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Age Determination and Mortality Estimates on an Unexploited Population of Jack Mackerel *Trachurus declivis* (Jenyns, 1841) from South-east Australia

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AGE DETERMINATION AND MORTALITY ESTIMATES ON AN UNEXPLOITED POPULATION OF JACK MACKEREL *TRACHURUS DECLIVIS* (JENYNS, 1841) FROM SOUTH-EAST AUSTRALIA

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Abstract

Analysis of length-frequency distributions and measurement of the marginal increment were used to validate the annual nature of rings on otoliths of *Trachurus declivis*. The age structure of 1000 *T. declivis* collected from south-east Australian waters between January 1977 and January 1978 was assessed from their otoliths. The calculated values for the von Bertalanffy growth constants were L_{∞} = 46.4, K = 0.20 and T_o = -0.87. A sample of otoliths from a previous study on *T. declivis* from the same area was 're-aged'. Growth curves produced from the two studies were the same. No difference in growth rates between males and females was apparent. The best estimate of natural mortality for the south-eastern stock of *T. declivis* was found to be between 0.63 and 0.70.

INTRODUCTION

The genus *Trachurus* has a worldwide distribution in temperate waters and is of commercial or potentially commercial importance in most major fishing countries. World landings have increased from 1.7 million tonnes in 1973 to 2.7 million tonnes in 1978 (FAO 1978).

In Australian waters *Trachurus declivis* is distributed over the southern half of the continent from Shark Bay, Western Australia, to the mid New South Wales coast. Potential yield of the south eastern stocks has been reported as being between 10 000 and 100 000 tonnes (Maxwell 1979). However, at present there is no major fishery for this species in Australia.

A number of studies have reported on age and growth in *Trachurus;* these include *T. trachurus* (Geldenhuys 1973; Macer, 1977), *T. murphyi* (Kaiser 1973), *T. japonicus* (Kim *et al.* 1969) and *T. symmetricus* (Wine and Knaggs 1975). These studies have examined length-frequency distributions and used growth marks on urohyals and otoliths for age determination.

For *T. declivis,* preliminary age estimates were obtained by Shuntov (1969), who did not state how the fish were aged, and James (1975) who utilised the length-frequency distribution of 0 to 2 age group *T. declivis* from New Zealand. Webb and Grant (1979) provide the most comprehensive study of age and growth in this species. However, while they showed a regular periodicity of mark formation on otoliths they provided little evidence that these marks were annual events.

The rationale behind the present work was to establish pre-exploitation population parameters for *T. declivis*. In particular, the study aimed to validate the otolith rings as annual events and to provide estimates of mortality.

MATERIALS AND METHODS

Material available to this study was collected by the F.R.V. *Courageous* between January 1977 and January 1978. Monthly samples were taken on the east coast between New South Wales and Tasmania (34°30'S to 43°35'S). Bottom depths varied from 30 to 340 m. *T. declivis* were captured using either an Engel mid water trawl (308 mesh by 800 mm) with a 10 mm cod end liner, or a Frank and Bryce bottom trawl (30.5 m headline, 230 mm wing mesh) with or without a 40 mm cod end liner. Sagittal otoliths were removed, cleaned of mucus and stored dry in envelopes. Fork-lengths (FL) were measured to the nearest centimetre on an offset measuring board for length-frequencies, and to the nearest millimetre for age analysis. 1000 otoliths were examined from a total of 20 966 fish for which length-frequency data were available. In addition, otoliths from 281 fish used in Webb and Grant's study were re-examined. These specimens were collected by the F.R.V. *Courageous* between October 1975 and February 1976.

Webb and Grant (1979) describe the treatment of *T. declivis* otoliths for ageing and we follow their methodology. Of the otoliths examined, 2% were unreadable. Otolith and ring radii of 246 fish were measured using a micrometer eyepiece and the results used for back calculations. Otolith radius was measured from the centre of the nucleus to the posterior tip of the otolith and ring radius from the centre of the nucleus to the outer edge of each opaque zone.

Von Bertalanffy growth curves were calculated using an iterative computer program based on the method of least squares.

Validation of otolith rings as annual events

A number of methods for validating the rings as annuli were attempted. Otolith radii of all 0, 1, 2 and 3 group fish were measured. For each age group a plot of otolith radius against month of capture was constructed. In temperate areas fish growth is more rapid during summer and slows during winter. If the rings are annual this plot would be expected to show a steep increase in otolith radius during summer followed by a slower rate of increase in the winter and then a further rise in the succeeding summer (Christensen 1964). However, no clear relationship was apparent. This was probably due to the limited sample of 0 and 1 group fish which could be expected to show larger growth increments. Greater numbers of 2 (289) and 3 (339) group fish were available but these specimens were not caught in sufficient numbers throughout the year (Fig. 1).

Previous studies on fish ageing have validated the time scale by examining the growth pattern at the extreme edge of the otolith from samples collected throughout the year. (Williams and Bedford 1974). In this way the time of zone formation may be determined. However, in *T. declivis* otoliths the extreme edge almost always showed as a hyaline zone, probably because of the thinness of the otolith in this region.

Tong and Vooren (1972) used a quantitative method which involved measurement of the 'marginal increment' on otoliths of *Cheilodactylus macropterus*. The width of the area outside the last hyaline zone was measured, the latter being the outermost hyaline zone with opaque material on both sides. Using fish with the same number of otolith rings they demonstrated a cyclic fluctuation in marginal increment with a period of one year, showing that one opaque and one hyaline zone were formed annually.

