Estimates of Age and Growth for

South Pacific Albacore

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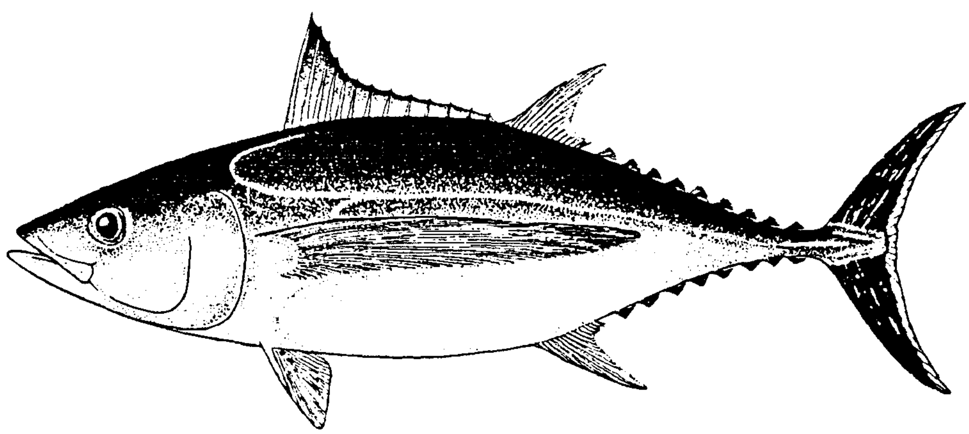

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1. BACKGROUND

Tagging programmes aimed at generating information on the demographic traits of South Pacific albacore have been conducted each year since 1986 (Labelle and Sharples 1991). During such operations, albacore were generally caught by means of troll fishing gear. Once the fish were on board, a tuna dart tag was inserted under the second dorsal fin, and the fish released immediately afterwards. In some cases, tetracycline was also injected in the fish prior to release to provide confirmation of the periodicity of ring formation on hard parts. Tagged fish were released mainly in the Subtropical Convergence Zone (STCZ: 35-40°S, 170-130°W), but also coastal waters of New Zealand and in the Tasman Sea. Information on the recovery of tagged fish has been provided on a voluntary basis by commercial fishermen, and through systematic sampling conducted at several canneries.

Information on the recovery of 11 tagged albacore has been submitted to the SPC since tagging activities began (Table 1). The recapture data indicate that tagged fish were at liberty from two to thirty months before capture, with the average time being 13 months. The corresponding monthly growth rates based on this incomplete data set, ranged from 0.55 cm for an 88 cm fish, to 1.42 cm for a 71.3 cm fish. The growth rates observed seem to cluster in two groups, with high growth rates ($>1 cm \cdot month^{-1}$) associated with fish which were tagged and recovered after 1989 (Fig. 1). It should be noted that the length at recovery for these three fish were estimated from the weight at recovery, since no measurements were taken at the time of capture. Thus, the possibility exists that this clustering pattern is simply the result of inaccurate estimates of length at recovery, rather than of environmental or physiological factors. Still, in the absence of sufficient evidence to reject some of the available data, the empirical estimates of growth rates are considered to be representative of the variation in growth rate within the South Pacific albacore population.

In order to gain additional insight into the growth rates of South Pacific albacore, otoliths were collected from 144 albacore caught in the STCZ during the 1986-87 fishing season. Based on the number of increments on the sagittae, Wetherall *et al.* (1989) estimated monthly growth rates to be ~1.6 cm for 55-65 cm fish, and ~1.0 cm for fish which are 80-85 cm in length. The estimates of length-at-age based on the samples were ~64 cm and ~79 cm for two and three year old fish respectively. Such results suggested that the modes observed on length frequency histograms resulted from distinct spawning events occurring at six month intervals (semi-annual cohorts). The authors noted that such growth rates appeared to be relatively high for albacore tuna, and that the daily growth estimates could not be validated given the absence of recovery data on tetracycline injected albacore from the South Pacific.

Additional estimates of growth rates for South Pacific albacore were reported by Hampton *et al.* (1990), based on an analysis of modal progressions of length frequency data from the STCZ by means of the MULTIFAN method (see Fournier *et al.* 1990). The authors noted that among the models tested, those based on the assumption that the modes represented annual cohorts provided better agreement with existing retrun data than those based on the assumption of semi-annual cohorts. Estimates of monthly growth rates associated with the best fitting model were ~0.55 cm for 80 cm fish, which are about half of those proposed by Wetherall *et al.* (1989).

