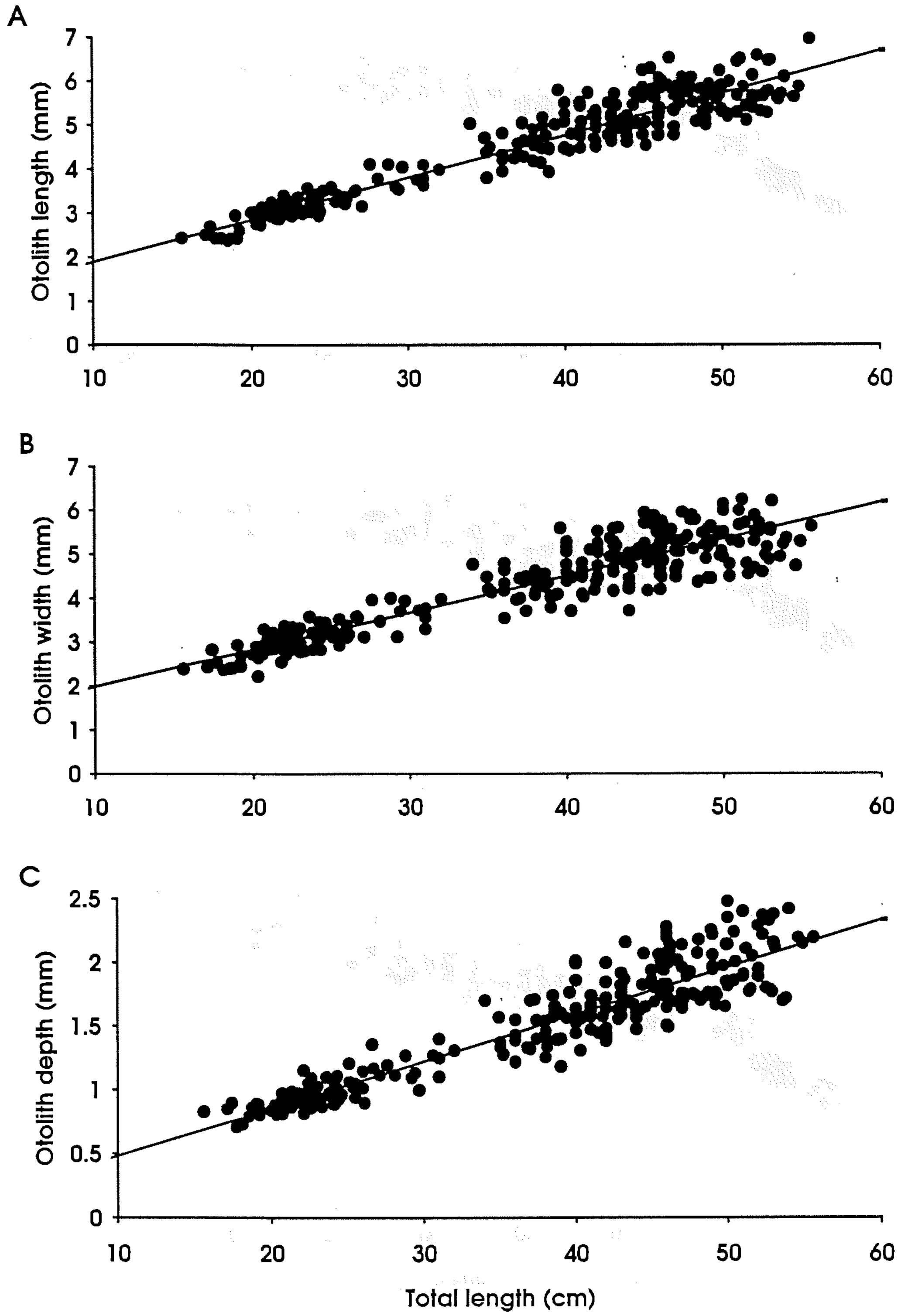


Figure 4.2. Smooth oreo (all fish combined) - relationship between:
A. Otolith length and fish length (OL = 0.096 FL + 0.937, R^2=0.903, n=265)
B. Otolith width and fish length (OWD = 0.084 FL + 1.149, R^2=0.840, n=265)
C. Otolith depth and fish length (OD = 0.037 FL + 0.113, R^2=0.861, n=265)

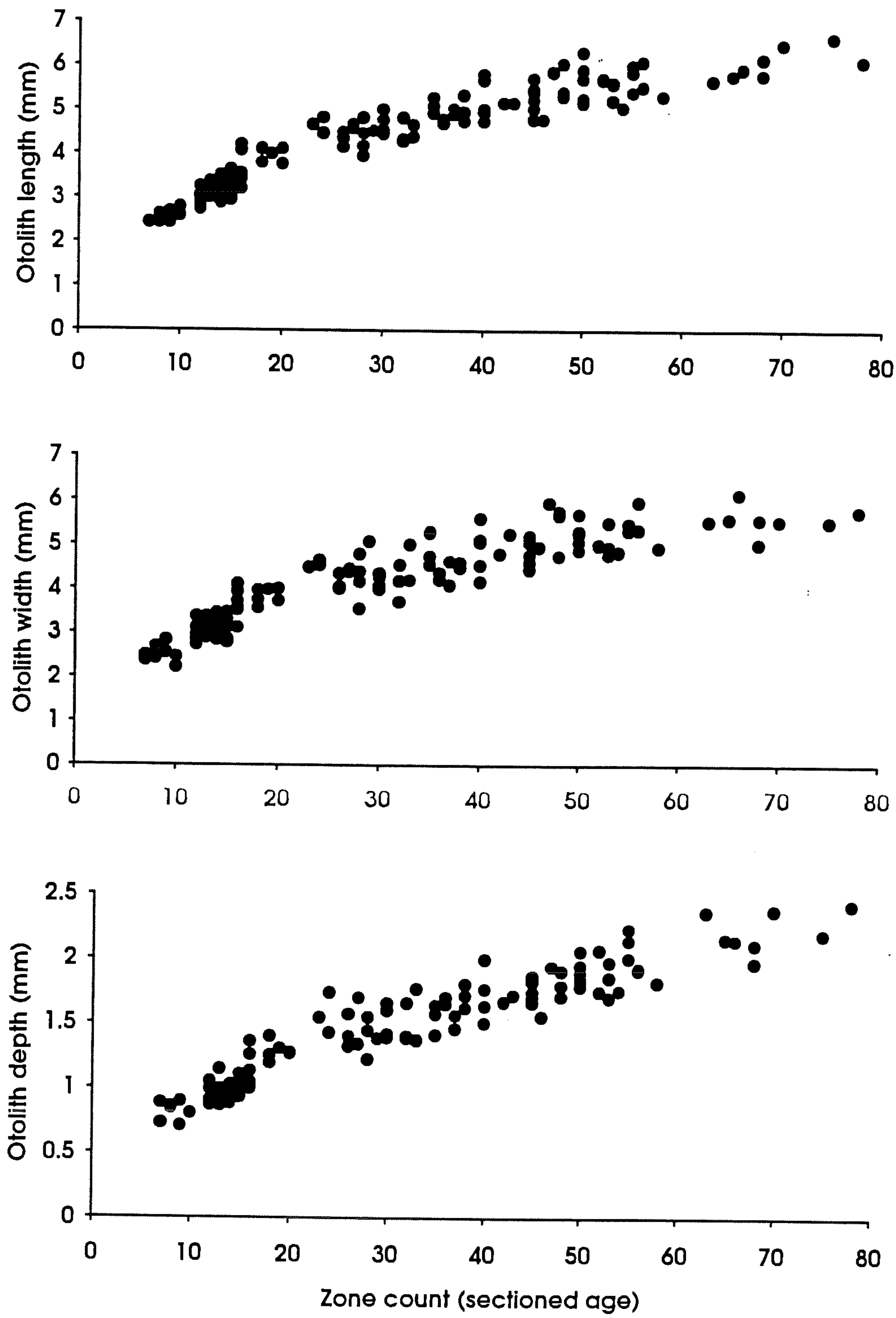
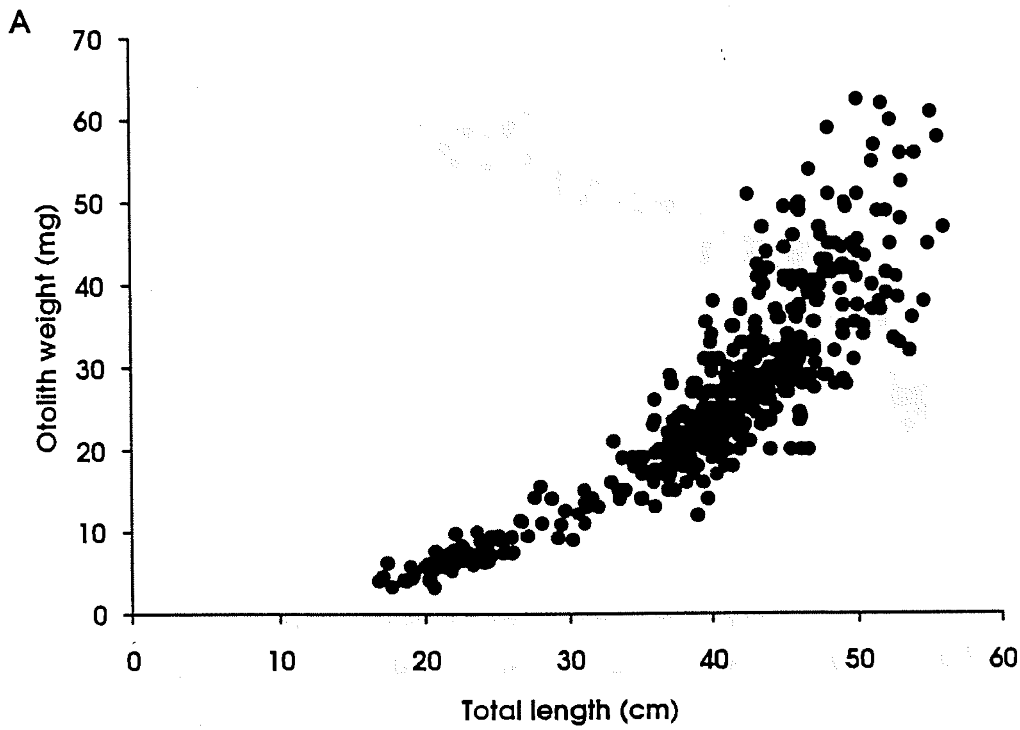


Figure 4.3. Smooth oreo (all fish combined) - the relationship between:
A. Otolith length and sectioned age (n=127)
B. Otolith width and sectioned age (n=127)
C. Otolith depth and sectioned age (n=127)



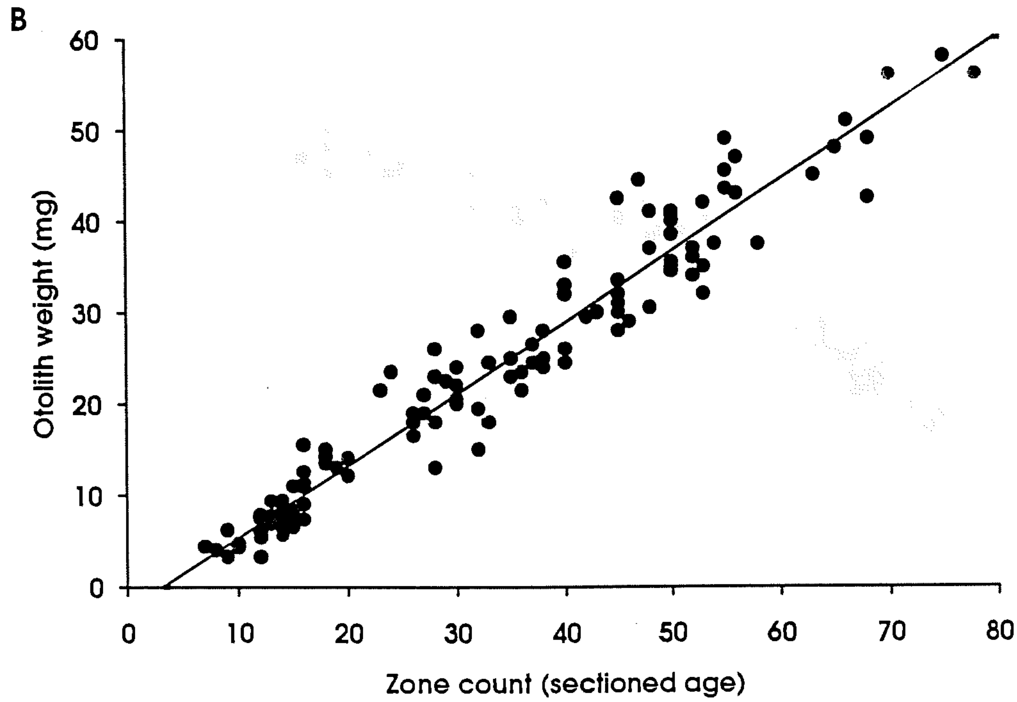


Figure 4.4. Smooth oreo (all fish combined) - relationship between:
A. Otolith weight and fish length
B. Otolith weight and sectioned age (OW = 0.785 SA - 2.480, R^2=0.944, n=128)

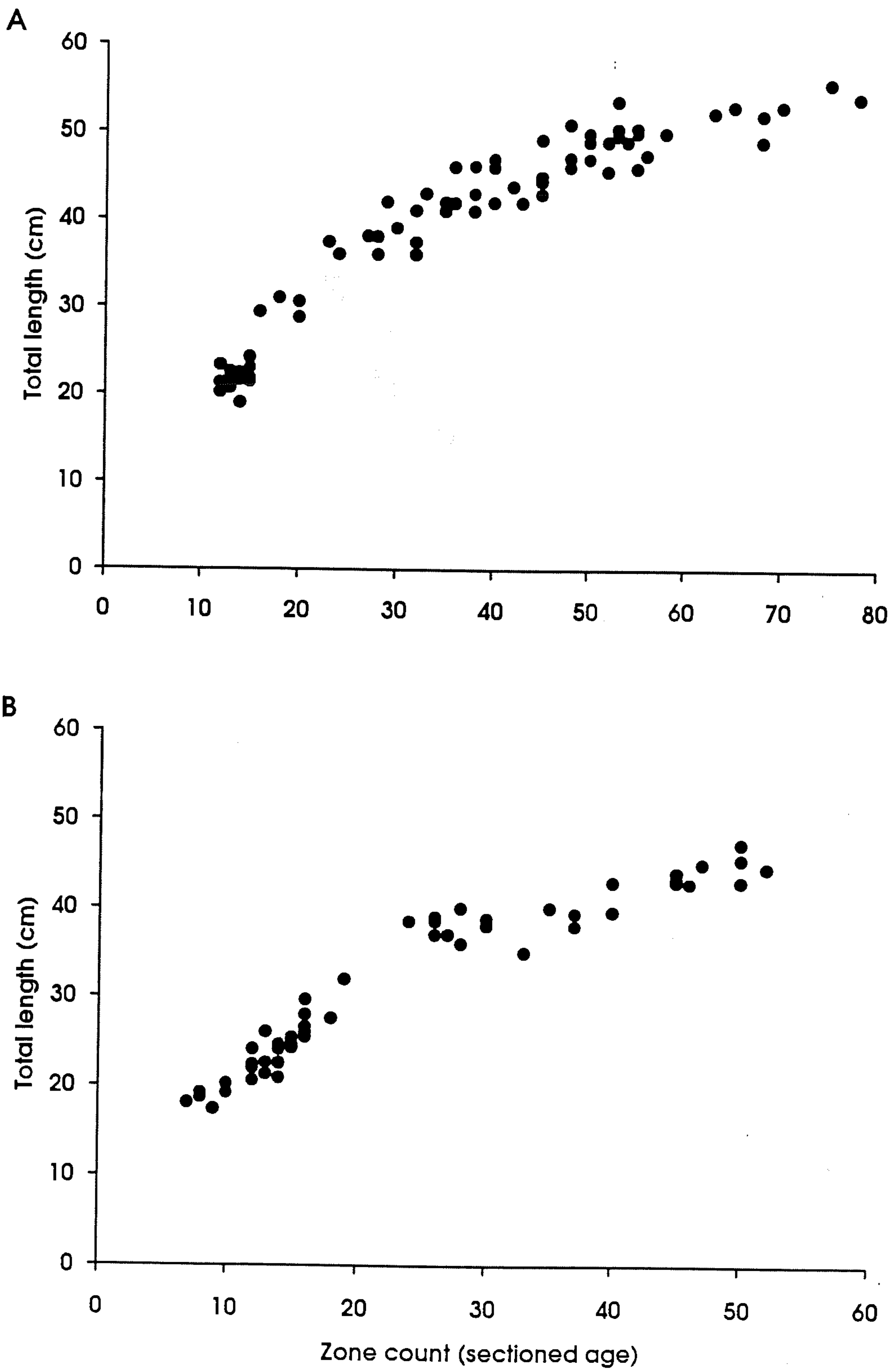


Figure 4.5. Smooth oreo - relationship between fish length and sectioned age
A. Females (n=70) B. Males (n=56)

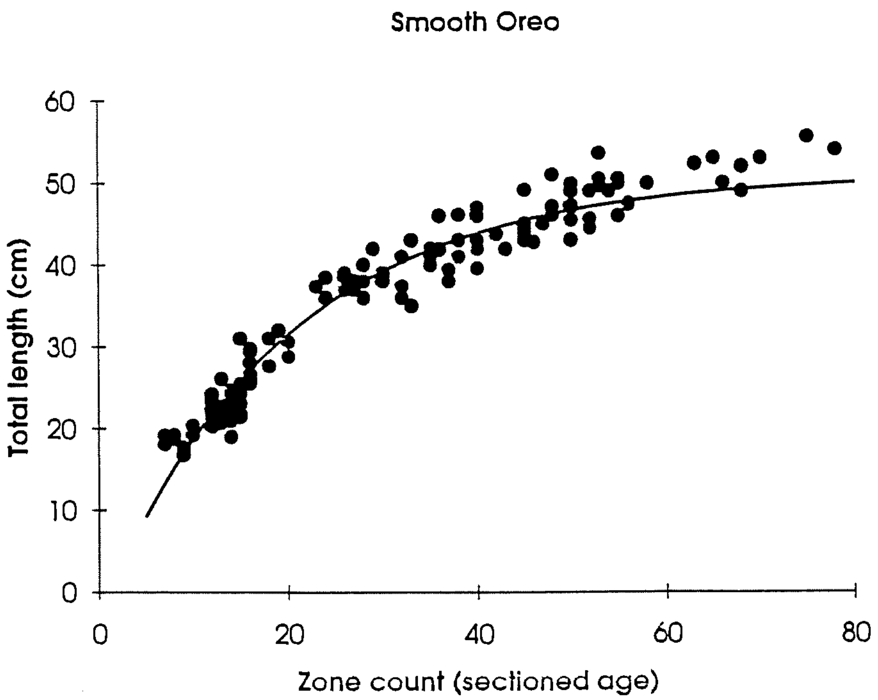


Figure 4.6. Von Bertalanffy growth curve for smooth oreo (N=131).