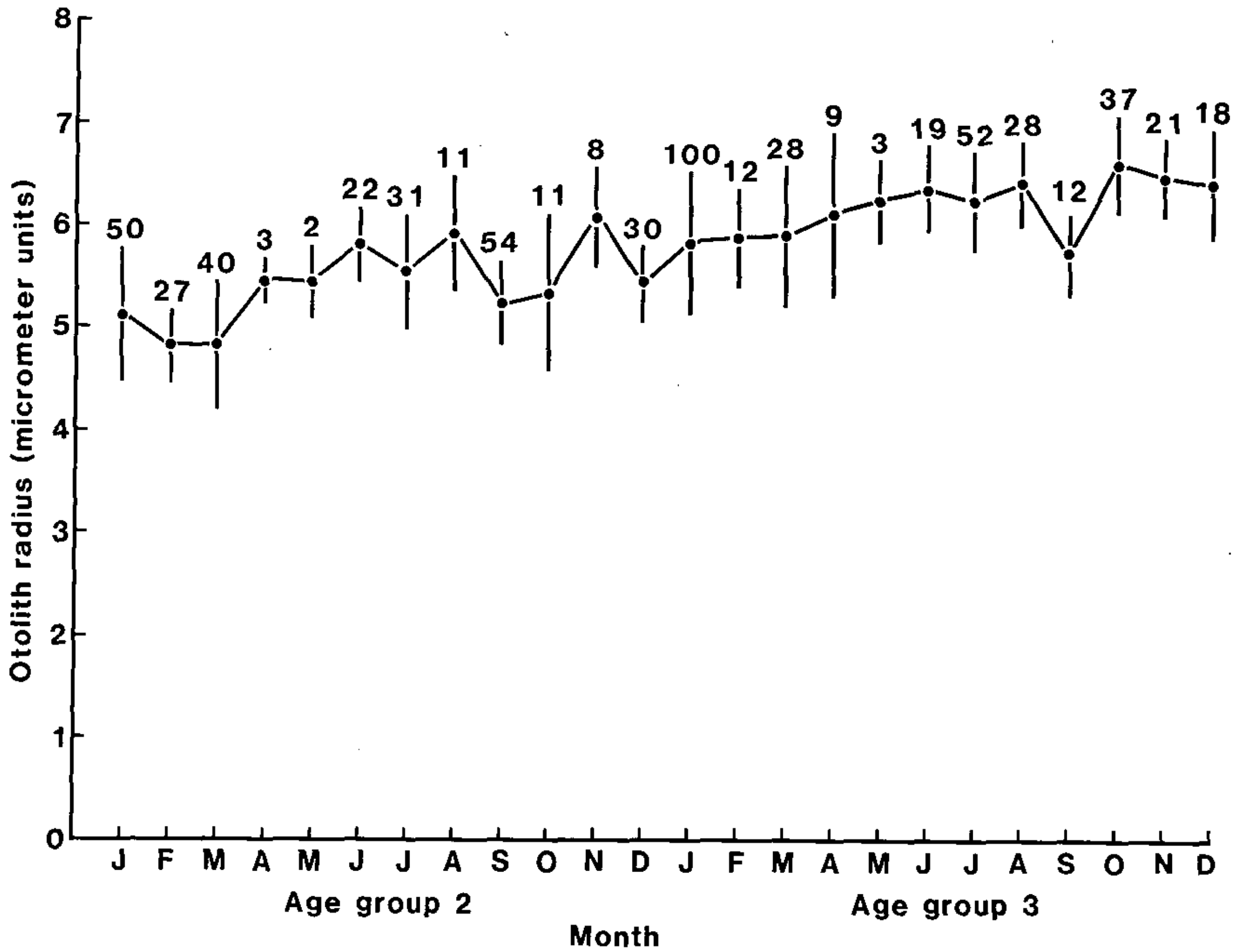

Figure 1. Monthly increase in otolith radius for age group 2 and 3 *T. declivis*. Numbers represent sample size, bars are plus or minus one standard deviation from the mean.

For *T. declivis*, monthly sample sizes for fish of any specific age group were very low and data were sufficient only for the 4 year group. Since only a single year could be used it was not possible to demonstrate a regular cycle in the marginal increment. However, there is some evidence that the marginal increment reaches a maximum around November-January and a minimum in May (Fig. 2) suggesting that the rings may be laid down annually.

The final method involved analysis of length-frequency distributions. The 1977 data were plotted at monthly intervals and the mean lengths for the modes derived from 'Cassie' curves (Cassie 1954). Fish lengths for age groups 0-6 at the beginning of each month were then calculated using the von Bertalanffy growth equation. Figure 3 shows that there is reasonable agreement between the values derived from length-frequency analysis and those predicted by the von Bertalanffy equation. The poor fit for February and April of age group 0 fish may be explained by the fact that the von Bertalanffy equation does not accurately describe the early stages of growth. Using the method described by Pauly (1980) the