Using a different approach, Murray and Bailey (1989) provided estimates growth rates based on analysis of ring counts on caudal vertebrae. Based on a sample of 417 albacore caught in longline and troll fisheries, monthly growth rates were estimated at 0.61 cm for a 70 cm fish, and 0.56 cm for an 80 cm fish. The authors noted that their estimates of the von Bertalanffy growth parameters did not agree with those reported for albacore in other regions, and attributed this to deficiencies in the sample data used. Additional vertebrae samples were obtained fròm large albacore by the above authors after their preliminary analysis was conducted. These data were kindly provided to the staff of the SPC's Tuna and Billfish Assessment Program (TBAP) for further analysis of growth rates. Thus the main objective of this report is to describe the analysis conducted on these data, the results obtained, and account of the current state of knowledge on growth rates of South Pacific albacore.

2. SAMPLING AND ANALYTICAL METHODS

Murray and Bailey (1989) provided a detailed description of the sampling methods used to collect and process vertebrae samples. Briefly, samples were collected during 1987 and 1988 from commercial troll vessels fishing in the Tasman Sea, coastal New Zealand waters, and the STCZ, as well as from Japanese longliners operating off the east coast of New Zealand. Upon landing, the fish were measured and sexed. The 35th and 36th vertebrae were then removed from the caudal keel, trimmed and frozen. Additional details on the preparation method, and the ring counting technique were reported by Murray and Bailey (1989).

Samples which had not been used for the first analysis conducted by Murray and Bailey (1989) were processed according to the same methods, and these new data were added to the original data set. The resulting data set consisted of 494 samples. For the present study, estimates of the von Bertalanffy growth parameters were based on this final data set. Vaugham and Kanciruk (1982) found that a non-linear least squares fit to be the preferred method for fitting the von Bertalanffy growth equation. This is also the procedure relied upon by the program FISHPARM (Saila *et al.* 1988) used by Murray and Bailey (1989) to generate the initial estimates. Therefore, least-squares estimates of the von Bertalanffy parameters were generated by means of the nonlinear Simplex algorithm of the statistical program SYSTAT (Macintosh versions 5.1).

In order to determine if the growth parameter estimates based on these vertebrae counts are more representative of actual growth patterns than those derived from alternative sources of data (length frequency or sagittae rings), the predictions made with each growth model were compared to the actual figures obtained from the tagging programmes. For each recovery case where release and recovery sizes were available, the corresponding sizes at return were predicted through a procedure similar to that used by Laurs and Wetherall (1981). The predicted fork lengths at return (L_r) were determined as follows;

(1) $$L_r = a + bL_i$$

where: L_i = fork length at the tagging

a = intercept = $L_\infty \cdot (1\text{-}e^{-kt})$

b = regression coefficient = e^{-kt}

t = time at large = r-i

k = estimated growth coefficient for a given model

L_∞ = estimated asymptotic size for a given model

Given that the von Bertalanffy growth estimates were not provided by Wetherall *et al.* (1989), the sizes at recovery were based on the predicted length-at-age figures provided by these authors. The age at release of each tagged fish was first estimated by reference to the estimates provided in Table 2 of Wetherall *et al.* (1989). The associated time at large was then added to the age at release to provide an estimate of the age at recovery. The associated length at recovery was then obtained from the length-at-age figures provided by these authors. Simple linear regressions of the observed to expected length at recovery were then generated for each model, and were compared to each other to determine which ageing method provided the best description of the empirical observations of growth rates from tag return data.

3. RESULTS

3.1 Trends and peculiarities in growth patterns

The length of the fish sampled for vertebral ageing ranged from 44 cm to 110 cm (Table 2), which corresponds to the entire size range of albacore caught in surface and longline fisheries operating in the South Pacific (Labelle and Murray 1991). The corresponding number of vertebrae rings observed in this sample ranged from one to thirteen. If one assumes that each ring count category constitutes a distinct age group, then there were 13 age groups present among the fish sampled. At the present time, there exists no reliable estimates of the actual age of an albacore when the first ring is formed. Thus, the actual age of fish with a given number of ring is not known with certainty. In the following discussion, fish with three rings will be referred to as a three year old fish for practical purposes only. The reader should keep in mind however that this fish could well be four, five, or more years of age depending on whether the fish was one, two, or more years of age when the first ring was formed.