Figure 5.1 Sectioned black oreo otoliths viewed with transmitted light.

a) 36.2 cm TL, M; 48 years (40x magnification)

b) 41.5 cm TL, M; 100 years (100x magnification)

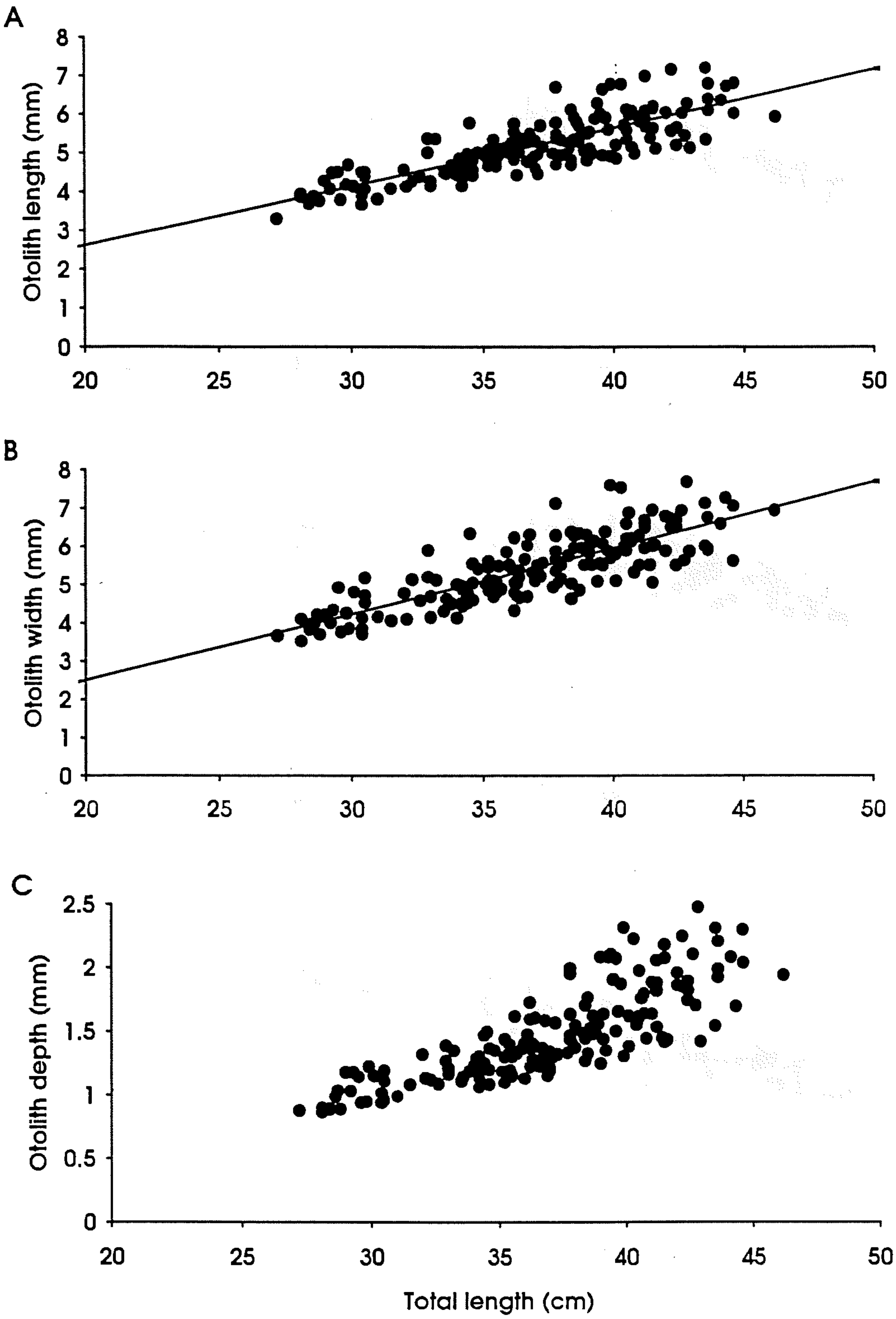


Figure 5.2. Black oreo (all fish combined) - relationship between:
A. Otolith length and fish length (OL = 0.152 FL - 0.152, R^2=0.679, n=166)
B. Otolith width and fish length (OWD = 0.173 FL - 0.957, R^2=0.667, n=166)
C. Otolith depth and fish length (n=166)

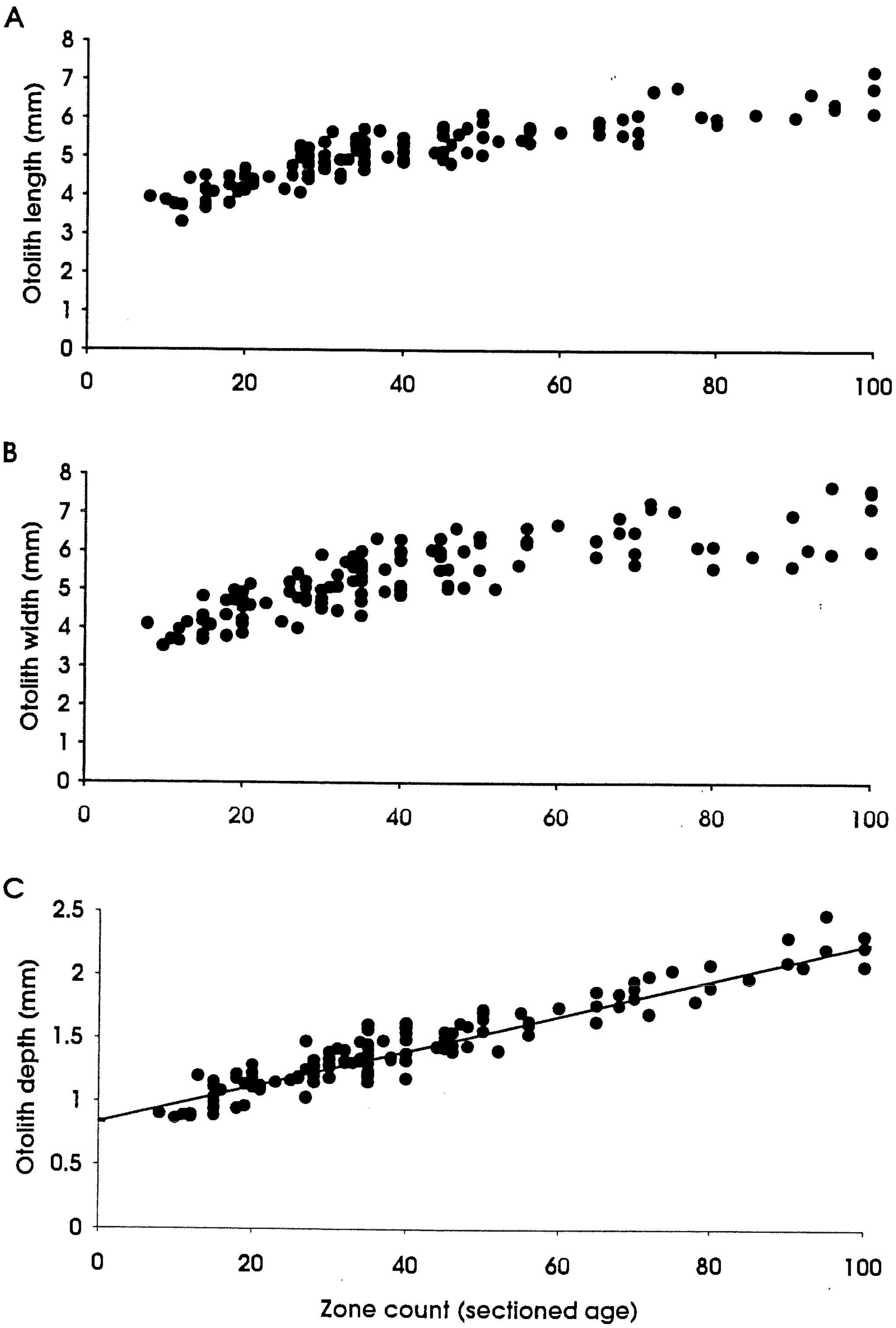


Figure 5.3. Black oreo (all fish combined) - relationship between:
A. Otolith length and sectioned age (n=121)
B. Otolith with and sectioned age (n=121)
C. Otolith depth and sectioned age (OD = 0.014 SA + 0.835, R^2=0.913, n=121)

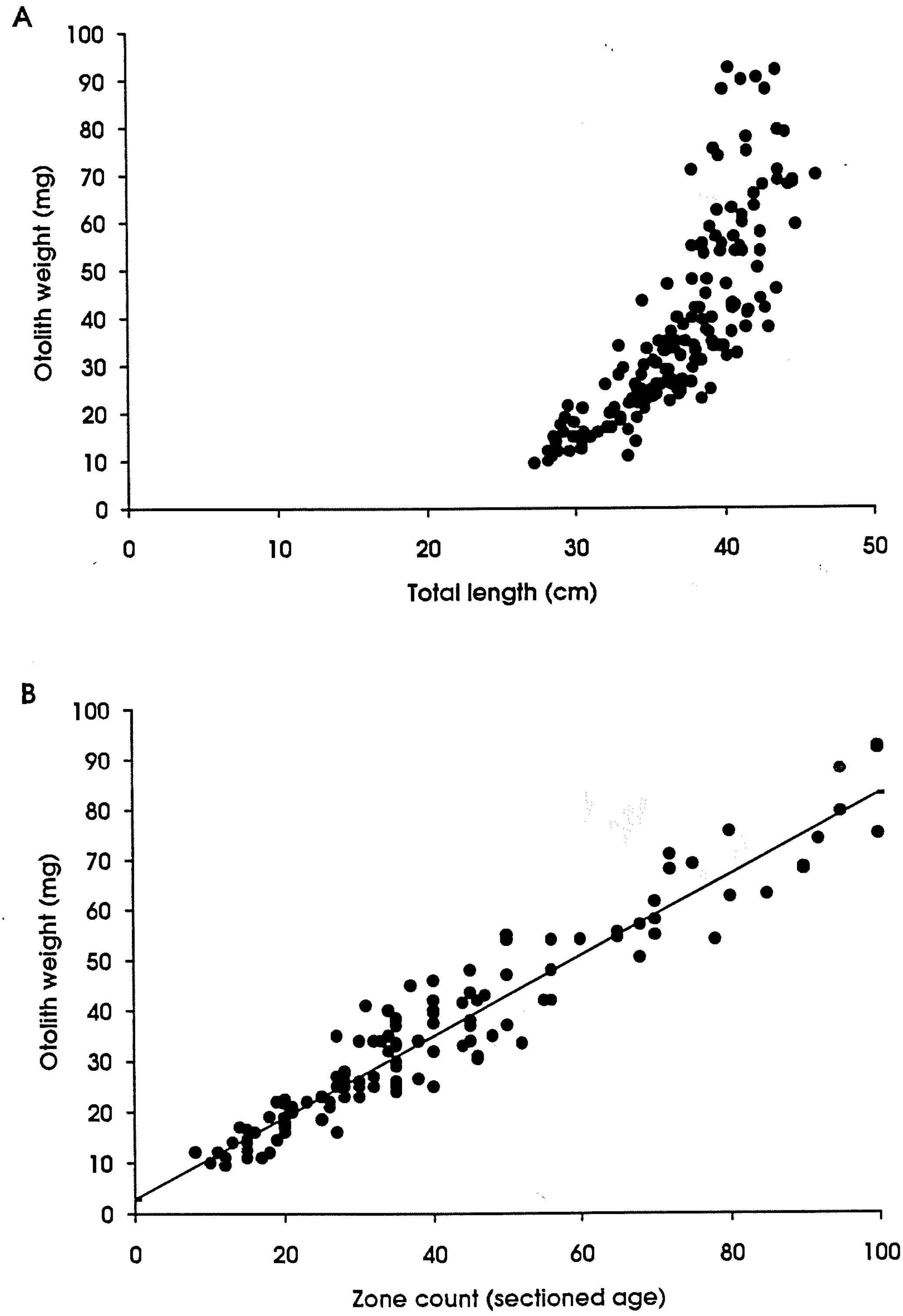


Figure 5.4. Black oreo (all fish combined) - relationship between:
A. Otolith weight and fish length (n=173)
B. Otolith weight and sectioned age (OW = 0.801 SA + 2.929, R^2=0.923, n=126)

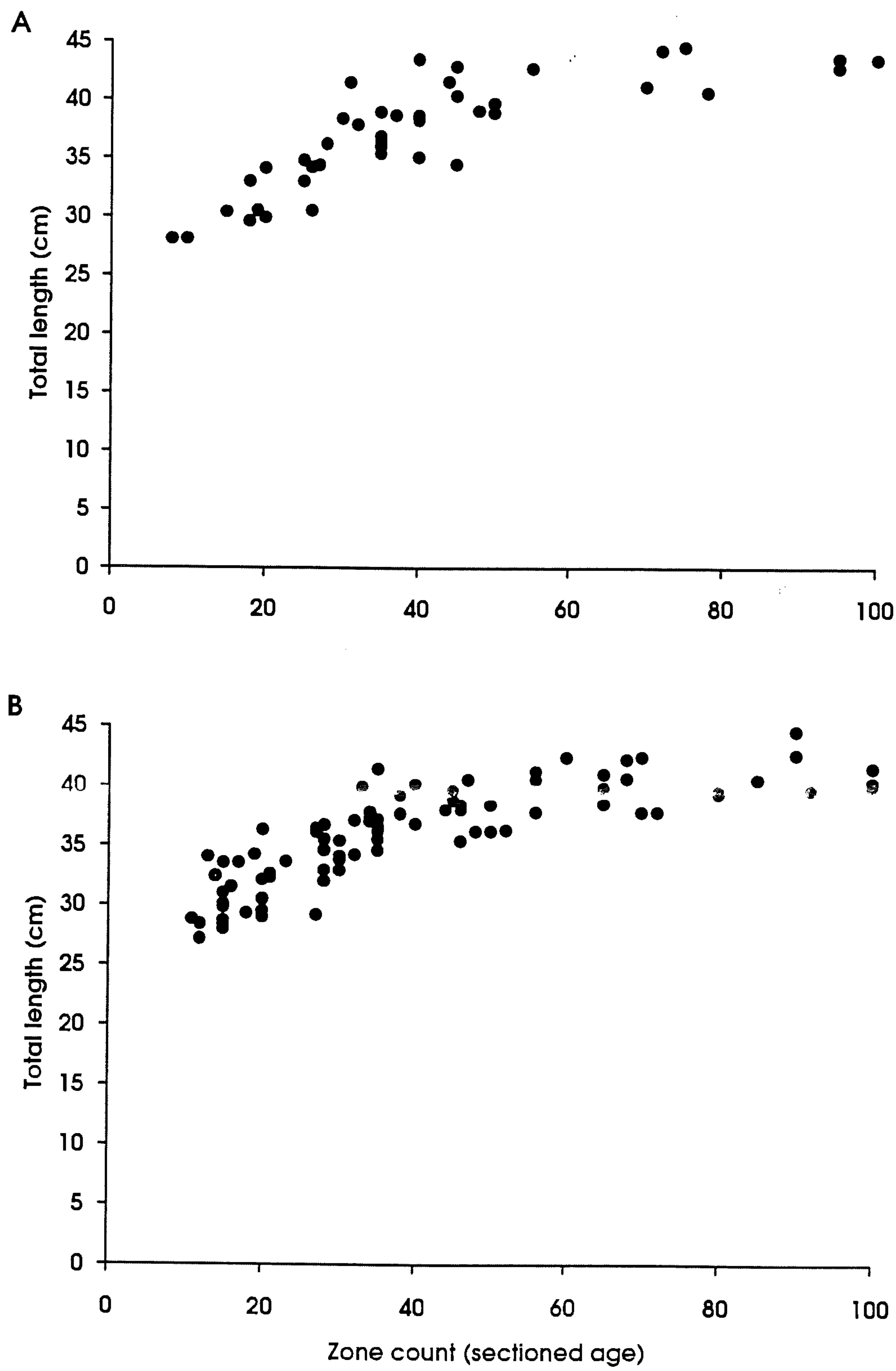


Figure 5.5. Black oreo - relationship between fish length and sectioned age
A. Females (n=43) B. Males (n=84)

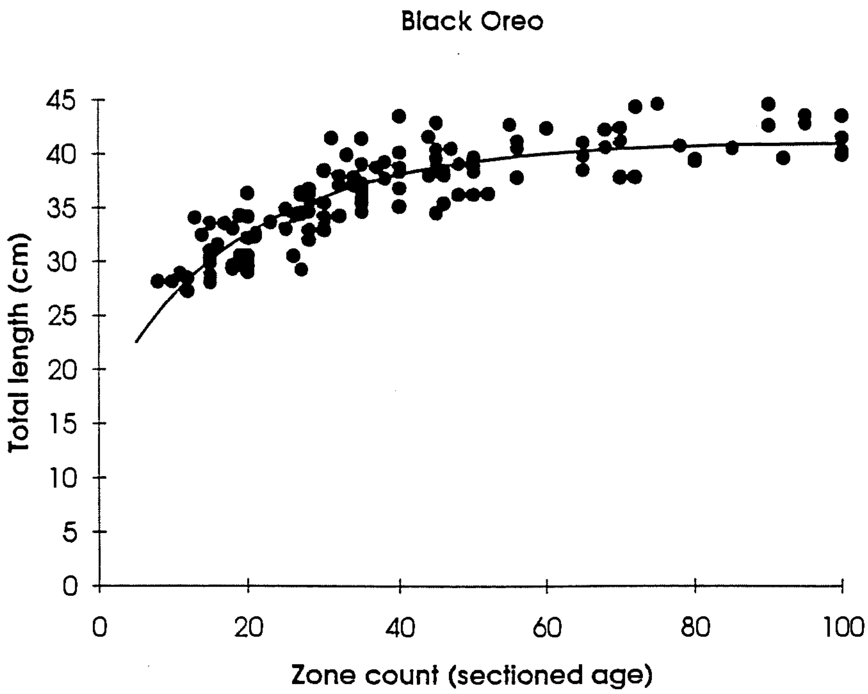


Figure 5.6. Von Bertalanffy growth curve for black oreo (N=127).