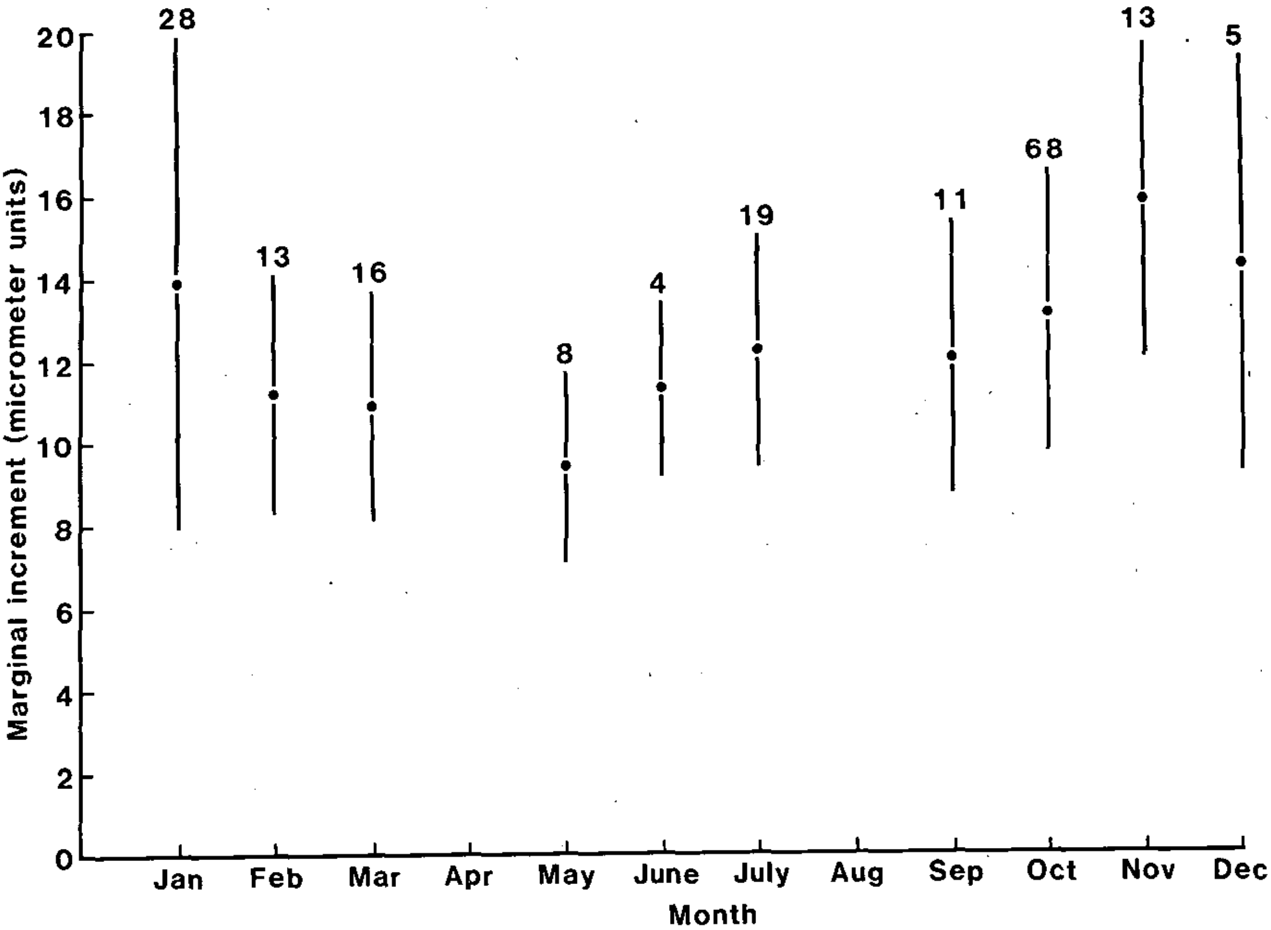

Figure 2. Marginal increments for *T. declivis* otoliths. Numbers represent sample size, bars are plus or minus one standard deviation from the mean.

von Bertalanffy curve superimposed on the May 1977 length-frequency sample is shown in Figure 4. May was chosen as it was the month which contained the greatest number of modes. Age groups 0-5 are shown and these correspond to modes in the length-frequency distributions supporting the ageing and the annual nature of the rings.

Comparisons with previous growth curves

Consistency in interpretation of marks on fish hard parts by different workers has always been a problem. Williams and Bedford (1974) consider that "otolith reading remains, for the present at least, as much an art as a science." During a study of the biology of *T. declivis* by CSIRO a number of workers had, at different times, independently aged *T. declivis* using both scales and otoliths. This provided an opportunity to compare these readings with our own and with those of Webb and Grant (1979).

As an initial check on our ageing technique 281 (23%) of Webb and Grant's *T. declivis* otoliths were 're-aged'. An additional 1000 fish were then aged from otoliths collected between January 1977 and January 1978. In both cases no significant difference was found between the growth rate of males or females. The von Bertalanffy growth curve generated from the data in the present study was compared to the growth curve reported by Webb and Grant (1979) and was found to be the