Sample sizes for all age groups were greater than 20, except for the first and last two groups. Considerable variation in size within most age groups is apparent, and is greatest for the middle age groups (Fig 2). The size variation of fish in the first age group does not appear to be well represented by the sample data, as the corresponding sizes were clustered near the lower limit of the size range sampled. This is attributed to the fact that fish near the lower size limit do not contribute much to the troll fishery (Labelle and Murray 1991), and the resulting catch sample. Thus, the estimated average size for this age group based on sample data is without doubt positively biased to some extent. Estimates of average length-at-age may well be biased for the two oldest age groups as well because of the small sample sizes.

Differences in average size between the successive age groups were calculated to reveal any anomaly in growth patterns (Fig. 3). In theory, absolute growth should increase rapidly during the initial years, and decrease progressively in later life (see Ricker 1975). The pattern observed for albacore agrees with theoretical expectations, except for the high growth rates observed for age 8→9 and 11→12. The unusually large growth increment for the latter category could be attributed to the low sample sizes, but the one associated with the age 8→9 cannot be discarded so easily since the sample sizes were much larger. These apparent anomalies could very well influence the predicted growth rates, and should be accounted for during the estimation process.

3.2 Estimates of growth rates based on vertebrae counts

Estimates of the von Bertalanffy growth parameters were first generated based on all measurements in the final data set since there was not sufficient grounds to simply reject the measurements associated with one year old fish, or those of fish older than nine years of age. However, in view of the apparent anomalies in growth rates, and the potential for sampling biases, the growth parameters were also estimated from a subset of the final data set, which did not include age 1 and age 9+ albacore (Table 3, age groups 2-8). The predicted lengths-at-age were also determined from the growth parameter estimates obtained by Murray and Bailey (1989) to see if the additional samples were consistent in terms of the length-at-age relationship.

The predicted length-at-age generated by Murray and Bailey (1989) based on the original data set provided a reasonably good fit to the data for ages 1-7, but overestimated the average sizes of the older age groups (Model A, Fig. 4). A linear regression of the residuals against age (Model A, Fig. 5) revealed a significant negative relationship ($P \approx 0.0001$). Murray and Bailey (1989) noted that their estimate of asymptotic length was unrealistically high (192 cm), which was attributed to the dominance of troll caught fish in the samples used. In support of this hypothesis, the estimate of asymptotic length based on the second data set containing the additional sample data was much lower (~127 cm), and was comparable to the L_∞ figures reported by Murray and Bailey (1989) for albacore stocks from the North Pacific Ocean (range: 104-145 cm) and the Indian Ocean (128 cm). The predicted lengths-at-age showed a substantially better fit to the actual measurements (Model B, Fig. 4), and the residuals were more uniformly distributed across all age groups (Model B, Fig. 5).

When only the measurements associated with ages 2-8 from the final data set were used for estimation purposes (Model C, Fig. 4), the predicted lengths-at-age for the first seven age groups were nearly identical to those obtained with model B, but were slightly higher for the remaining age groups. Accordingly, the corresponding growth coefficients were similar, but the estimated asymptotic length was higher in the later case (~139 cm). Linear regressions of the residuals against age (Model C, Fig. 5) revealed no significant relationship between these variables ($P \approx 0.9746$). Growth parameter estimates derived from age groups 2-8 were therefore considered to be the best estimates available from vertebrae ring count samples.

3.3 Comparison of growth rates based on different types of data

Regressions of the predicted lengths-at-recovery against the actual lengths-at-recovery indicated that the growth rates proposed by Wetherall *et al.* (1989) overestimated the lengths-at-recovery (Fig. 6). The slope of the regression was substantially greater than 1.0 when all release-recapture records were used in the regression, and even when only the pre-1990 release-recapture data were used (Model E, Table 3). By contrast, the predicted growth rates based on analyses of vertebrae counts and length frequency modes (Models C and D, Table 3) underestimated the lengths-at-recovery. For both of these models, the amount of discrepancy between the predicted and actual values was less than for the previous model. The slopes and intercepts of the two corresponding regressions were very similar. The adjusted coefficient of determination (r^2) was greater for model #4 than for model #3 when all release-recapture records were used and when only the pre-

1990 release-recapture data were used. However, under both of these conditions, the slopes of the regressions based on model #3 were closer to unity that the one based on model #4. Such results indicate that the growth rate estimates based on the analysis of vertebrae ring counts provide a marginally better fit to the actual growth rates observed than the estimates based on the analysis of modal progressions on length frequency histograms. It should be noted that when all release-recapture records were used for assessment purposes, the best predictor of growth rates underestimated the observed growth rates by about 7%.