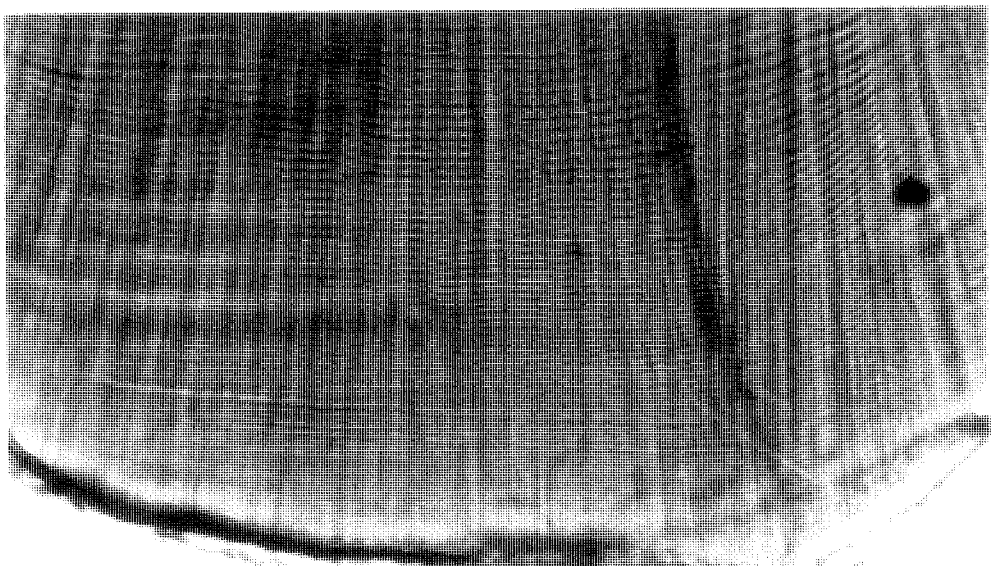
Figure 6.1 Sectioned spiky oreo otoliths viewed with transmitted light.

a) 26.8 cm TL, F; 20 years (40x)

b) 35.1 cm TL, M; 70 years (40x)

c) 34.8 cm TL, M; 100 years (100x)





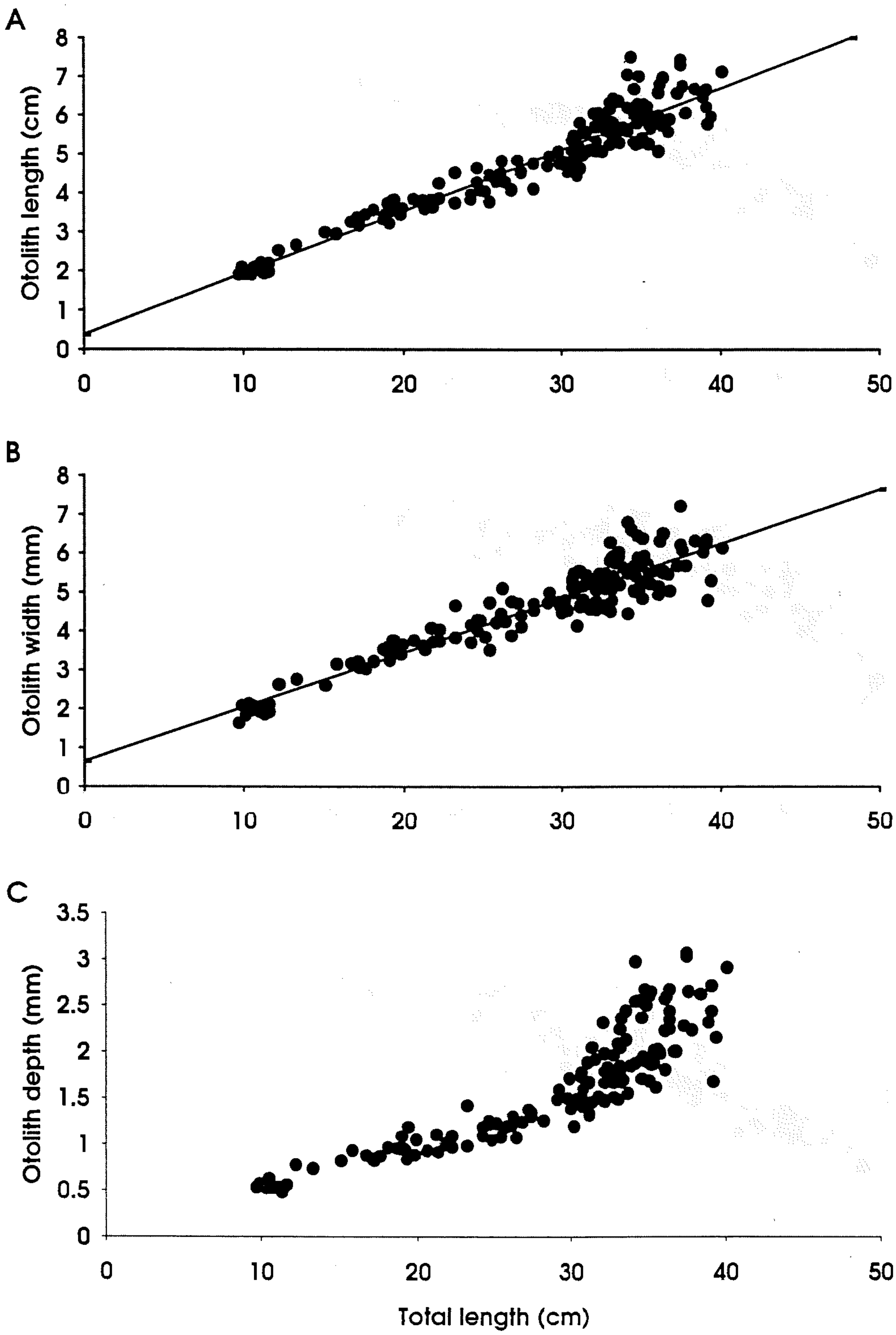


Figure 6.2. Spiky oreo (all fish combined) - relationship between:
A. Otolith length and fish length (OL = 0.158 FL + 0.383, R^2=0.907, n=151)
B. Otolith width and fish length (OWD = 0.140 FL + 0.654, R^2=0.878, n=151)
C. Otolith depth and fish length (n=151)

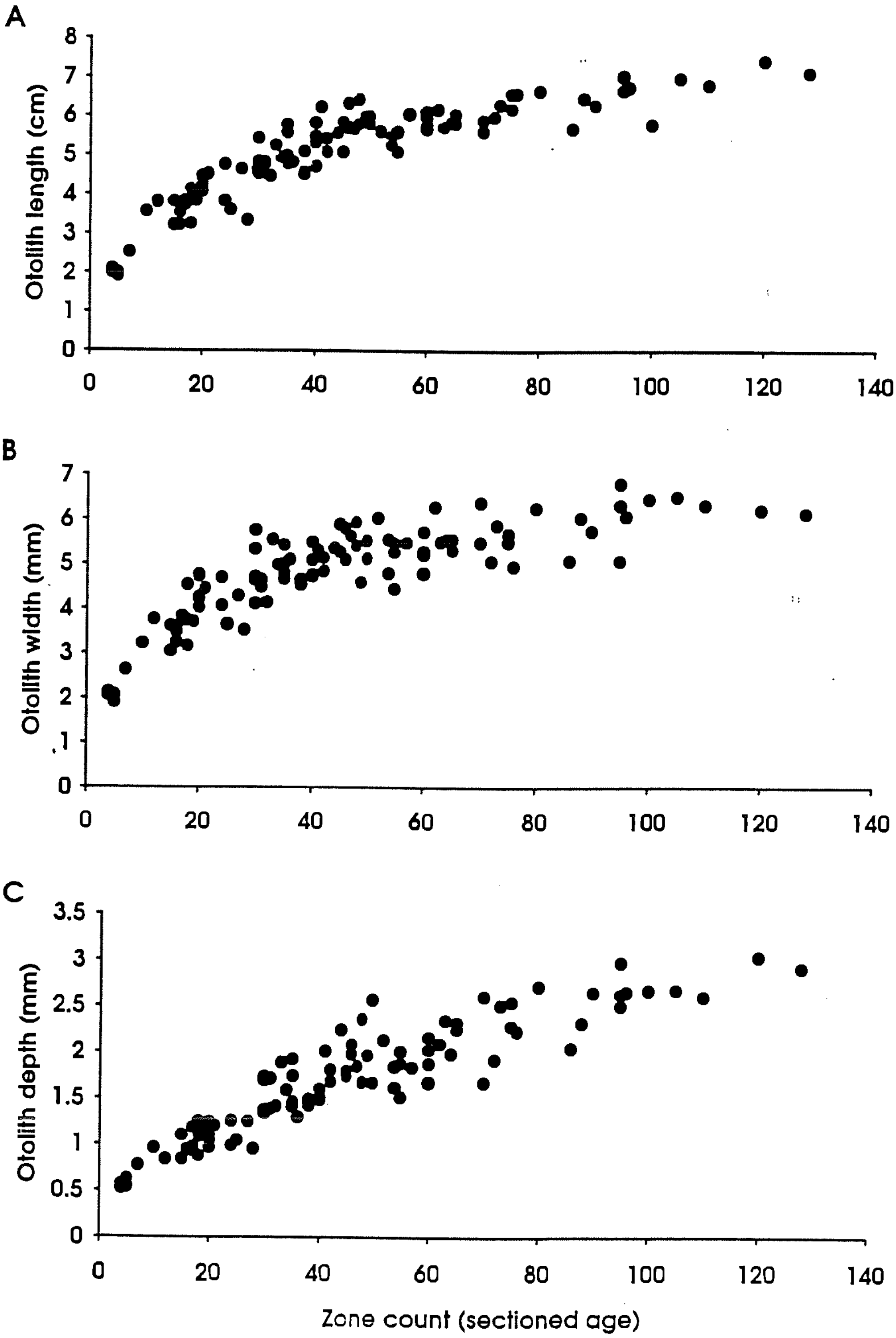
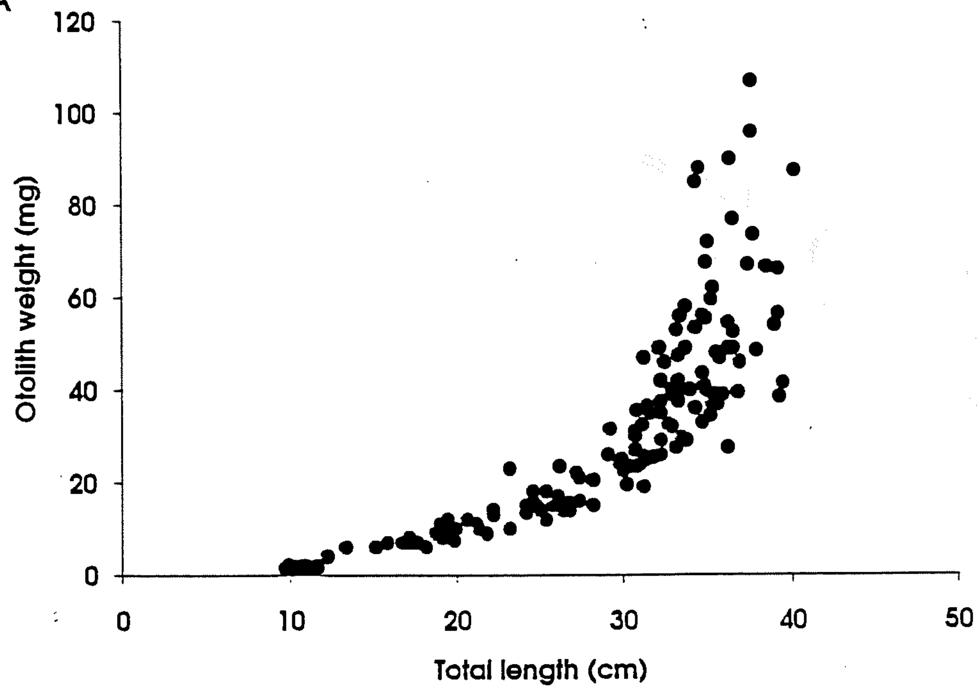


Figure 6.3. Spiky oreo (all fish combined) -relationship between:
A. Otolith length and sectioned age (n=104)
B. Otolith width and sectioned age (n=104)
C. Otolith depth and sectioned age (n=104)

A



B

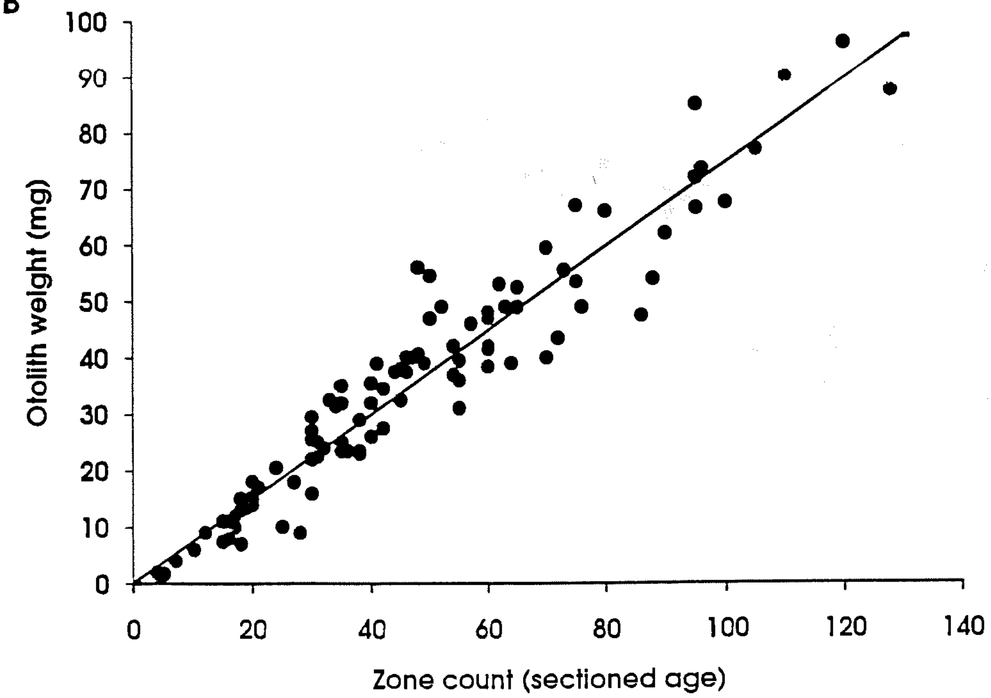


Figure 6.4. Spiky oreo (all fish combined) - relationship between:
A. Otolith weight and fish length (n=150)
B. Otolith weight and sectioned age (OW = 0.746 SA + 0.201, R^2=0.922, n=103)