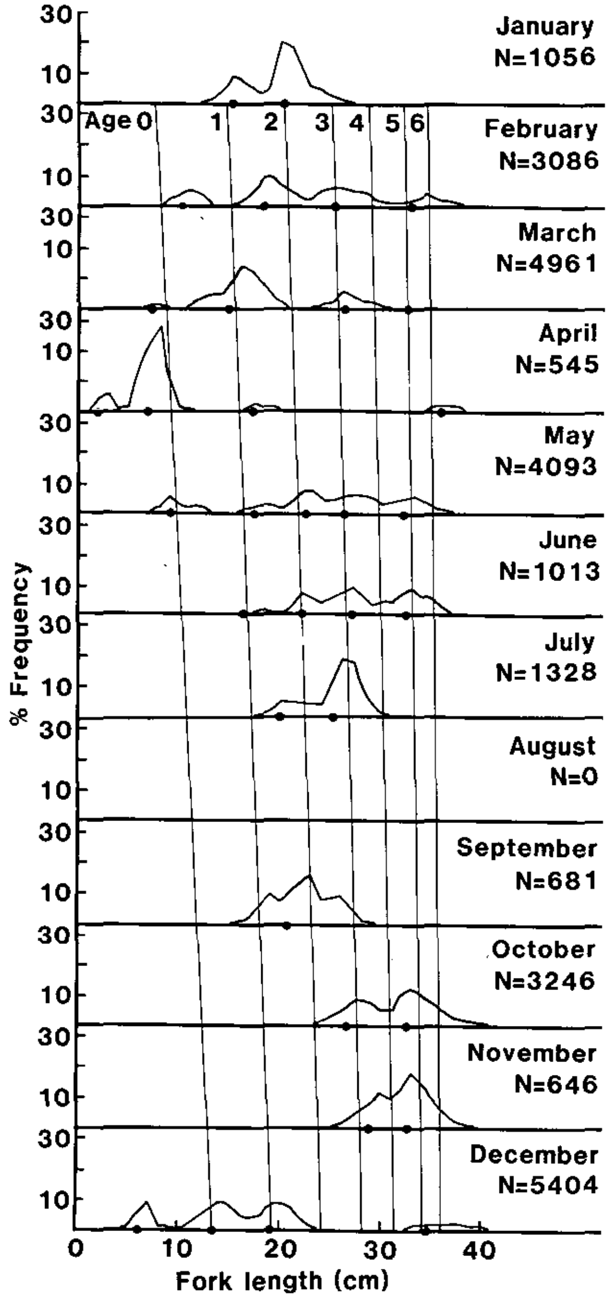

Figure 3.

Length-frequency distributions for the 1977 catch of *T. declivis*. Solid lines represent lengths for age groups 0-6 at the beginning of each month predicted by the von Bertalanffy growth equation. Solid dots are modes picked by Cassie curves.

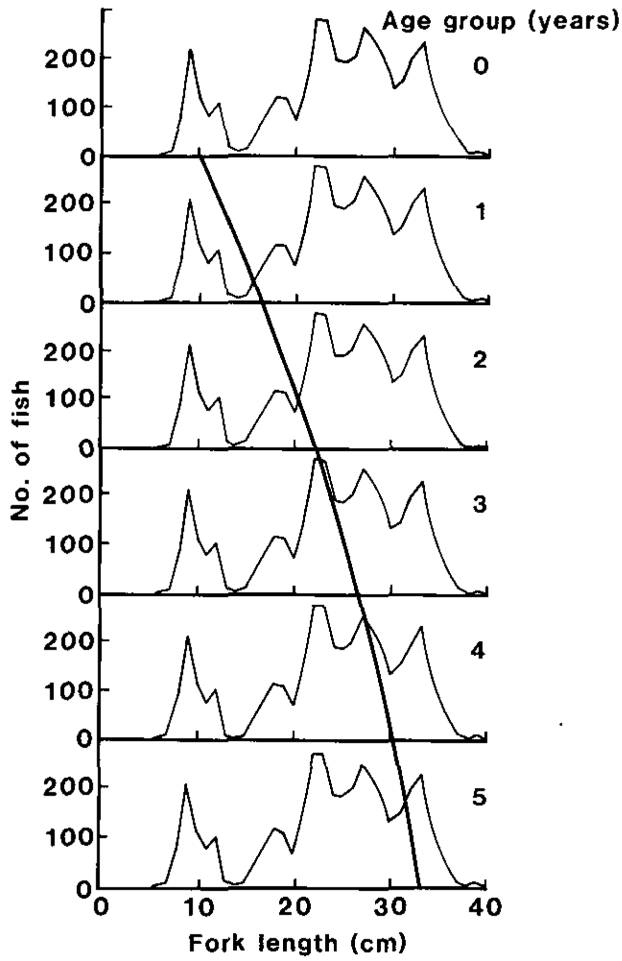

Figure 4.

Repeated May length frequency distribution for *T. declivis* fitted with von Bertalanffy growth curve (1977 catch).

same (Fig. 5). However the variability in lengths for a given age (expressed as standard deviations) was higher in our 're-aged' sample of Webb and Grant's *T. declivis* otoliths, particularly in fish over age 6 (Table 1), than was found by these authors.

As a further check on the ageing technique back calculations were carried out on a sample of 246 otoliths from the 1000 fish collected between January 1977 and January 1978. The regression of otolith radius on fish length is described by the equation

$$L = 2.38R^{1.34} \qquad r = 0.94\ (P<0.001)$$

where L = fish fork length (cm)