4. DISCUSSION

The results of the present analysis adds support to the notion that average growth rates in South Pacific albacore are less than those proposed by Wetherall *et al.* (1989), and are in the order of ~0.5 $cm \cdot month^{-1}$ for an 80 cm fish. The present analysis also indicates that vertebrae ring counts can be used to assess growth rates of South Pacific albacore, and can provide estimates comparable to those obtained by means of the MULTIFAN microcomputer program. Length frequency data collected during the 1990-91 season have recently been compiled, and will be subject to a MULTIFAN analysis in the near future to provide a more conclusive assessment of growth rates. It should be noted that growth estimates from length frequency data and from vertebrae ring counts have not yet been validated by reference to growth data from tetracycline labelling experiments. Hopefully, tetracycline injected albacore will be recovered in the near future, and the information provided will be used for validation purposes.

There is considerable uncertainty remaining about the nature of the factor(s) responsible for the discrepancy between the actual growth rate figures and those predicted on the basis of vertebrae rings. The possibility exists that the actual growth rate figures are somewhat positively biased simply because the fish were not measured accurately under field conditions. Attempts to process fish rapidly while sampling on the docks in Noumea revealed that there is generally a tendency to obtain length measurements which exceed the actual lengths. However, there are several other hypotheses which could account for the differences observed. Year to year changes in growth rates due to oceanographic conditions might have been responsible for differences in growth rates between the tagged group, and the one used for ageing purposes. However, most of the fish sampled for ageing purposes were captured during the same years (1986-1988) and over the same latitudes (NZ and STCZ) as most of the fish which were tagged and recaptured.

Murray (1990) hypothesized that there might exist sexual differences in growth rates. Should the differences be substantial, sampling vertebrae from one sex in particular, or tagging mainly members of one sex, could account for the discrepancies in growth rates obtained with either model. Many of the tagged fish recovered so far were not sexed, so the possibility exists that the tagged fish recovered were predominantly of one sex. An examination of the vertebrae data available failed to reveal any difference in growth rates between sexes, but this could be attributed to the disproportionately small number of female samples collected.

Laurs and Wetherall (1981) gave evidence that tagging and handling stress can account for a reduction in growth rates for North Pacific Albacore following tagging. Should this hold true for South Pacific albacore as well, the discrepancy between the actual and predicted growth rates should be even larger than reported here. Additional tagging and ageing data will have to be obtained in order to resolve the discrepancies between the actual and predicted growth patterns. For this purpose, the current sampling program on longline catches in Noumea will be extended, and hard parts (otoliths, fin spines, vertebrae) will be collected every week from as many fish as possible by SPC staff for subsequent age determination. Until additional information is obtained, the estimates obtained from analysis of length data and from vertebrae ring counts can serve as approximate predictors of length-at-age. Since their corresponding estimates of growth rates were similar, and were determined for independent data sources, there is considerable support for the notion that the predicted growth patterns are representative of actual growth rates in this species. In light of the results obtained, it seems reasonable to assume that the distinct rings observed are associated with annual growth increments.

Murray and Bailey (1989) noted that the ease and speed of the vertebral ageing method made it a particularly useful [and cost-effective] ageing method. This method can be used to provide relatively quick estimates of relative age, even under field conditions. However, the results of the present analysis indicate that the technique may occasionally provide inaccurate estimates of age for fish greater than 73 cm (lower limit of age 8 fish). Assuming that albacore growth conforms to theoretical patterns, then it could be hypothesized that the anomalous growth increment associated with the age 8-9 transition is due to physiological factors, which prevented the deposition of clearly visible vertebra rings. For temperate species, yearly growth bands are deposited on hard parts due to the slowing down of temperature-dependent processes during the winter, followed by an increase in metabolic rates during the warmer periods of the year. Temperature-dependent processes also affect species such as albacore which are known to undertake extensive migrations across latitudinal gradients. One could speculate that albacore within the 88-95 cm size range have a restricted distribution pattern, and remain within a narrow range of water temperature, which would greatly reduce the clarity of the bands deposited. This range restriction might be associated with spawning events, where it would serve to concentrate potential spawners in specific areas. Interestingly, Bailey (1990) noted that female albacore within the 86-97 cm size range exhibited relatively high gonadosomatic indices ($10^4 \cdot W/L^3 > 2.0$), which is considered to be an indicator of spawning condition in yellowfin tuna of the western tropical Pacific Ocean (Koido and Suzuki 1989).