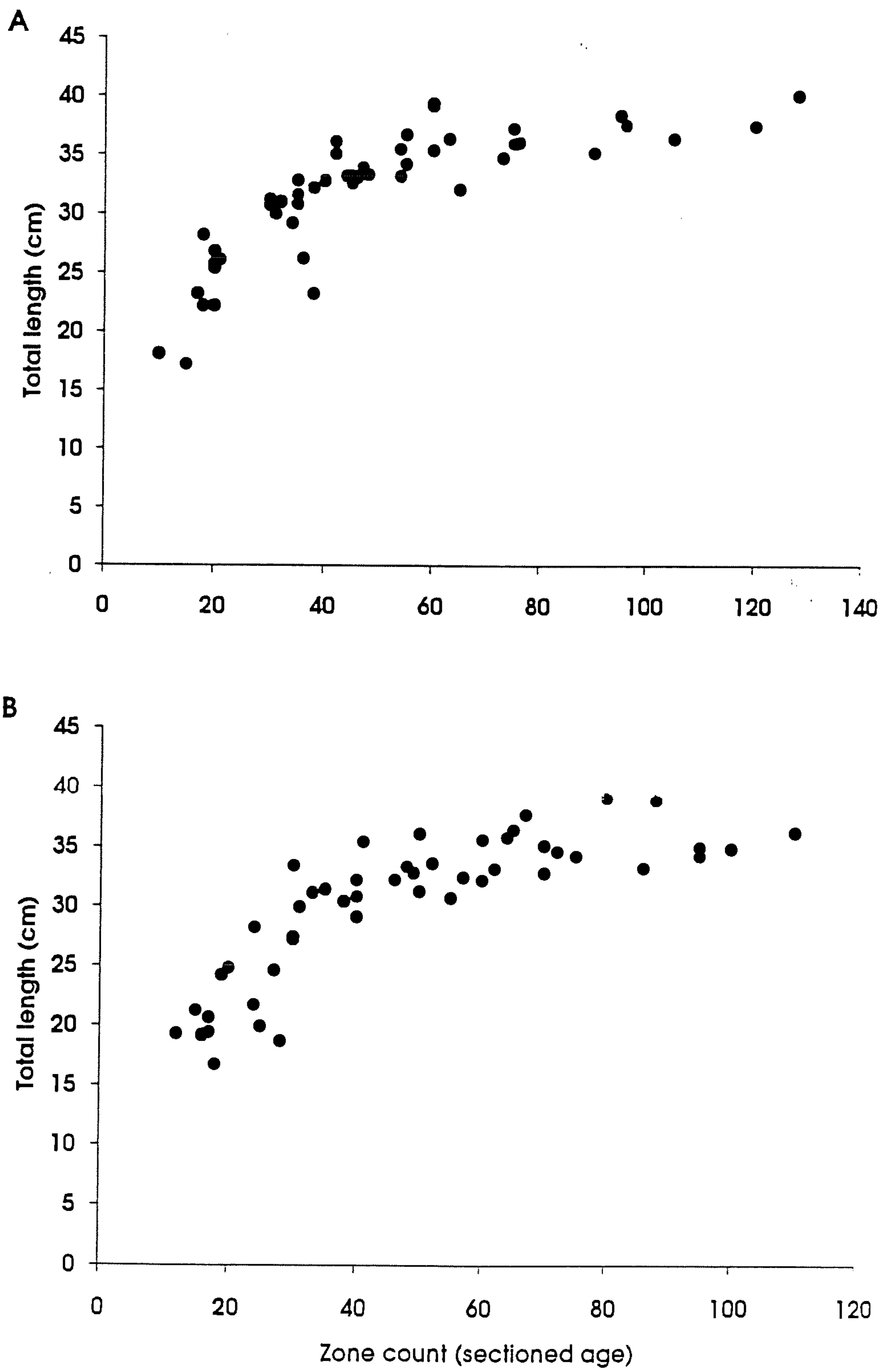


Figure 6.5. Spiky oreo - relationship between fish length and sectioned age
A. Females (n=49) B. Males (n=50)

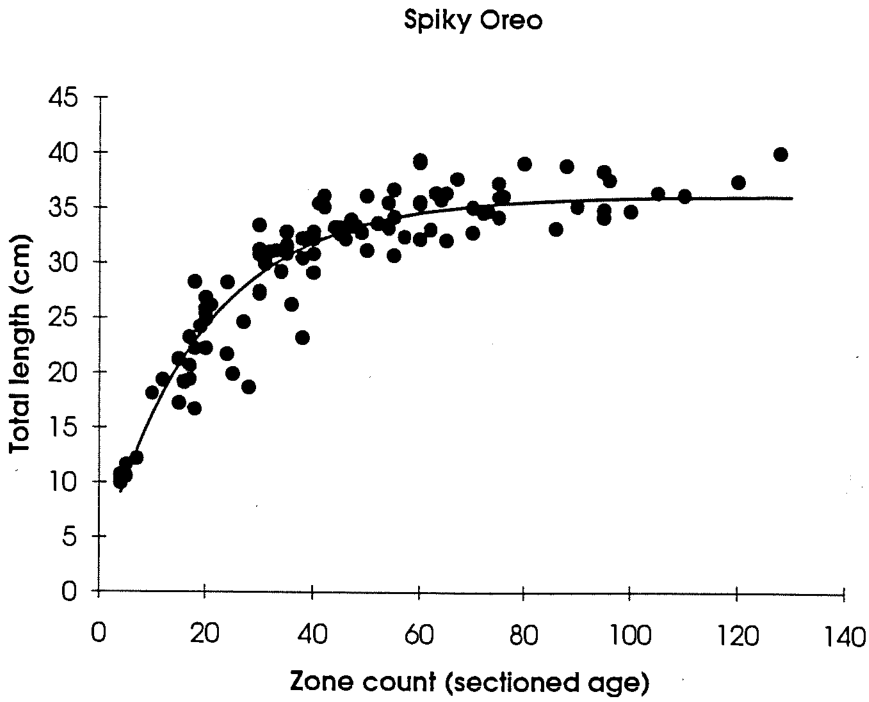


Figure 6.6. Von Bertalanffy growth curve for spky oreo (N=106).

Fishing Industry Research and Development Trust Fund

Application for Grant - 1991/92

SECTION 1 - PROJECT TITLE

Development of methods to age commercially important dories and oreos.

SECTION 2 - KEYWORDS

ageing/dories and oreos/stock assessment/south-eastern Australia

SECTION 3 - OBJECTIVES

1. To develop methods for ageing dories and oreos using hardparts.

2. To validate assigned ages of juveniles by analysing poly-modal length frequency distributions.

SECTION 4 - JUSTIFICATION

Knowledge of the age structure of fish populations is fundamental to an understanding of their dynamics and the effect of exploitation upon them. No methods, however, for the routine ageing of dories (Family Zeidae) and oreos (Family Oreosomatidae) have been developed in Australia. This was noted by the Demersal and Pelagic Fish Research Group at their meeting at Queenscliff in May 1990 (DPFRG 29) who stated that "assessment of these species is difficult because methods for ageing them still need to be developed.

Four species of dory (Family Zeidae) are landed in the South East Trawl Fishery (SET), John dory (*Zeus faber*), mirror dory (*Zenopsis nebulosus*), king dory (*Cyttus traversi*) and silver dory (*C australis*). The combined catch of these species in the SET in 1989 was approximately 800 tonnes valued in excess of $2 million.

John dory comprise a high value/low volume catch taken predominantly from the Eastern Sector of the fishery. Catches have been stable at about 250-300 tonnes but there is no detailed assessment of likely sustainable yields. John dory are also taken as a by-catch of the east coast trawl fishery but catch details were unavailable.

Mirror dory are taken as a by-catch of the gemfish fishery, mostly in the Eastern Sector. Recently catches have increased to about half of the peak landings of 800 tonnes in 1978. The reasons for the decline and subsequent increase is not known but possibly reflects fishing practices. There is some evidence, from length frequency distributions, that recent increases could be due to several strong year classes. Without age composition data, however, it is not possible say that this is the correct interpretation.

King dory are taken almost exclusively from the South West Sector. Annual catches are about 100 tonnes. Catches from western Bass Strait appear low when compared to the estimated biomass but CPUE data from this area and anecdotal reports from fishermen suggest declining catch rates.

Silver dory are taken in smaller amounts than the other three and throughout the fishery.

The relative importance of these species to the fishery is likely to increase in the next few years following the depletion of some of the major species, eg gemfish and redfish. It is also expected that with the implementation of ITQs there will be a need for detailed assessments of all species caught in the SET.

Oreos are caught in deepwater (> 600m), at present as a by-catch of the orange roughy fishery. Five species of oreo are found in the SET; warty (*Allocyttus verrucosus*), spiky (*Neocyttus rhomboidalis*), smooth (*Pseudocyttus maculatus*) and black oreo (*A.* sp) are common. The fifth species, ox-eyed oreo (*Oreosoma atlanticum*) is rarely caught.

Total landings of oreos during 1989 was about 200 tonnes, comprising mostly smooth and spiky. There is potential, however, for greatly increased landings as considerable discarding occurs mostly due to marketting problems. Also, large (>20 tonnes) individual catches have been reported (J Lyle, Dept Sea Fisheries Tasmania, pers. comm.).

It is anticipated that in Australia as fishing down of the orange roughy resource occurs and marketing problems are solved there will be increased target fishing for oreos.

Black and smooth oreos are also an important constituent of the deepwater trawl fishery in New Zealand with the annual combined catch in excess of 20,000 tonnes.

Warty oreo have been aged from otoliths and scales (Mel'nikov 1982) but assigned ages were not validated. Carter (1990 unpublished MS) found that sectioned otoliths were easier to interpret than whole otoliths but due to the irregular crystalline structure of many otoliths this technique could only be used with a small proportion of those sampled. Consequently, Carter used vertebrae.

Davies et al (1988) examined the otolith ultrastructure of smooth and black oreo identifying rings analagous to both daily and annual increments. Deposition was found to be irregular and they concluded that this would make validation difficult. Sample sizes, however, were very small (14 and 25 for smooth and black oreo respectively).

This proposal is for an 18 month research program designed to develop methods to age dories and oreos but with less emphasis given to silver dory, the least commercially important of the dories. It is aimed at the SET but some of the species are also taken in the adjoining Great Australian Bight Trawl Fishery and the results will be applicable to this fishery as well. It should be noted that the proposal is aimed at developing methods for ageing rather than providing definitive growth and mortality estimates. However, if methods are developed and adequate samples are available growth and mortality estimates may be forthcoming.

The proposal will receive support from the Fisheries Research Institute (New South Wales) and the Division of Sea Fisheries (Tasmania) in the provision of otoliths sampled from commercial landings and research surveys, and size distribution data from market sampling.

The success of the project may be gauged primarily from the methods developed and the relevance of the ageing data to the management of the fishery.

REFERENCES

Carter, D. (1990) Age and growth of the warty oreo (*Allocyttus verrucosus*). Unpublished Ms, Marine Science Laboratories.

Davies, N.M., Gauldie, R.W., Crane, S.A., and Thompson, R.K (1988). Otolith ultrastructure of smooth oreo, *Pseudocyttus maculatus*, and black oreo, *Allocyttus* sp., species. Fishery Bulletin 86, 499-515.

Mel'nikov, Y.S. (1981). Size-age composition and growth pattern of *Allocyttus verrucosus* (Oreosomatidae). Ichthyology 21, 178-184.

SECTION 5 - PROPOSAL IN DETAIL.

a) Plan of Operation

i) Method of Procedure

Development of Methods to Age Dories and Oreos

Initially historical collections of otoliths held at the Marine Science Laboratories, Queenscliff and by the Division of Sea Fisheries, Tasmania will be examined. Otoliths have been collected from mirror and king dory, and warty, spiky and smooth oreo. A range of techniques will be employed including:

- examination of whole otoliths
- sectioned otoliths
- burnt cross-sections
- stained whole and sectioned otoliths

In addition, samples of fresh fish will be obtained and all hard parts, including vertebrae, dorsal spines and opercular bones, examined.

For John dory and black oreo (only recently caught in Australian waters) all hard parts will be examined to ascertain the most useful structure for ageing purposes,

Validation of Assigned Ages of Juveniles.

Length frequency distributions of dories and oreos, from previous survey and commercial sampling by the Fisheries Division, Victoria, Division of Sea Fisheries Tasmania and the Division of Fisheries, NSW, are available for most species. These distributions show distinct modes particularly for small fish which appear to represent distinct cohorts. These will be used to validate ages determined from hard parts.

ii) Facilities Available

The Marine Science Laboratories of the Fisheries Division will provide the following:

- office, laboratory space and vehicles
- microscope and computer facilites

- assistance of market measurers for sampling
- technical advice from the Central Ageing Facility

b) Supporting Data

i) Previous work in this or related fields

Previous resarch on dories and oreos to date has basically been aimed at monitoring size distributions. It has been undertaken as part of routine market sampling (Vic, Tas, and NSW) and of surveys of the continental slope (Vic and Tas). In addition, Ms D Carter of MSL conducted a Masters Qualifying project on a preliminary examination of age and growth of warty oreo.

The Marine Science Laboratories has a proven record in conducting this type of research. It has demonstrated skills in the ageing of a wide range of fish species (including orange roughy). Techniques such as sectioning and breaking and burning otoliths are routinely employed at the laboratories.

SECTION 6 - RESEARCH PRIORITY

The proposed program falls within the Councils stated priority of advancement of fisheries science namely fish ageing techniques. The proposal also addresses the priority of fish resource assessment, particularly biology and population dynamics.

SECTION 7 - TRANSFER OF RESULTS TO INDUSTRY

Results of the study will be presented to industry directly in the form of meetings and seminars and as articles in popular magazines such as Australian Fisheries. Application of the results to the management of the fishery will take place through the normal consultative processess.

Results will be presented at the annual meetings of the Demersal and Pelagic Fish Research Group and where applicable as manuscripts for publication in scientific journals.

SECTION 8 - PREDICTED COMMENCEMENT & COMPLETION DATE

Commencement Date: 1/7/91

Duration of Project 1.5 (in years)

Completion Date: 31/12/92

SECTION 9 - REQUESTED BUDGET

Item	Requested	Indicative
	1991/92	1992/93
Salaries & Wages	30815	15760
Operating Expenses	6000	2500~~0~~
Travel Expenses	1507	754
Capital Items	Nil	Nil
TOTAL	$ 38 322	$19 014

SECTION 10 - FUNDS SOUGHT FROM OTHER SOURCES

SOURCE Nil $

SECTION 11-FINANCIAL CONTRIBUTION OF APPLICANT(See Appendix 1)

	1991/92	1992/93	Total
Salaries and Wages	5977	3003	8980
Operating Expenses	18396	9382	26276
Total	$ 24373	$ 12385	$ 35256

SECTION 12 - BUDGET IN DETAIL

	Requested 1991/92	Indicative 1992/93
Salaries and Wages		
Scientific Officer (SCI-1)	24187	12400
Overtime	3000	1500
On costs @15%	3628	1860
TOTAL	30815	15760
Travelling Costs		
Travel allowance (15 days)	1507	754
TOTAL	1507	754
Operating Costs		
Fish purchases	1500	500
Vehicle running costs	2000	1000
Freight	1000	500
Miscellaneous costs (Resin, slides etc)	1500	500
TOTAL	6000	2500
Capital Items		
Total capital items	Nil	Nil
TOTAL REQUESTED BUDGET	38322	19014

SECTION 13 - ORGANIZATION

Head Responsible for Project Dr Wayne Chamley

Name of Organization Fisheries Division

Address Department of Conservation and Environment
240 Victoria Parade
East Melbourne Victoria 3004

Telephone (03) 4124011 Fax (03) 4124623

SECTION 14 - PROJECT SUPERVISOR

Name Dr David Smith

Address Department of Conservation and Environment
Marine Science Laboratories
P O Box 114
Queenscliff Victoria 3225

Telephone (052) 520 111 Fax (052) 520 270

SECTION 15 - STAFF INVOLVED ON PROJECT

Dr David Smith (SCI-3) PhD (10%) Project Supervisor

Scientific Officer (SCI-1) to be appointed

Market Measurers (5%)

SECTION 16 - ADMINISTRATIVE CONTACT

Name Mr Paul Walker

Address Department of Conservation and Environment
P O Box 114
Queenscliff Victoria 3225

Telephone (052) 520 111 Fax (052) 520 270

FINANCIAL INFORMATION

Justification of Information

Travelling Costs

Travel allowance - this has been costed on the basis of 15 days travel to ports throughout Victoria to obtain samples of dories and oreos as required. *High Priority.*

Operating Costs

Fish purchases - obtaining samples for age determination purposes will, in some cases, require the purchase of fish. Species such as John dory command a premium price in fish markets. *High priority.*

Vehicle running costs - required for to and from travel to ports etc. *High priority.*

Freight - to cover the costs of interstate transfer of otoliths, whole fish etc. *High priority.*

Miscellaneous costs - to cover the purchase of materials used in ageing, such as slides, sectioning blades, chemicals and resins, plus general consumables. *High priority.*

Appendix 2

Validation of otolith increment age estimates for a deepwater fish species, warty oreo, *Allocyttus verrucosus*, by radiometric analysis.

Bryce D. Stewart[1], Gwen. E. Fenton[2], David C. Smith[1], Stephen. A. Short[3]

1 Department of Conservation and Natural Resources, Marine Science Laboratories, P. O. Box 114, Queenscliff, Victoria 3225, Australia.