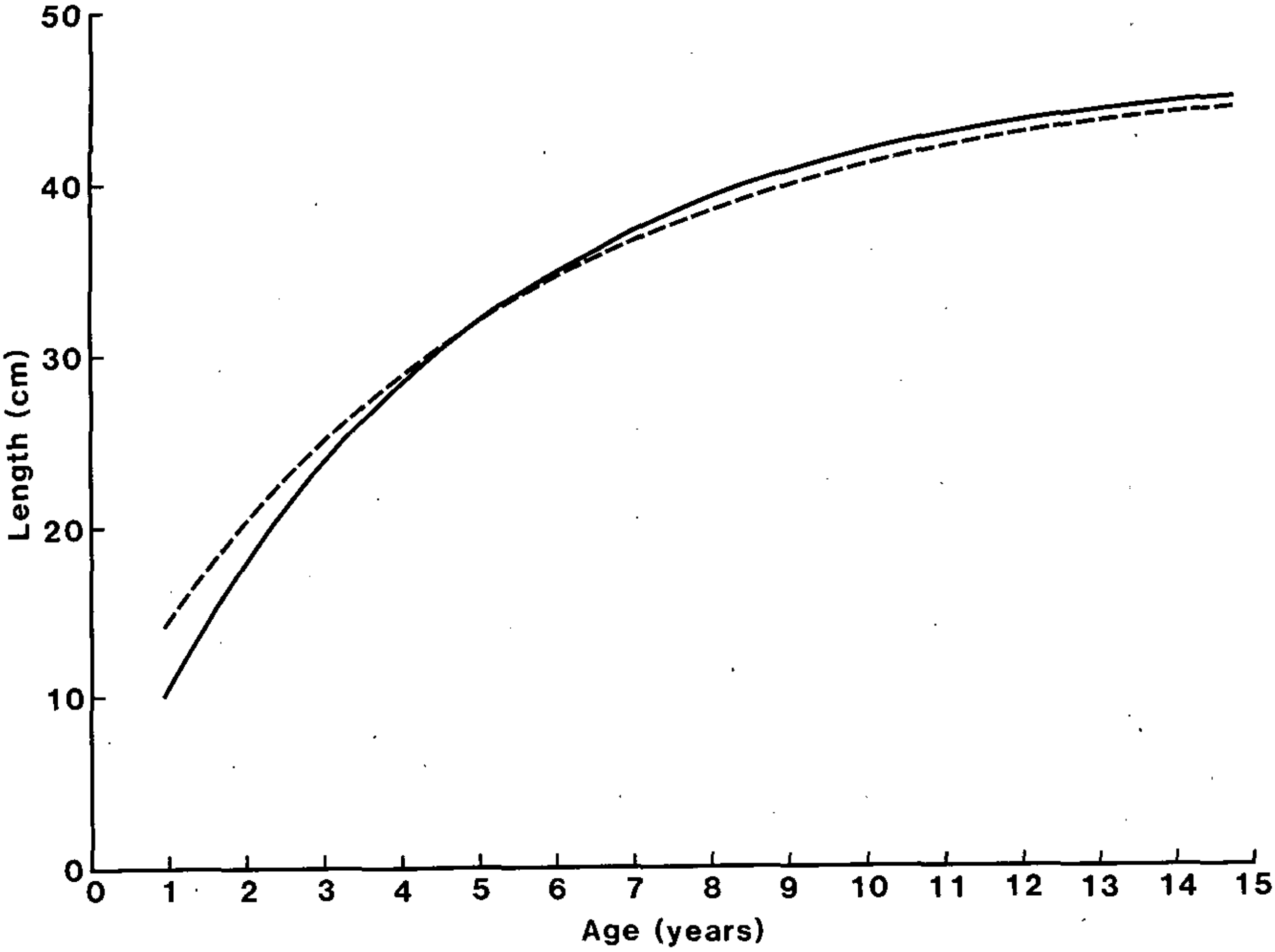

Figure 5. von Bertalanffy growth curves for Australian *T. declivis*. Solid line, Webb and Grant (1979), N = 1242. Dashed line, Present study, N = 1000.

R = otolith radius (micrometer units)

Using this equation it was possible to calculate fish length at the time of completion of each opaque ring, while allowing for individual growth rates of the fish.

$$\ell_i = \frac{Lf(r_i)}{f(R)}$$

Using the above regression:

$$\ell_i = L \left(\frac{r_i}{R}\right)^{1.34}$$

where ℓ_i = fish length at completion of the ith opaque ring (cm)

r_i = otolith radius at completion of the ith opaque ring (micrometer units)

L = fish length at capture (cm)

R = otolith radius (micrometer units)

The growth curve produced from the back calculated lengths is lower (mean fish lengths are smaller at a given age) than one constructed from the ages of these fish at capture (Table 2). The age at capture method depends on the 'rounding' of fish age with reference to an arbitrary birth date. Thus some individuals might be under-aged by almost one year, and, on average, fish would be under-aged

Table 1. Comparison of the mean length (cm) at age of Webb & Grant's (1979) data and the 're-ageing' of 281 of their otoliths in the present study.

	Webb & Grant (1979)			Present Study		
Age (years)	Sample size	Mean length (cm)	Standard Deviation	Sample size	Mean length (cm)	Standard Deviation
1	30	11.65	2.18	21	13.1	3.8
2	60	16.59	2.46	26	16.8	2.6
3	339	21.86	3.01	49	20.6	4.7
4	293	27.54	2.55	31	31.0	2.8
5	178	32.86	1.86	54	34.0	2.8
6	67	35.71	1.04	37	36.4	1.7
7	67	37.24	0.58	17	37.8	2.7
8	80	38.81	0.67	7	39.0	1.1
9	51	39.93	0.60	12	40.6	2.0
10	31	40.74	0.38	12	41.1	1.0
11	19	41.68	0.44	7	41.9	0.8
12	16	42.65	0.47	7	42.6	1.7
13	4	43.62	0.25			
14	3	44.50	0.50			
15	3	45.83	0.28	1	44.1	
16	1	47.00				

Table 2. von Bertalanffy growth constants for Australian *T. declivis* (present and previous studies)

Data	Sample Size	L_∞ (S.E.) (cm)	K (S.E.)	t_0 (S.E.) (years)
CSIRO, 1973 (scales)	122	46.7 (2.53)	0.32 (0.06)	-0.24 (0.34)
CSIRO, 1977 (otoliths)	306	46.7 (1.31)	0.18 (0.01)	-0.41 (0.10)
Webb & Grant, 1979	1242	46.3 *	0.23 *	-0.10 *
Present Study				
'Re-ageing' sample of Webb & Grant	281	49.3 (1.49)	0.16 (0.01)	-1.03 (0.14)
Total sample, 1977-78 collection	1000	46.4 (0.79)	0.20 (0.01)	-0.87 (0.08)
Sub-sample, age at capture	246	49.1 (4.25)	0.15 (0.03)	-1.68 (0.20)
Sub-sample, back calculated age	246	47.5 (2.16)	0.16 (0.02)	-1.40 (0.15)