2 Zoology Department, University of Tasmania, G. P. O. Box 252C, Hobart, Tasmania 7001, Australia.

3 Environmental Radiochemistry Laboratory, ANSTO, Private Mail Bag 1, Menai, N. S. W. 2234, Australia

Abstract

Validation of age estimates for deep-water fish species has been difficult in the past as standard validation techniques are not applicable. In this study, otolith increment age estimates for a deepwater species, warty oreo, *Allocyttus verrucosus*, were validated by comparison with the results from ^{210}Pb / ^{226}Ra radiometric analysis. Initially, whole and broken and burnt otoliths were examined, however, these were found unsuitable for age determination. Transverse sectioning and subsequent grinding of otoliths to a thickness of approximately 0.2 mm revealed increments which provided age estimates for a range of fish sizes. Age estimates ranged from 7 years for an immature fish of 15.2 cm TL to 130 years for a female fish of 36.5 cm TL. Age at maturity was estimated at 24 years for males and 28 years for females. In comparison, radiometric analysis of whole otoliths, using a single linear otolith mass growth rate model suggested maximum ages of 130-170 years for fish of length 34-35 cm. Radiometric ages were also recalculated using a two-stage otolith mass growth rate model in which the growth rate was assumed to slow after maturity to 90 % of the pre-maturity rate. This reduced the maximum age to 132±15 years for a mean fish length of 34.5 cm. Age at maturity for females was estimated at 34 years. The similarity between age estimates from otolith increment counts and radiometric analysis strongly supports the accuracy of results from both methods and encourages further use of such comparisons as an alternative validation technique.

Introduction

Warty oreo, *Allocyttus verrucosus*, is widely distributed in the southern hemisphere (James et al. 1988). Adults inhabit a depth range on the continental slope of 500 to 1300 metres but are most common in depths greater than 800 metres (James et al. 1988). Warty oreo, along with three other oreo species: smooth, *Pseudocyttus maculatus*, black, *Allocyttus niger* and spiky, *Neocyttus rhomboidalis*, are taken commercially in Australia, with a combined catch of 1500 tonnes in 1991 (Lyle et al. 1992). Smooth and black oreos also form a significant fishery in New Zealand with catches of approximately 20 000 tonnes per annum in recent years (Lyle et al. 1992). In Australian waters, oreos were originally taken as a by-catch of orange roughy (*Hoplostethus atlanticus*) fishing but they are becoming an increasingly important component of the south east trawl fishery. In view of the increasing commercial interest in all the oreo species, accurate estimates of age are required for management purposes.

Two previous studies have produced estimates of age and growth for warty oreo. Mel'nikov (1982) estimated age using growth zones on the scales claiming these zones were more clearly defined than those on otoliths. The estimated maximum age was 15 years for females and 14 years for males, although the bulk of the catch was composed of fish 6-9 years old. Carter (1990) attempted to use vertebrae to age warty oreos and claimed a maximum age of approximately 25 years. The age estimates were not validated in either study.

Validating age estimates determined from hard part increment counts is inherently difficult for deepwater fish species. Standard validation methods such as comparison with tagged individuals (Francis et al. 1992), and fluoro-chemical marking (Fowler and Doherty 1992; Francis et al. 1992), are not applicable for species living at extreme depths. Analysis of marginal increments (Mace et al. 1990), and poly-modal length frequency distributions (Gooley 1992), are of limited use as these methods are generally only appropriate for juveniles or young adults. Recent development in radiometric ageing of otoliths (reviewed in Smith et al. 1991 and Fenton and Short 1992), provides an alternative method to increment counts for ageing deep water fish species. Comparison of age estimates determined from these two methods therefore has the potential to be a very useful validation technique.

In this study, we examine the suitability of sagittal otoliths for ageing warty oreo and compare age estimates determined from increment counts and $^{210}Pb/^{226}Ra$ radiometric analysis of whole otoliths. Estimates were determined independently from different specimens in separate laboratories.

Methods

A. Otolith Increment Counts

Otolith Collection

Warty oreos were collected by otter trawl in Western Bass Strait during May 1988, in depths ranging from 800 to 1200 m. Otoliths were dissected from 235 fish and stored dry in envelopes on which relevant information such as location, length, weight and sex was recorded. Total length (TL) of individuals was measured to the nearest millimetre and weight to the nearest gram. Fish ranged in TL from an immature individual of 13.8 cm to a female fish of 37.2 cm.

Otolith Preparation and Examination

1. Whole Otoliths

Pairs of whole sagittal otoliths from warty oreos were examined under a dissecting microscope using reflected light, at magnifications from 6.4 to 50 times. All otoliths were immersed in water and viewed against a black background. Warty oreo sagittal otoliths consist of a regular dorsal lobe separated by a narrow waist at the primordium from an irregular ventral lobe (Figure 1). All age estimates were determined from increment counts along the dorsal lobe.

2. Breaking and Burning

Sagittal otoliths from 5 warty oreo individuals were also examined using two variations of the

"Breaking and Burning" technique (Christensen 1964). Initially, the right otoliths were cut in half transversely and then the cut face was baked on a hot plate until the otoliths were a light brown colour. For comparison, left otoliths were baked whole and then mounted in resin (as for sectioning) before being cut in half. In both cases otoliths were viewed under immersion oil.

3. Sectioning

The left otoliths from all warty oreos were sectioned transversely by mounting them in blocks of clear polyester resin, generally lined up in two rows, with five otoliths in each row. After sufficient time for curing, sections were taken using a Gemmasta circular saw fitted with a diamond impregnated blade of 0.15 mm thickness. Using this procedure up to 5 otoliths were included in each section. Several sections were taken of each row to ensure the primordia of each otolith was included. Sections were then mounted on slides with polyester resin and ground down on wet and dry paper (400 grade followed by 800 grade) to a thickness of approximately 0.1-0.2 mm.

Initially, sections containing all five otoliths were mounted and ground down as a whole. Best results were obtained, however, by mounting each otolith section individually to grind it down. Once sections were judged to be of satisfactory quality a coverslip was mounted on the slide to produce a permanent preparation.

Age estimates were normally obtained by counting increments from the primordia (situated on the distal face) to the proximal edge (Figure 2). In several cases, however, increments were clearer along the dorsal lobe and hence were counted along that plane. To gain estimates of inter and intra reader variability, a random subsample of 50 otoliths were aged twice by the primary reader and then again by a secondary reader. Beamish and Fournier's (1981) method was used to estimate precision and the slope of a regression between age estimates was compared to one to determine if there was any bias. All otoliths were read without any reference to biological information or previous age estimates.

4. Otolith morphometrics

To determine the nature of otolith growth, otolith morphometrics were also measured. Otolith length, width and depth was measured to the nearest micrometre using a customised "Optimas" image analysis system and otolith weight was measured to the nearest microgram. For the first 100 specimens measurements were taken on both otoliths, however, a paired *t*-test revealed no significant difference between left and right otoliths at the 0.05 level. As a result, subsequent measurements were only taken on the left otoliths.

B. Radiometric Analysis

Otolith Collection

Warty oreos were collected off the west coast of Tasmania in depths from 800 to 1200 m during cruises by the Tasmanian Department of Primary Industry, Division of Sea Fisheries in August and November 1988. Sagittal otoliths were dissected from fish and stored dry.

Radiometric analysis was restricted to female fish, except for fish < 17 cm TL. Individual otoliths were weighed to the nearest 0.1 mg. The small size and bilobed shape of warty oreo otoliths made isolation of otolith cores impractical. Whole otoliths were therefore radioanalysed. Samples of approximately 1 g were required for the radioanalysis making pooling of otoliths necessary in all cases. For the smallest size classes (< 17 cm) it was necessary to pool in excess of 100 otoliths. Selection of the otoliths for each analysis was based on similarity of fish length, otolith weight, sex, site and date of collection.

Radiometric analysis

The analysis of ^{210}Pb via its alpha-emitting, short-lived daughter proxy ^{210}Po, followed the method described in Fenton et al. (1991), employing high resolution alpha-spectrometry. Polonium-210 (half-life 138 days) was assumed to be in equilibrium with ^{210}Pb in all samples, since all samples were collected more than 1 year before analysis. The ^{210}Po reagent blank was 0.0082 ± 0.0015 dpm. Recovery of ^{210}Po was invariably > 90%. Instrumental background counts (for ^{208}Po and ^{210}Po) were less than 1 count per day. Analysis of radium-226 was made using a direct alpha spectrometry technique (Fenton et al. 1991). Mean activity of the ^{226}Ra reagent blank was 0.0192 ± 0.0019 dpm. In this study, the reagent blanks for ^{210}Po and ^{226}Ra were even lower than obtained in a previous study on orange roughy (Fenton et al. 1991) (0.0103 ± 0.0027 dpm and 0.0255 ± 0.0023 dpm respectively) due to improved quality control of reagents used for radioanalysis.

Stable element analysis

The level of stable lead, barium, calcium and strontium in three otolith samples was analysed. Samples from juvenile, pre-maturity and post-maturity warty oreos were chosen. An aliquot of the dissolved otolith solution used for ^{210}Pb and ^{226}Ra analysis was analysed by inductively coupled plasma mass spectrometry (ICP-MS) for lead and barium and inductively coupled plasma atomic emission spectrometry (ICP-AES) for strontium and calcium.

Results

A. Otolith Increment Counts

Whole otoliths

Age estimates from whole otoliths were generally only possible for fish below 25 cm in length. As a result, of the 235 pairs of otoliths examined, age estimates were only possible from 47. Confidence in the majority of these age estimates was also low. Otoliths from larger fish were normally only clear at the edge and it was often difficult to distinguish between what at this stage were presumed to be annual increments, and other structures. It was concluded that examination of whole sagittal otoliths was not suitable for age determination.

Breaking and Burning

Limited success was achieved with the "breaking and burning" technique. Cutting otoliths in half and then baking them enhanced the visibility of increments towards the edge of otoliths, but the otolith centres were very difficult to interpret. This process was also very time consuming. Embedding previously baked otoliths and then cutting them in half was less time consuming, but otoliths were virtually unreadable. It was concluded that both variations of the "breaking and burning" technique were unsuitable for age determination.

Sectioning

Sectioning and subsequent grinding of otoliths was by far the most successful method for obtaining age estimates. Much more detail was visible than in either whole or broken and burnt otoliths and the technique also allowed for faster processing than breaking and burning. Of the 235 sectioned otoliths examined, age estimates were obtained from 138. Failure to obtain age estimates was due to unsuccessful preparations (50), unclear otoliths (45) and broken otoliths (3). The high number of unsuccessful preparations was caused largely by the difficulty of sectioning and grinding precisely to the mid plane of the otolith. Assigned ages ranged from 7 years for an immature fish of 15.2 cm TL to 130 years for a female fish of 36.5 cm TL. The first 4 to 5 increments visible in warty oreo otoliths were particularly broad and opaque and these were followed by a rapid transition to narrower increments (Figure 3). In otoliths aged at greater than 50, the increments became extremely narrow but were regular towards the edge of the otolith (Figure 4).

Beamish and Fournier's (1981) method gave a low intra-reader variability of 3.3%. A regression of the two age estimates gave a slope of 0.97, and was not significantly different from one (t=1.04, df=48, ns), showing there was no significant bias.

Inter-readability tests produced similar results with a low variability of 3.8 % and a regression slope of 0.96. This was not significantly different from one (t=1.02, df=46, ns), again showing there was no significant bias.

Otolith growth

The nature of otolith growth was examined in a number of ways. Initially, otolith length, width and depth was plotted against fish length (Figure 5). There is a linear relationship between both otolith length and width with fish length, but there is a curvilinear increase of otolith depth with fish length.

Otolith length, width and depth were also plotted against sectioned age estimates (Figure 6). The relationship between otolith length and width with age is asymptotic. Growth in otolith depth with age, however, appears to be linear over the size range examined.

Otolith weight was also plotted against fish length and sectioned age estimates (Figure 7). There is a curvilinear increase of otolith weight with fish length but a linear relationship (R^2=0.94) between otolith weight and age, giving an otolith mass growth rate of 0.859 mg.yr^{-1}.

Overall, these results indicate that above a certain age and fish size, otoliths virtually cease to grow in length and width, while growth in otolith depth continues. This continued growth in otolith depth accounts for the linear increase of otolith weight with age throughout the lifespan of warty oreo.

B. Radiometric Analysis

Stable element analysis

The results of the ICP-MS and ICP-AES analysis are provided in Table 1. Low levels of stable lead were found in all three samples tested. Stable lead ranged from 0.10-0.63 ppm with the highest level found in the juvenile fish. Barium levels were ranged from 4.61-8.39 ppm. The ratio of Pb/Ba ranged between 0.02-0.11. The Sr/Ca ratio ranged between 0.0073 and 0.0084.

Fenton and Short (1992) proposed that the pattern of ^{210}Pb and ^{226}Ra uptake could be checked indirectly by measuring levels of the stable elements lead and barium. Any major change in the stable element uptake patterns would be reflected in an equivalent change in the uptake of ^{210}Pb and ^{226}Ra into the otolith. Although most of the ^{210}Pb present in the otolith is derived by radioactive decay of the ^{226}Ra a small amount may be incorporated from the environment (i.e. allogenically). The barium and ^{226}Ra contents of warty oreo otoliths remained fairly constant throughout life. The ICPMS analyses showed that while stable lead uptake from the environment into the otolith was low, it was slightly higher in smaller fish (LH2167 18.5cm) than in the larger fish. The diet of warty oreos shows little seasonal difference in diet, with only minor variation in percentage occurrence of prey items over a 2 year period (Lyle et al. 1991). Furthermore warty oreos do not perform vertical migrations (Mel'nikov 1980). However, stable Pb/Ba ratios did not change significantly between the juvenile specimens and the older fish suggesting an insignificant change in R (=(^{210}Pb/^{226}Ra)$_o$) the intial ^{210}Pb/^{226}Ra activity ratio at the time of deposition into the otolith.

^{210}Pb and ^{226}Ra analysis

The results of the radiometric analysis are given in Table 2. The radium specific activities ranged between 0.0391 ± 0.0031 and 0.06794 ± 0.0042 dpm.g^{-1} with a mean value of 0.053 ± 0.009 dpm.g^{-1}. There was no significant difference between the ^{226}Ra specific activities of pre-maturity fish and post-maturity fish ($t=0.31;p>0.5;n=11$). Activity ratios have been calculated using the actual ^{226}Ra specific activities for each analysis. The ^{210}Pb specific activities ranged from 0.0080 to 0.0560 dpm.g^{-1} with higher levels recorded for larger (older) fish. The radiometric results combined with the stable element checks confirm that the ^{210}Pb present in the otoliths is largely formed by in-situ decay of ^{226}Ra and therefore can provide an independent method to determine fish age.

The uptake activity ratio R (^{210}Pb/^{226}Ra)$_o$) was estimated from the ratios obtained for the smallest/youngest fish analysed. R must be below 0.2 since 4 analyses fall below this value. Plotting the ^{210}Pb specific activities against fish length indicated that R would not be greater than 0.1 (exponential model) and it could be as low as 0 (linear model). The value chosen for all calculations of age was 0.05. Note that a R value of 0.1 would only reduce the oldest fish ages by about 10 years and a R value of 0.0 would increase ages by about 10 years.

Calculation of fish age

1) Mean otolith age

The mean otolith age has been calculated from the degree of ^{210}Pb ingrowth (assuming an initial activity ratio of 0.05) using the equation:.

$$t = \frac{-1}{\lambda_p}\left[\frac{\ln(1-A)}{1-R}\right]$$

where t = age (years)

λ_p = decay constant for ^{210}Pb (0.03114 years^{-1})

A = $(^{210}Pb/^{226}Ra)_t$ = activity at time t

R = $(^{210}Pb/^{226}Ra)_o$ = initial activity ratio at time of deposition (assumed to be 0.05)

The mean otolith age of warty oreo ranged from 3.9-54.4 years (Table 2). This calculation takes no account of otolith mass growth, however it is useful to demonstrate that fish age will be significantly greater than, (approximately twice), the mean age of the otolith. However in order to calculate fish age radiometrically the mass-growth regime of the otolith has to be taken into account, since the otolith adds mass gradually throughout life.

2) Constant growth model

The simplest model of otolith mass growth assumes a constant mass growth (linear) model. Ages have therefore been calculated (Table 2) using the linear growth model equation derived by Bennett et al. (1982):

$$A = 1-(1-R)\frac{1-e^{-\lambda_p t}}{\lambda_p t}$$

where A = $(^{210}Pb/^{226}Ra)_t$ = activity at time t

R = $(^{210}Pb/^{226}Ra)_o$ = initial activity ratio at time of deposition (set 0.05)

λ_p= decay constant for ^{210}Pb (0.03114 year^{-1})

Application of this model to the radiometric data gives a maximum age of 174 years for a pooled sample of 6 fish 34.9 ± 0.8 cm TL (Table 2).

The age at maturity (t_1), was estimated from the relationship of linear mass growth radiometric age and fish length for warty oreo < 32 cm TL:

$$\text{Linear age}=-25.168 +2.1231 \text{ fish length} \qquad (R^2=0.61)$$

Using 28 cm TL as the length of female maturation (Lyle et al. 1991), this corresponds to an age at maturity of 34.3 years.