* not given

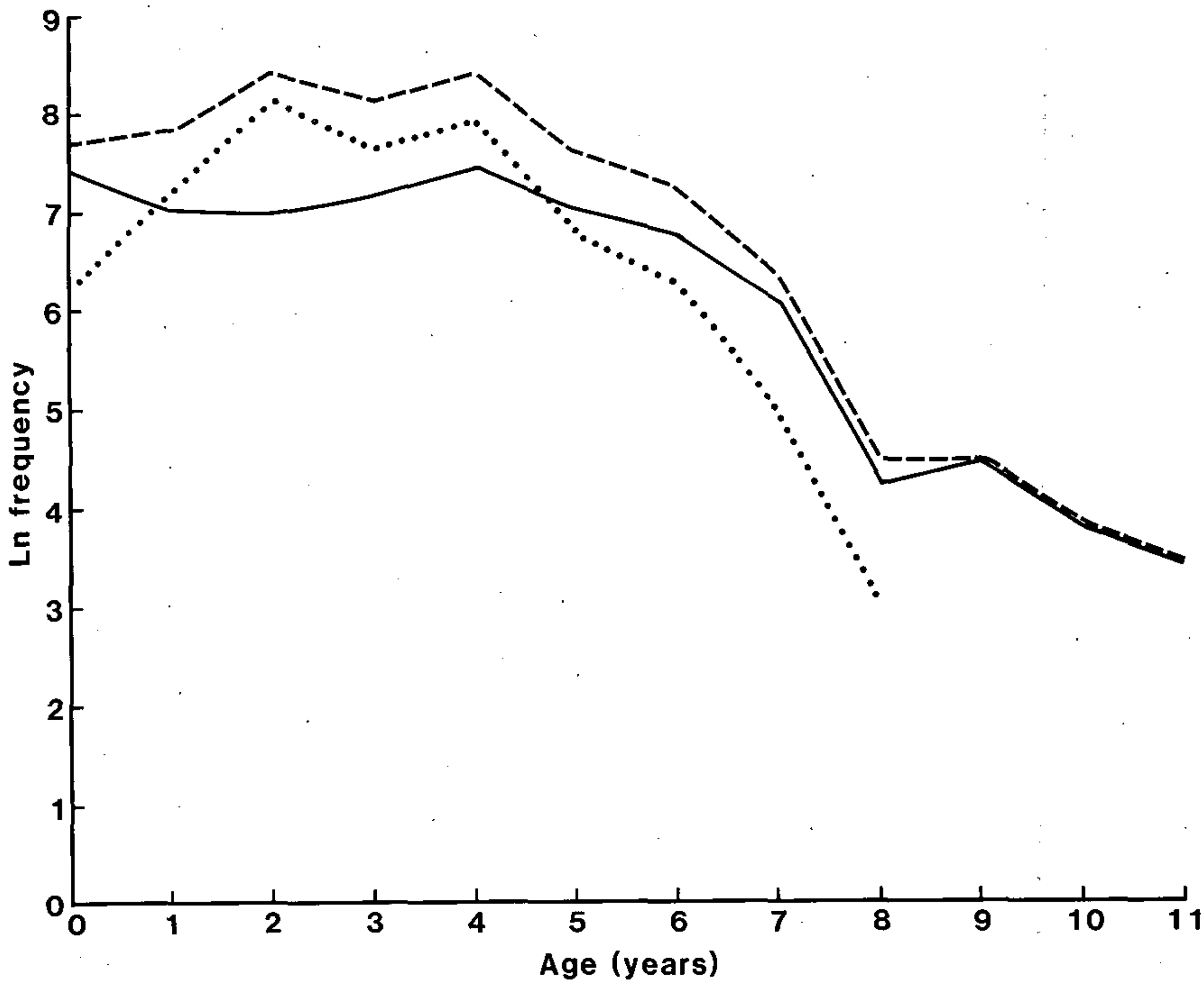

Figure 6. Catch curves for the 1977 *T. declivis* data. Solid line using data from north of 39°S, dotted line from south of 39°S and dashed line using combined data from these areas.

by about six months. Back calculating to the last annulus reduces this variability by referring more precisely to the fish's actual lifespan. When six months growth was subtracted from the mean fish lengths at a given age, derived from the age at capture method, the two curves were in close agreement.

Ageing of *T. declivis* prior to the above studies had been attempted by CSIRO on two separate occasions (unpublished data). In 1973 ageing was carried out using both otoliths and scales. When both were 'read' from the same fish there was 71% agreement on the age (99% ± one year). Analysis of the 1973 scale readings in the present study generated a growth curve which is different to that produced from our otolith readings and those of Webb and Grant (Table 2). The probable reason for this difference is that when the ageing was conducted in 1973 it was thought that *T. declivis* lived for only 5 or 6 years. This almost certainly resulted in a bias in the ageing. For example, only 6 fish were aged 7 or 8 and none were aged over 8 years although 20 out of the 122 fish were more than 40 cm FL.

In addition, no fish were aged 0 or 1, none being caught less than 18.4 cm FL, and this would have affected the growth curve. Otoliths are much easier to read than scales in *T. declivis*, and since both give similar results, only otoliths have been used since 1973. Further ageing was carried out in 1977 and the preliminary readings were made available to the present study. No birth date had been assigned and the hyaline zones, whether complete or not, had been counted, their number being recorded as the age of the fish in years. This method would age some fish a year older than our method and would greatly affect the 0 and 1 year olds. A growth curve was generated from these data and the growth constants are presented in Table 2. Despite this variation the curve is in reasonable agreement with that produced from the 1000 fish aged in the present study. Again no significant difference was apparent between the growth rates of males and females.