3) <u>Two phase growth-rate model</u>

The mass growth of fish otoliths has generally been shown to reduce after maturity in several species, (Pannella 1980; Williams and Bedford 1974; Boehlert 1985). Bennett et al. (1982), in their radiometric ageing study of *Sebastes diploproa*, estimated growth slowed to 30% of its initial rate beyond age 14 years. Fenton et al. (1991) inferred that otolith mass-growth slowed to approximately 45% of its juvenile rate for mature orange roughy. Recent data on the mass growth of orange roughy otoliths based on sectioned ages (Smith et al. in press) has found that the reduction is closer to 60% beyond maturity.

However, the results for warty oreo from the examination of sectioned otoliths do not suggest a significant change in otolith mass growth rate after maturity. There is some slight indication of a reduction from the radiometric data (Figure 8). The relationship between otolith weight and linear growth model radiometric ages for all warty oreos gives a mass growth rate of 0.80 $mg.y^{-1}$ (Figure 10). Plotting otolith weight against the linear growth model radiometric ages of warty oreos < 28 cm TL, however, gives a greater mass growth rate of 0.967 $mg.y^{-1}$ (Figure 11). To assess the implications of this, a post-maturity rate of 90% of the pre-maturity rate has been applied here ie. G2= 0.884 $mg.y^{-1}$ and the ages of warty oreo beyond maturity recalculated using the two phase linear growth rate model essentially as derived by Bennett et al. (1982):

$$Ae^{-\lambda_R t} = \frac{t_1 G_1}{M_t}\left[1-(1-R)\left\{\frac{1-e^{-\lambda_p t_1}}{\lambda_p t_1}\right\}e^{-\lambda_p(t-t_1)}\right] + \frac{(t-t_1)G_2}{M_t}\left[1-(1-R)\left\{\frac{1-e^{-\lambda_p(t-t_1)}}{\lambda_p(t-t_1)}\right\}\right]$$

where $A = ({}^{210}Pb/{}^{226}Ra)_t$ = activity ratio at time t

$R = ({}^{210}Pb/{}^{226}Ra)_o$ = initial activity ratio at time of deposition (set to 0.05)

λ_p = decay constant for ^{210}Pb (0.03114 year^{-1})

λ_R = decay constant for ^{226}Ra (0.00043 year $^{-1}$)

G_1 = otolith mass growth rate until maturity (mg.y^{-1})

G_2 = otolith mass growth rate after maturity (mg.y^{-1})

t_1 = age at maturity (years)

M_t = otolith mass at age t

The extra term $e^{-0.5\lambda_R t}$ accounts for the minor decay of ^{226}Ra since deposition as it is evident that mature warty oreo may grow to ages (approx 100 years) that are a significant fraction of the 1600 year half-life of ^{226}Ra. Using this two stage linear growth model significantly reduces the maximum radiometric age to 132 years for the pooled sample of 4 fish 34.5 ± 0.5 cm TL (LH 1143). The re-calculated radiometric ages of all post-maturity warty oreos are also given in Table 2.

C. Comparison of growth curves derived from increment counts and radiometric age estimates.

The relationship between fish length and sectioned age for males and females is shown in Figure 10. Although sample sizes are relatively small, there are indications that females grow faster than males and reach a greater maximum age. Lyle et al (1991) found that, in Tasmanian waters, greater than 50% of male warty oreos were sexually mature at 24 cm and 50% of females at 28 cm. This is equivalent to ages of about 24 and 28 years respectively.

The von Bertalanffy growth curve calculated using age estimates from sectioned otoliths (sexes combined) was compared to that derived from the radiometric analysis using the two stage otolith mass growth model. The parameters were:

L_{inf}=31.73; k=0.056; t_0=-3.4 for section ages, and

L_{inf}=34.38; k=0.037; t_0=-7.6 for radiometric ages.

This demonstrates close agreement between the results from the two methods (Figure 11).

Discussion

In the present study incremental analysis of transverse otolith sections and radiometric analysis found remarkably similar age estimates for warty oreo. Both clearly demonstrated that warty oreo is a long-lived species in contrast to estimates made in earlier studies (Mel'nikov 1981; Carter 1990). The close agreement between the results determined from increment counts and radiometric analysis of whole otoliths supports the value of age estimates by both methods. Bennett et al. (1982), used a similar comparison of increment counts and radiometric ages to confirm longevity in the splitnose rockfish, *Sebastes diploproa.*

Oreo species have until now proven difficult to age using otoliths. Our study found that whole warty oreo otoliths were unsuitable for age determination. This was also the conclusion that Mel'nikov (1981) reached. The breaking and burning technique also proved unsuccessful. In a study by Davies et al. (1988), otoliths of the related species smooth oreo, *Pseudocyttus maculatus*, and black oreo, *Allocyttus niger*, were examined whole, thinly sectioned (about 20 um) and using acetate peels under scanning electron microscopy. They were unable to determine ages, a fact they attributed to the complexity of the crystal morphology of the otoliths.

In this study, however, transverse sectioning and subsequent grinding of otoliths to a thickness of approximately 0.2 mm successfully produced age estimates for a wide range of fish sizes. Inter- and intra-reader variability tests showed that these results were highly repeatable. Sectioning the otoliths and analysis of otolith morphometrics revealed that as fish increase in age their otoliths continue to thicken after growth in otolith and fish length has virtually ceased. Numerous studies in recent years have reported similar patterns of otolith growth in long lived species (Bennett et al. 1982; Kenchington and Augustine 1987; Alexander et al. 1993; Smith et al. in press), and all emphasise the need for sectioning to reveal the full incremental structure of otoliths and hence obtain accurate age estimates.

Examination of the otolith sections revealed a distinct change in increment width and appearance after the first 4 to 5 years. This appears to correlate with the transition from the pelagic juvenile phase to the demersal adult phase which occurs at a fish length of approximately 8 to 9 cm (James et al. 1988). Fish are also known to undergo a substantial change in body form during this transition. Annala (1992), reports that preliminary, unvalidated age estimates from New Zealand also indicate a 4 to 5 years pelagic juvenile phase for both smooth and black oreo. Several other studies have also reported changes in otolith increment width and appearance with transitions in life history (Victor 1982, 1986; Fowler 1989; May and Jenkins 1992), and environment (Campana 1984; Nielson and Geen 1985).

Otolith increment analysis indicated a very high age at maturity of 24 years for males and 28 years for females. The radiometric data suggests a similar but slightly older age of 34 years for females. Preliminary results for the other oreo species smooth, black and spiky also indicates ages at first maturity between 20 and 30 years (Stewart and Smith 1993).

The presence of a two-stage otolith mass growth rate for warty oreo was not clear from examination of increments in sectioned otoliths. This may have been in part due to the low number of fish analysed less than 20 cm TL (n=9; with the minimum size 14.8 cm). However, the radiometric analysis suggested a slight reduction in mass growth after maturity although, not suprisingly, this was not statistically significant given the unavoidably large errors associated with radiometric ages. It is interesting that there is little evidence for a reduction in otolith mass growth for warty oreo while several other species have clearly shown such a reduction (Pannella 1980; Williams and Bedford 1974; Boehlert 1985; Smith et al. submitted). The radiometric determination of fish age using whole otoliths is reliant on the assumption of linear mass growth rates for the otolith. In the case of warty oreos the mass growth rate data inferred from both radiometry and counting of increments have proven to be very similar with otolith mass growth close to a single linear rate through life. The requirement to assume linear mass growth rates of otoliths for computing radiometric ages can be avoided if the otolith cores can be removed and analysed (Campana et al 1990; Smith et al., 1991). Although coring is preferable for radiometric ageing of fish, the propeller shape and small size of the otoliths of warty oreo made this option impractical.

There is, therefore, little doubt that warty oreo is extremely long lived and slow growing. For the other oreos, preliminary results also indicate maximum ages ranging from 80 to 130 years (Stewart and Smith 1993). Smooth and black oreo are known to have low fecundity (Conroy and Pankhurst 1989), and it is likely that warty oreo would be similar. If this is the case, the combination of low fecundity, high age at maturity and longevity would make warty oreo particularly susceptible to exploitation. Our results therefore have important implications for the future management of the fishery. In addition, in cases where standard validation techniques are not applicable, our study supports the continued practice of comparing results from otolith increment and radiometric analysis.

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References

Anderson, J. R., Morison, A. K., Ray, D. J.. (1992). Age and growth of the Murray cod, *Maccullochella peelii* (Perciformes: Percichthyidae), in the lower Murray-Darling basin, Australia, from thin-sectioned otoliths. *In* Age determination and growth in fish and other aquatic animals. (Ed. D. C. Smith) Aust. J. Mar. Freshwater Res. 43: 983-1013.

Annala, J. H. (1992). Oreos. In. Report from the fishery assessment plenary, May 1992: stock assessments and yield estimates. MAF Fisheries, Auckland, 155-159.

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

Bennett, J. T., Boehlert, G. W., Turekian K. K. (1982). Confirmation of the longevity in *Sebastes diploproa* (Pisces: Scorpaenidae) from $^{210}Pb/^{226}Ra$ measurements in otoliths. Mar. Biol. 71: 209-215.

Campana, S. E. (1984). Microstructural growth patterns in the otoliths of larval and juvenile starry flounder, *Platichthys stellatus*. Can. J. Zool. 62: 1507-1512.

Campana, S. E., Zwanenburg, K. C. T., Smith, J. N. (1990). $^{210}Pb/^{226}Ra$ determination of longevity in redfish. Can. J. Fish. Aquat. Sci. 47: 163-165.

Carter, D. L. (1990). Development of a suitable method of age determination of Allocyttus verrucosus (warty oreo). M.Sc. preliminary thesis, (Department of Biological Sciences: Deakin University, Australia). 42p.

Christensen, J. M. (1964). Burning of otoliths, a technique for age determination of soles and other fish. J. Cons. int. Explor. Mer. 26: 73-81.

Fenton, G. E., Short, S. A., Ritz, D. A. (1991). Age determination of orange roughy *Hoplostethus atlanticus* (Pisces: Trachichthyidae) using $^{210}Pb:^{226}Ra$ disequilibria. Mar. Biol. 109: 197-202.

Fenton, G. E., Short, S. A. (1992). Fish age validation by radiometric analysis of otoliths. *In* Age determination and growth in fish and other aquatic animals. (Ed. D. C. Smith) Aust. J. Mar. Freshwater Res. 43: 913-922.

Fowler, A. J. (1989). Description, interpretation and use of the microstructure of the otoliths from juvenile butterfly fishes (family: Chaetodontidae). Mar. Biol. 102: 167-181.

Fowler, A. J., Doherty, P. J. (1992). Validation of annual growth increments in the otoliths of two species of damselfish from the southern Great Barrier Reef. *In* Age determination and growth in fish and other aquatic animals. (Ed. D. C. Smith) Aust. J. Mar. Freshwater Res. 43: 1057-1068.

Francis, R. I. C. C., Paul, L. J., Mulligan, K. P. (1992). Ageing of adult snapper (*Pagrus auratus*) from otolith annual ring counts: validation by tagging and oxytetracycline injection. *In* Age determination and growth in fish and other aquatic animals. (Ed. D. C. Smith) Aust. J. Mar. Freshwater Res. 43: 1069-89.

Gooley, G. J. (1992). Validation of the use of otoliths to determine the age and growth of Murray cod, *Macculochella peelii* (Mitchell) (Percichthyidae), in Lake Charlegrark, Western Victoria. *In* Age determination and growth in fish and other aquatic animals. (Ed. D. C. Smith) Aust. J. Mar. Freshwater Res. 43: 1091-1102.

James, G. D., Inada, T., Nakamura, I. (1988). Revision of the oreosomatid fishes (family Oreosomatidae) from the southern oceans, with a description of a new species. New Zealand, J. Zool. 15: 291-326.

Kenchington, T. J., Augustine, O. (1987). Age and growth of the blue grenadier, *Macruronus novaezelandiae* (Hector), in south-eastern Australian waters. Aust. J. Mar. Freshwater Res. 38: 625-646.

Last, P. R., Scott, E. O. G., Talbot, F. H. (1983). Fishes of Tasmania (Tasmanian Fisheries Development Authority: Hobart). 563 pp.

Lyle, J. M., Kitchener, J. A., Riley, S. P. (1991). Warty Oreo Biology. In. An assessment of orange roughy resource off the coast of Tasmania. Final report to FIRDC (Project 87/65).

(Tasmanian Department of Primary Industry, Division of Sea Fisheries, Marine Research Laboratories: Taroona, Tasmania). 75-86.

Lyle, J. M., Riley, S. P., Kitchener, J. A. (1992). Oreos, an under utilised resource. Australian Fisheries. 51 (4): 12-15.

Mace, P. M., Fenaughty, J. M., Coburn, R. P., Doonan, I. J. (1990). Growth and productivity of orange roughy (*Hoplostethus atlanticus*) on the north Chatham Rise. N.Z. J. mar. Freshwat. Res. 40: 1-9.

May, H. M. A., Jenkins G. P. (1992). Patterns of settlement and growth of juvenile flounder, *Rhombosolea taparina*, determined from otolith microstructure. Mar. Ecol. Prog. Ser. 79: 203-214.

Mel'Nikov, Yu. S. (1980). Feeding perculiarities of *Allocyttus verrucosus*, Family Oreosomatidae. J. Ichthy. 20, 193-211.

Mel'Nikov, Yu. S. (1982). Size-age composition and growth pattern of *Allocyttus verrucosus* (Oreosomatidae). Ichthyology (English translation Vopr. Ikhtiol.) 21. 178-184.

Neilson, J. D., Geen, G. H. (1985). Effects of feeding regimes and deil temperature cycles on the otolith increment formation in juvenile chinook salmon, *Oncorhynchus tshawytscha*. Fish. Bull. 83: 91-101.

Smith, J. N., Nelson, R., Campana, S. E. (1991). The use of Pb-210 / Ra-226 and Th-228 / Ra-228 disequilibria in the ageing of otoliths of marine fish. *In* Radionuclides in the Study of Marine Processes. (Ed. P. J. Kershaw and D. S. Woodhead.) pp. 350-359. (Elsevier Applied Science: London.)

Smith, D. C., Fenton, G. E., Robertson, S. G., Short, S. A. (In press). Age determination and growth of orange roughy (*Hoplostethus atlanticus*): A comparison of increment counts with radiometric ageing. Can. J. Fish. Aquat. Sci.

Stewart, B. D., Smith, D. C. (1993). Development of methods to age commercially important dories and oreos. Progress report no. 3 (Department of Conservation and Natural Resources, Marine Science Laboratories internal report no. 206). 23 pp.

Victor, B. C. (1982). Daily otolith increments and recruitment in two coral-reef wrasses, *Thalassoma bifasciatum* and *Halichoeres bivattus*. Mar. Biol. 71: 203-208.

Victor, B. C. (1986). Delayed metamorphosis with reduced larval growth in a coral reef fish (*Thalassoma bifasciatum*). Can. J. Fish. Aquat. Sci. 43: 1208-1213.

List of Figures

Figure 9. Relationship between otolith weight and radiometric linear growth model ages for warty oreos <28 cm TL. (Error bars are $\pm$ 1 SD)

Figure 10. Relationship between fish length and sectioned age for A female (n=52), and B male (n=81) warty oreo.

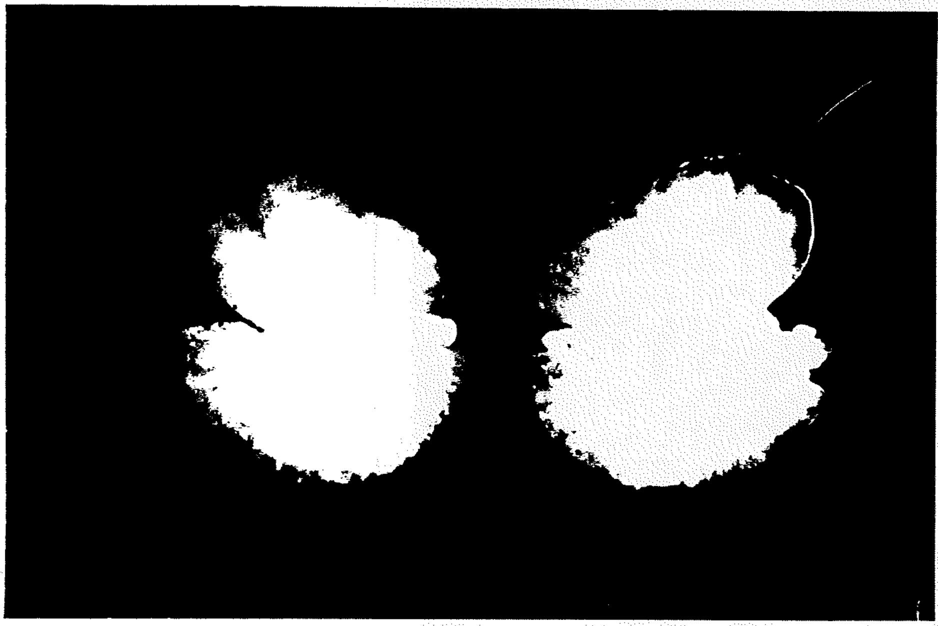
Figure 11. Comparison of warty oreo von Bertalanffy growth curves derived from increment counts (——) and radiometric linear growth ages (----).