Age structure and mortalities

An age-length key was constructed for each 2 cm length class using the 1000 aged fish from 1977 (Table 3). This was used in conjunction with the length-frequency data from the same period (20 966 fish) to estimate the age structure of the total catch (Kimura 1977; Westrheim and Ricker 1978), which is assumed to be representative of the stock (Table 4). A catch curve derived from the *Courageous* samples taken between January 1977 and January 1978 is shown in Figure 6.

Webb and Grant (1979) assumed that only one population of *T. declivis* is present in south-eastern waters and that the stock is migratory. The seasonality of aerial surface sightings suggest a southerly summer movement of surface schools out of New South Wales associated with the southward shifting 17°C sea surface isotherm (Maxwell 1979). Studies on stock discrimination in *T. declivis* from south-eastern Australia and the Great Australian Bight have been carried out using principal component analysis of meristic characters (Maxwell, personal communication). Results indicated distinct stocks in the Bight and New South Wales while no separation was evident between samples from New South Wales and Tasmania. Although there appears to be no biological basis for separate stocks specific bias in the size distribution of fish was evident. Samples from the north of the region contained fewer fish between 10 and 25 cm FL and many more over 30 cm FL than samples from the south. Since the absence of fish larger than 30 cm FL from the south would result in an artificially high mortality, the data were split into two regions, north of 30°S (n = 635) and south of 39°S (n = 365). Separate catch curves were produced from these two areas (Fig. 6). To determine total mortalities from the catch curves ages 4 and above were considered, those fish below 4 not being fully recruited to the fishing gear (Ricker 1975). To compare mortalities for the two areas, together with the combined data, linear regressions between ages 4-8 on the catch curves were calculated (since data for the southern area only extends to age 8) giving:

Z (instantaneous total mortality) = 0.91 (combined data); 0.74 (North of 39°S) and 1.16 (South of 39°S).

Since the *T. declivis* stock is unexploited, fishing mortality is negligible and thus

M (instantaneous mortality) = Z

The absence of large fish in the southern sample accounts for their apparently high mortality value and also, to a lesser extent, for that of the combined regions. The area north of 39°S was thus taken for the best estimate of mortality. Since

Table 3. Age-length key for *T. declivis* from 1977 *Courageous* catch (Numbers represent percentage of fish assigned a particular age in each size class)

Fish Length (cm)	Age in years 0	1	2	3	4	5	6	7	8	9	10+
4	100										
6	100										
8	40	60									
10	23	69	8								
12	7	41	48	4							
14	10	30	43	13	3						
16	2	23	67	4	4						
18	1	22	56	17	3						
20		11	51	29	9						
22		3	38	43	18						
24			6	52	41	2					
26			2	29	62	4	1	1			
28				39	51	9	1				
30				10	42	33	13	2			
32					16	47	30	7			
34					4	26	42	24	5		
36					1	9	41	42	3	4	
38						2	9	24	17	28	20
40								2	5	26	67
42								13			87

Table 4. Age composition of the 1977 catch of *T. declivis*

Age in years	0	1	2	3	4	5	6	7	8	9	10+
Number	2342	2974	4477	3504	3886	1675	1245	593	94	81	90
%	11.2	14.2	21.4	16.7	18.5	8.0	5.9	2.8	0.4	0.4	0.4