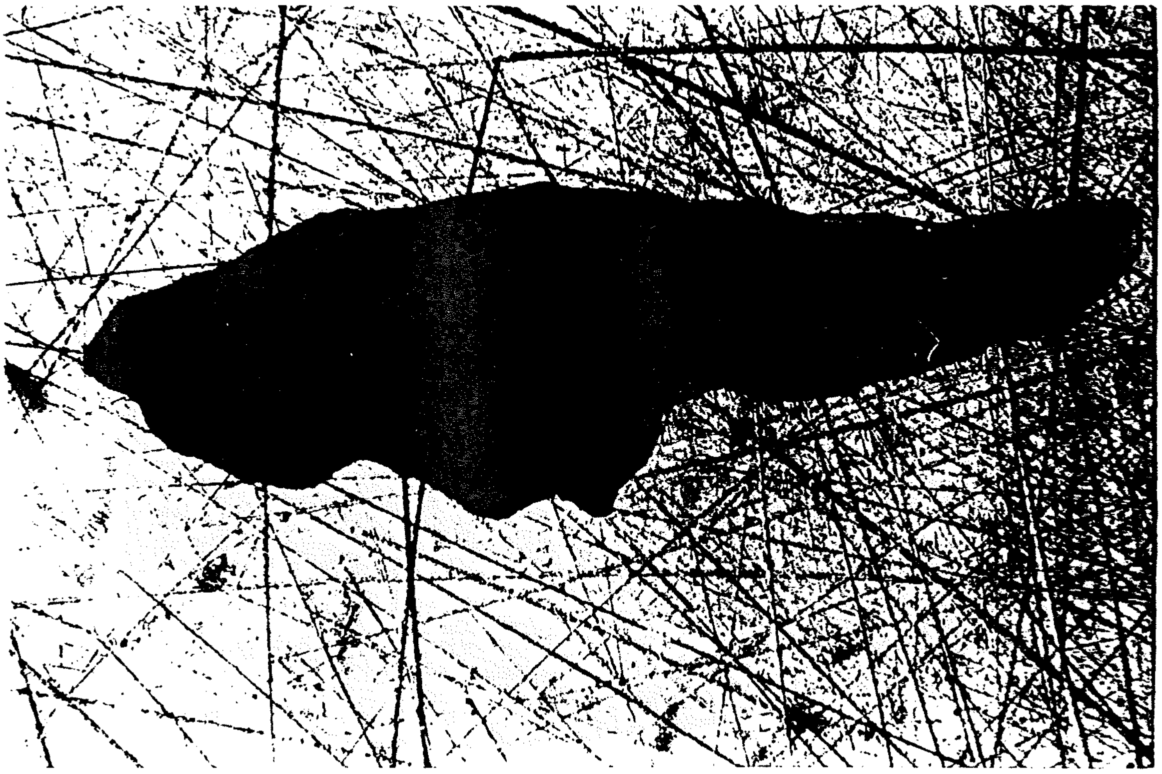
Table 1. Warty oreo whole otolith stable element data from ICP-MS and ICP-AES analysis.

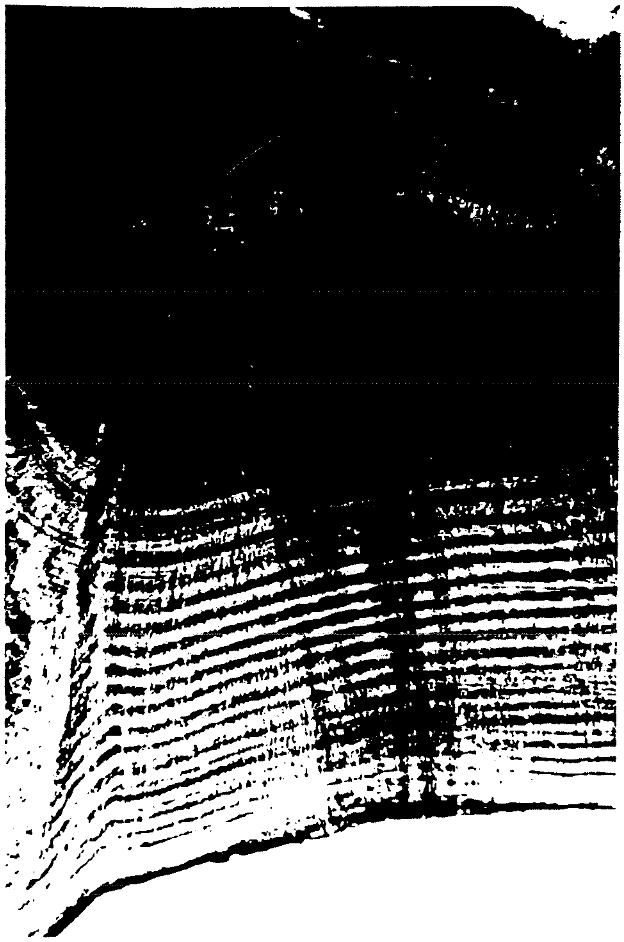
Sample Number	Mean Fish length (cm)	Pb ppm	Ba ppm	Pb/Ba ppm/ppm	Sr ppm	Ca ppm	Sr/Ca ppm/ppm
LH 2167	18.5±0.3	0.63	5.97	0.11	2845	389800	0.0073
LH 2168	26.3±0.7	0.098	4.61	0.02	2892	379700	0.0076
LH 2169	31.9±0.9	0.30	8.39	0.04	3058	362700	0.0084

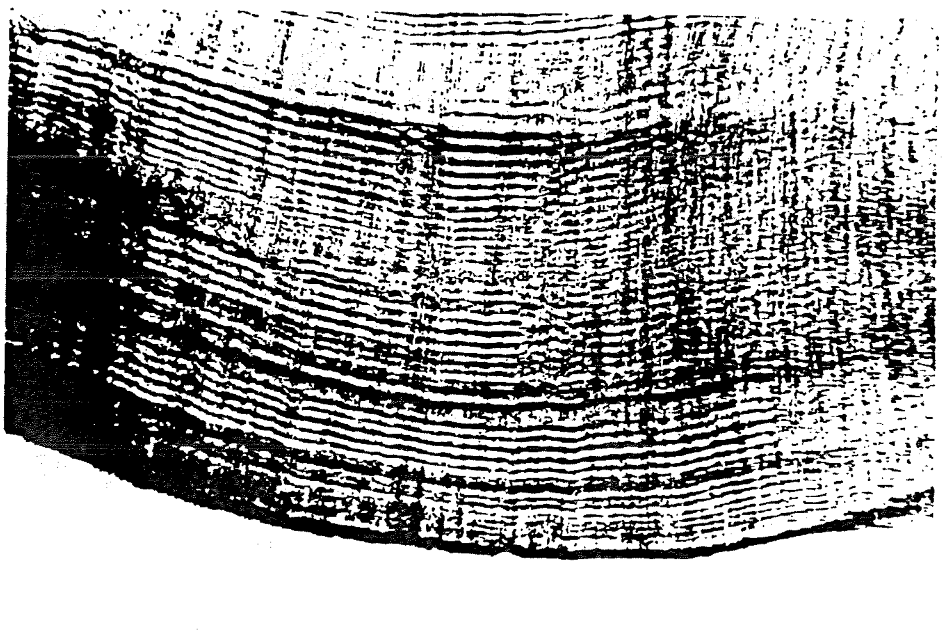
Table 2. Radiometric age determination of whole Warty Oreo otoliths. Errors expressed are ±1SD.

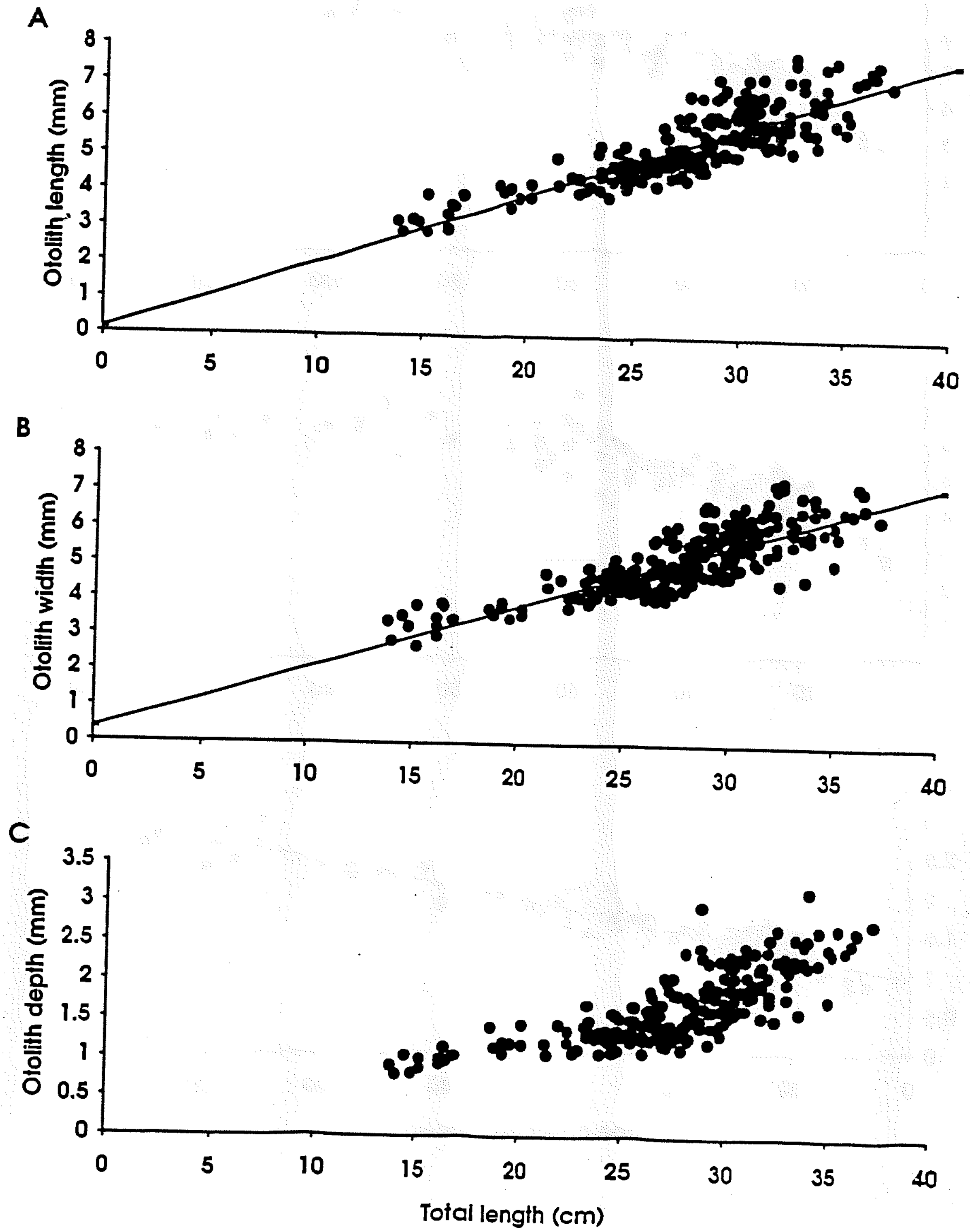
Sample Number	Mean Fish Length (cm)	Mean Otolith Mass (mg)	No. of Otoliths	$^{210}Pb/^{226}Ra$ activity ratio	Mean Otolith Age (years)	Constant growth rate otolith age (years)	Double growth rate otolith age (years)
LH 1529	14.3±*1.4*	7.4±*1.9*	143	0.232±*0.111*	6.8*(+7.4,-2.5)*	14.2 *(+11.2, -9.1)*	
LH 1348	14.9±*1.5*	8.1±*2.2*	138	0.191±*0.104*	5.2 *(+6.6,-2.1)*	10.6 *(+9.6,-8.0)*	
LH 1776	16.9±*0.6*	10.4±*1.7*	109	0.158±*0.062*	3.9 *(+4.5, -0.5*	7.9 *(+5.2, -4.7)*	
LH 2167	18.5±*0.3*	13.2±*2.5*	47	0.199±*0.104*	5.5 *(+6.7, -2.1)*	11.3*(+9.8, -8.2)*	
LH 1349	22.9±*0.6*	20.2±*2.8*	50	0.252±*0.051*	7.7 *(+4.5,-0.1)*	16.0 *(+5.0, -4.6*	
LH 2168	26.3±*0.7*	25.7±*5.1*	41	0.177±*0.066*	4.6 *(+4.8,-0.6)*	9.5 *(+5.7, -5.1)*	
LH 1350	29.8±*0.9*	47.4±*9.7*	25	0.548±*0.147*	23.9 *(+16.3,-6.5)*	55.5 *(+39.3, -23.2)*	46±*8*
LH 2169	31.9±*0.9*	57.9±*6.5*	11	0.496±*0.115*	20.4 *(+11.6,-4.1)*	46.2 *(+23.2,-16.4.)*	49±*7*
LH 1351	32.2±*0.6*	81.5±*6.3*	20	0.698±*0.100*	36.8 *(+17.2, -6.0*	95.9 *(+53.7,-29.7)*	78±*8*
LH 1143	34.5±*0.5*	129.6±*10.0*	8	0.766±*0.115*	45.0 *(+26.9, -9.4)*	128.0 *(+128, -47.7)*	118±*13*
LH 1142	34.9±*0.8*	87.9±*13.3*	12	0.825±*0.090*	54.4 *(+28.9, -2.5)*	173.5 *(+185,-62.0)*	93±*7*











A
Otolith length (mm)
B
Otolith width (mm)
C
Otolith depth (mm)
Total length (cm)

Fig 5

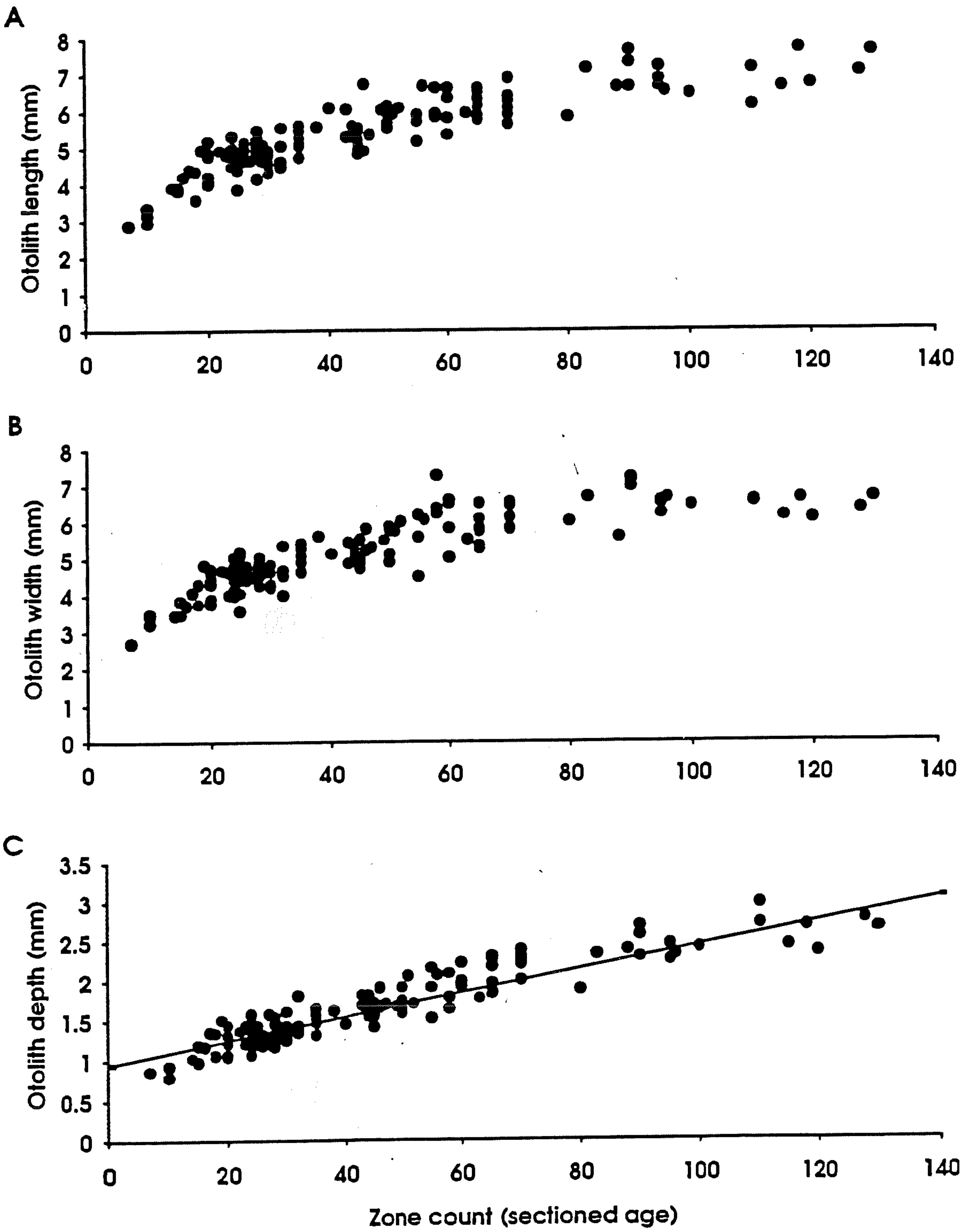
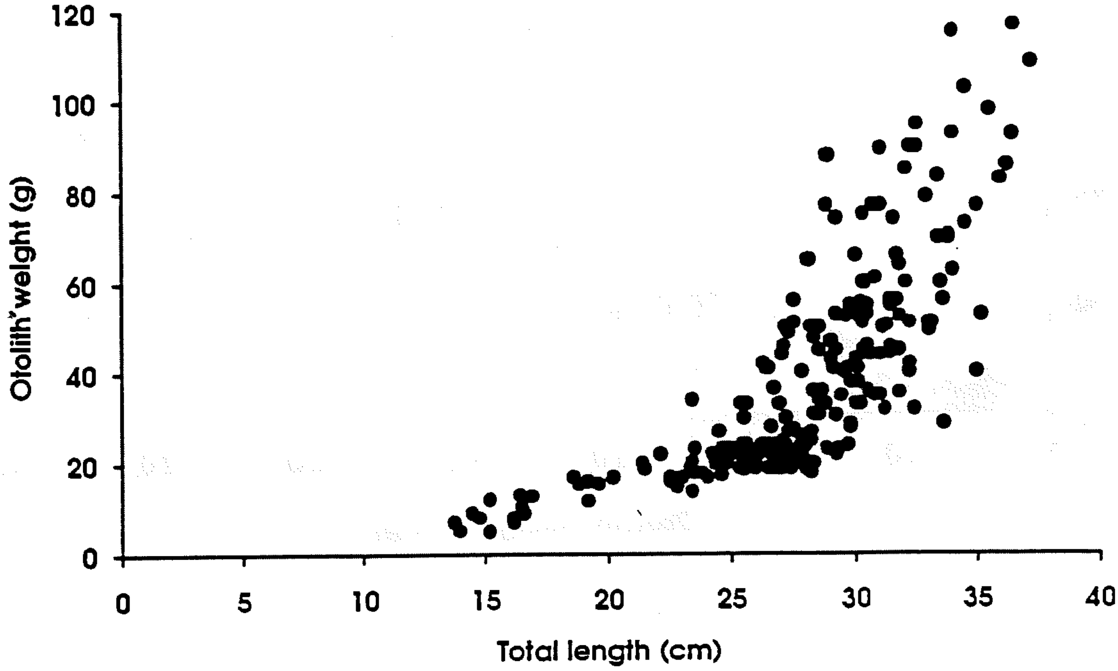