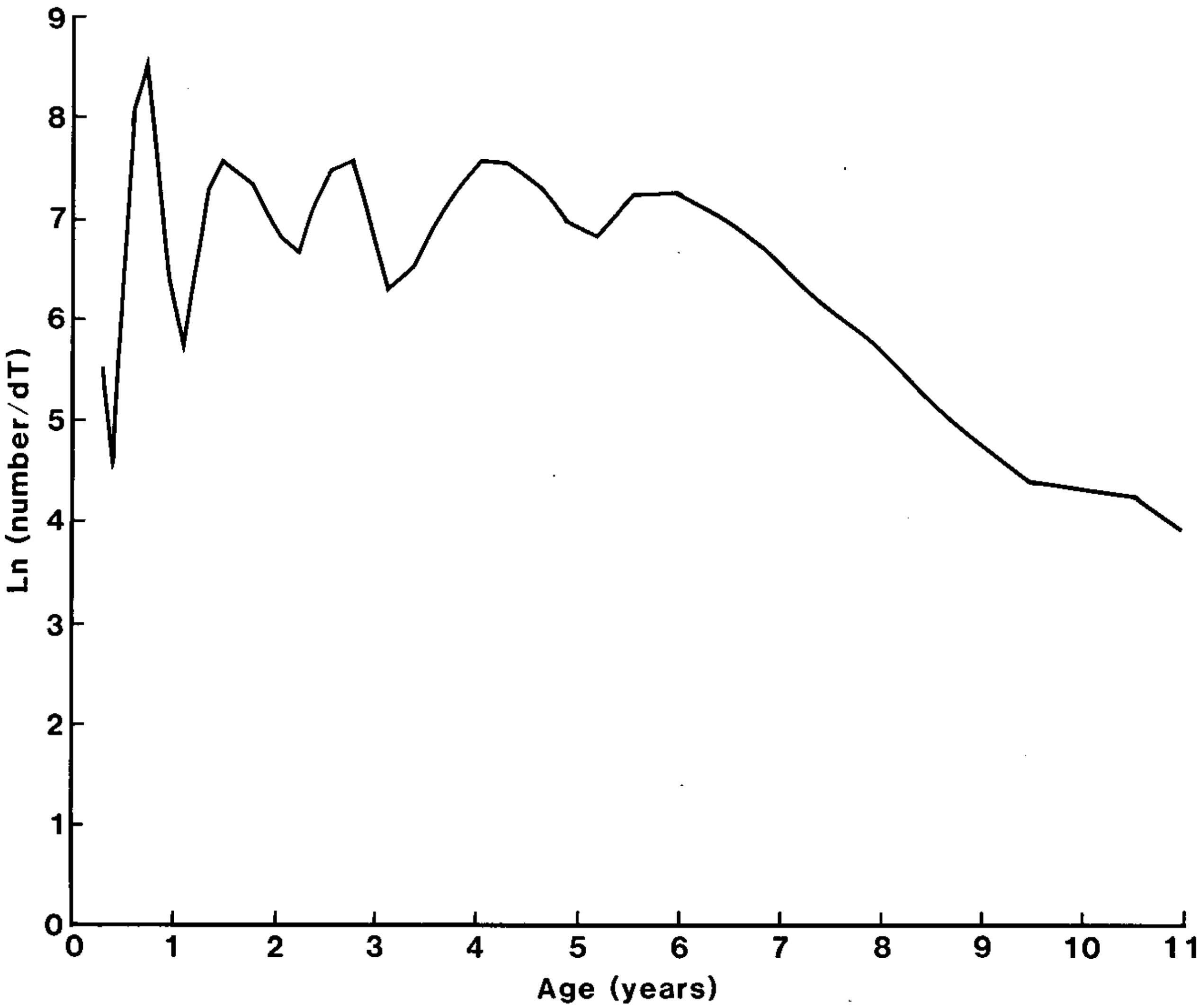

Figure 7. Catch curve for *T. declivis*, using the 1977 data from the area north of 39°S, following the method described by Pauly (1980).

fish over 8 years were available the regression was calculated between ages 4-11 and gave M = 0.63.

An alternative method (Pauly 1980) was also used to determine the natural mortality of fish from the northern area and gave a value for M of 0.70 (Fig. 7), the regression being calculated between ages 6-11. Mortalities were similarly derived for the 1976 catch data from the northern area. However, since an insufficient number of fish were aged in 1976 the 1977 age-length key was used. M was found to be 0.77 by Pauly's method and 0.61 from the standard catch curve.

DISCUSSION

While there have been several studies reporting on the ageing of *Trachurus* species from hard parts only a few workers have successfully validated observed marks as annual events.

Wine and Knaggs (1975) provide few details of their ageing of *T. symmetricus* and Kaiser (1973) does not make it clear whether the otolith ring formation is an annual event in *T. murphyi*. Macer (1977) used length-frequency data to show that the first four rings in *T. trachurus* otoliths were annual. However, he could not establish that this was true of subsequent rings. Geldenhuys (1973) used the time of formation of the opaque and hyaline zones to show that the rings in the otoliths were annual for *T. trachurus* off South Africa. Kim *et al.* (1969), working on *T. japonicus*, used the time of zone formation and length-frequency data to show that two hyaline zones were laid down in the urohyals each year. For *T. declivis* James (1975) used length-frequencies to calculate the length of one and two year old New Zealand specimens while Shuntov (1969), working on *T. declivis* from the Great Australian Bight, provided only length ranges for age. Webb and Grant (1979) showed that otolith rings in *T. declivis* were layed down at regularly increasing intervals from the nucleus in all fish. However, they only assumed that each ring corresponded to one years growth. Measurement of the marginal increment on otoliths of *T. declivis* in the present study suggests that the rings may be layed down annually. Analysis of length-frequency distributions further supports the annual formation of rings for at least the first six years.

The growth rate of *T. declivis* reported in the present study is in agreement with the results of Webb and Grant (1979) and with the CSIRO ageing conducted in 1977. Lengths at age 1 and 2 years are also similar to values obtained by James (1975) in New Zealand waters, as are lengths at age 4-6 when compared to Shuntov's (1969) figures from the Great Australian Bight.

The *T. declivis* stock in south-eastern Australian waters is presently unexploited and thus offers an opportunity to determine natural mortalities. However, in this study specific bias in the size distribution of fish was evident with samples from south of 39°S containing far fewer fish over 30 cm FL. While this might suggest emigration of larger specimens, fish of this size are certainly present in this region as catches of 31-37 cm individuals have predominated in midwater trawls (Collins and Baron 1981). In addition, young fish (less than age 4) were not caught in the quantities which might have been expected since the nets were fitted with 10 and 40 mm cod end liners with the specific purpose of retaining all the small fish. The most likely explanation relates to the tendency of *T. declivis* to school by size and to show differences in size distribution by depth. Smaller fish occur in shallower water and nearer the surface in offshore waters (James 1975; Shuntov 1969). The use of sub-surface sampling gear in the present study would thus make it difficult to obtain reliable length-frequency distributions. The use of echo sounders to locate *T. declivis* schools may have contributed to the low catches of small fish since they do not return such a strong echo and thus may have been under sampled.

An instantaneous natural mortality (M) of 0.63 was derived from the northern area catch curve while Pauly's (1980) method gave a value of 0.70. MacCall *et al.* (1980) calculated M for *T. symmetricus* to be 0.25 given a von Bertalanffy K value of 0.09, and the occurrence of fish over 30 years old. Our analysis for *T. declivis* produced a von Bertalanffy K value of 0.20 and a maximum age of about 15 and so different natural mortalities would be expected.

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