A
Otolith length (mm)
B
Otolith width (mm)
C
Otolith depth (mm)
Zone count (sectioned age)

Fig 6

A


Otolith weight (g)
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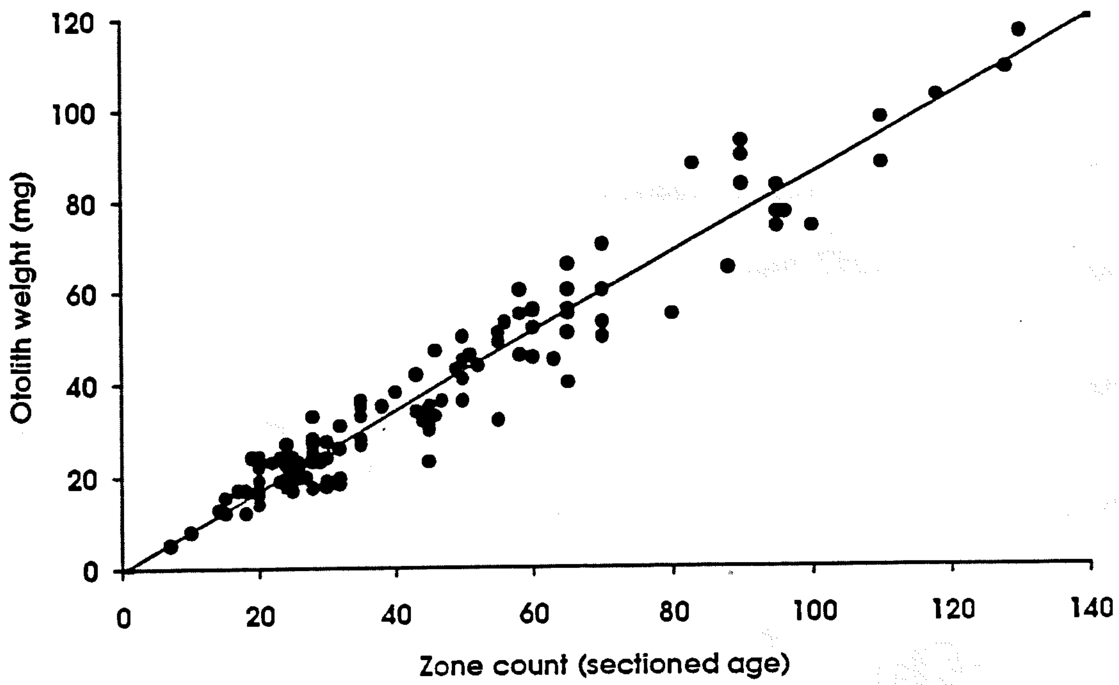
100
80
60
40
20
0
0
5
10
15
20
25
30
35
40
Total length (cm)


Otolith weight (mg)
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100
80
60
40
20
0
0
20
40
60
80
100
120
140
Zone count (sectioned age)

Fig 7

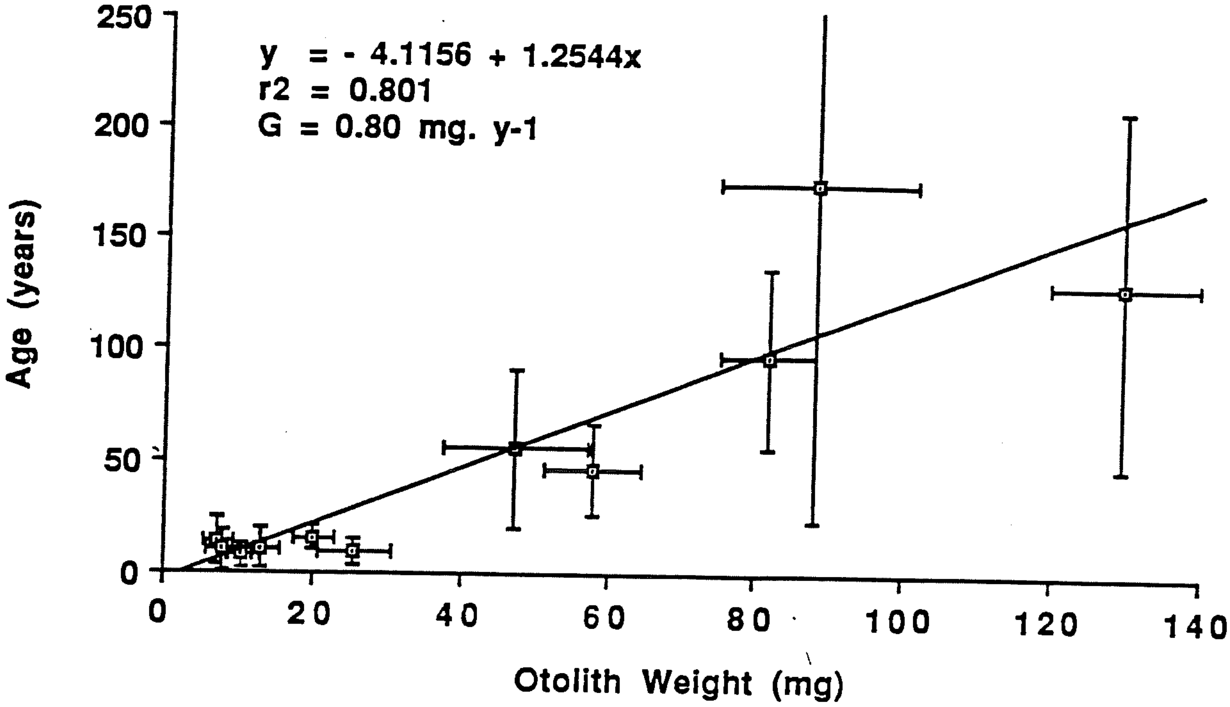
y = - 4.1156 + 1.2544x
r2 = 0.801
G = 0.80 mg. y-1
Age (years)
Otolith Weight (mg)
0
50
100
150
200
250
20
40
60
80
100
120
140

Fig 8

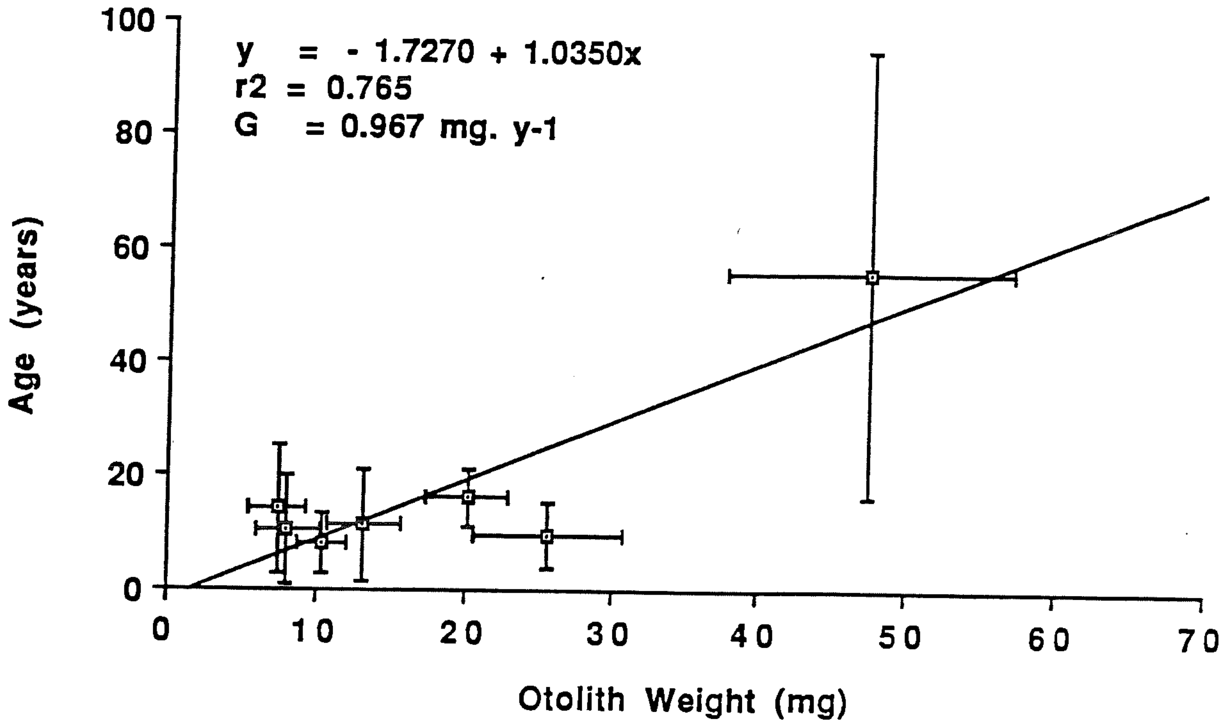
y = - 1.7270 + 1.0350x
r2 = 0.765
G = 0.967 mg. y-1
Age (years)
Otolith Weight (mg)
0
20
40
60
80
100
10
30
50
70

Fig 9

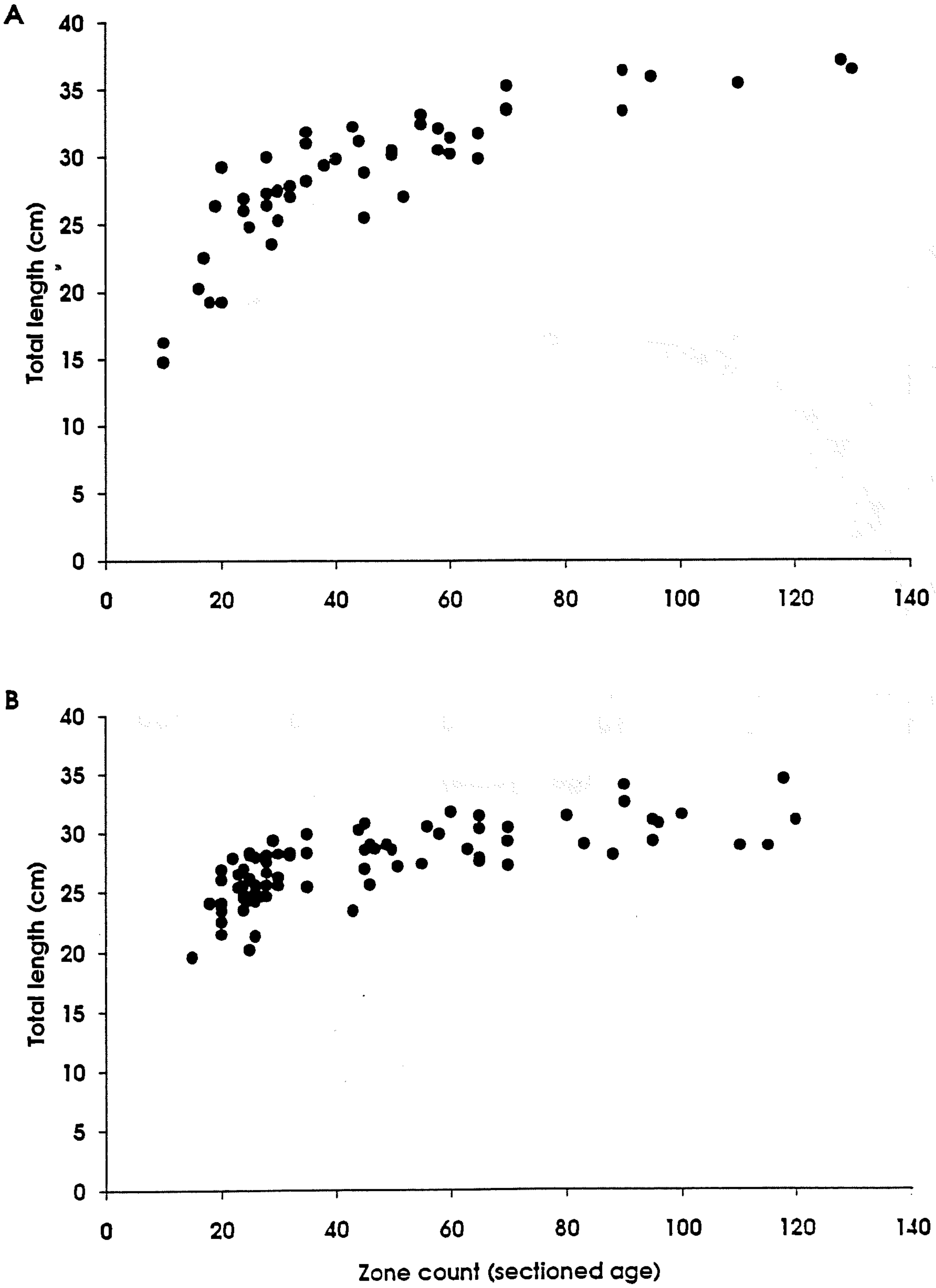
A
B
40
35
30
25
20
15
10
5
0
Total length (cm)
0
20
40
60
80
100
120
140
Zone count (sectioned age)

Fig 10

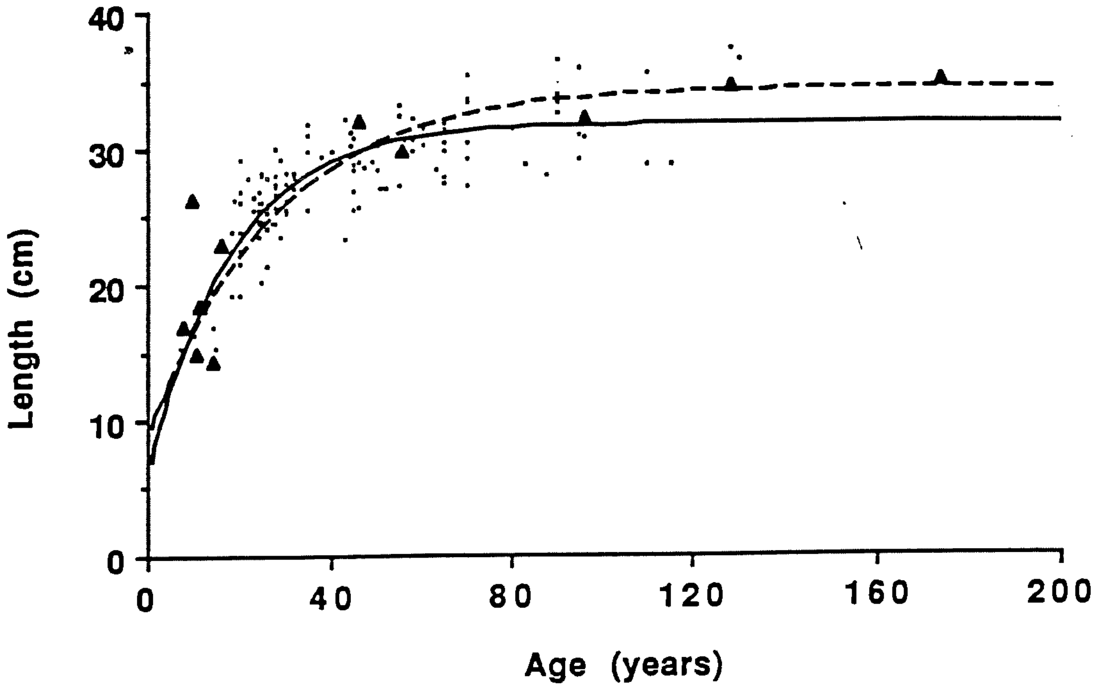

Fig 11