If the above hypothesis is true, then fish with nine rings could actually be 10 years old. However, all attempts to adjust the data set to account for such a hypothesis failed to provide growth rate estimates which were more similar to the actual rates observed from tagging data. Thus, there is not much support for the above hypothesis. An alternative explanation is that ageing errors were responsible for the anomalies observed. Murray and Bailey (1989) reported that fish with more than eight vertebral annuli showed evidence of ring compression. These authors noted that the distance from focus to annulus was smaller for fish with ten rings than for those with nine rings. Ring compression might make it difficult for readers to properly categorize a fish to a certain age group. Thus a fish with ten rings might be classified as a nine ring fish because the two rings near the edge look like a single ring. This would make the average size of a nine year old fish greater than it actually is, which would account for the unusually large growth increment. However, once again, all attempts made at adjusting the data set to account for this hypothesis failed to provide growth estimates that yield growth rate estimates which were more closer to the empirical growth rate estimates from tagging data. Hopefully, the additional sampling underway will provide further insight into the nature of the factors responsible for the anomalies observed.

5. ACKNOWLEDGEMENTS

The present analysis could not have been conducted without the collaboration of Dr. Talbot Murray and Mr. Kevin Bailey, who provided the sample data on vertebrae ring counts and the the complementary information. The author is sincerely grateful to them for their collaboration, and wishes to point out that they deserve much of the credit for having initiated this investigation. Financial assistance for this analysis and ongoing investigations on ageing methods conducted at the SPC was provided by Canada's International Center for Ocean Development (ICOD), and the EEC's Fifth European Development Fund.

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7. TABLES

Table 1. Summary of release and recovery statistics for South Pacific albacore. Statistics associated with tagged albacore recovered prior to 1990 were obtained from Lewis (1990). Additional statistics associated with tagged albacore recovered during the 1990-91 season were extracted from SPCs TBAP database.

Tag Code	Return Address	Tagging vessel	Release date	Lat.	Lon.	Size (cm)	Recapt. date	Vessel type	Lat.	Long.	Size (cm)	Days Free	Size diff	Growth / month	Comments
	Pago		28/02/86	40.3	150.4W	72	14/07/88	Asian L.	26.02	167.3W	88.0	867	16.0	0.56	
	Pago		09/03/86	40.2	145.5W	78	16/04/87	Asian L.	38.23	133.5W	86.0	403	8.0	0.60	
	Pago		30/01/87	37.4	153.4W	80	06/06/88	Asian L.	32.38	153.4W	92.0	493	12.0	0.74	
	Pago		27/02/87	40.4	177.0E	76	13/08/87	Asian L.	30.40	171.5E	80.0	167	4.0	0.73	
	Pago		28/02/87	39.4	151.0W	64	27/04/87	Asian L.	38.23	145.4W		58			
	Pago		25/02/87	40.2	177.1E	80	18/08/89	NZ Tr.	42.15	170.1E	96.5	905	16.5	0.55	
	Pago		01/02/88	38.2	173.0E	61	26/12/88	Jap. drif	38.47	158.3E		329			
A05720	Pago		n/a	n/a	n/a	n/a	18/05/91	Taiw L.	38.45	151.1W	70.7		70.7		
A00324	Pago	Kaharoa	02/02/90	39.0	172.3E	60	13/08/91	Jap. L.	33.22	174.4E	85.0	557	25.0	1.36	Est. FL from W
A00374	SPC	Solander 3	25/01/91	40.4	177.0E	82	24/07/91	Jap. L.	36.57	178.0E	89.9	180	7.9	1.33	Est. FL from W
A01889	SPC	Solander 3	22/02/91	41.2	151.3W	69	01/06/91	Taiw L.	39.00	146.5W	73.6	99	4.6	1.42	Est. FL from W

* All tags released prior to to Nov. 1990 were orange tags with Pago Pago printed as return address.
Fork lengths were estimated from weight using the equation proposed by Labelle & Murray (1991) for the STCZ 1989-90: $FL = 35.5386\ W^{0.33841}$

Table 2. Summary statistics on sizes of albacore aged from vertebrae ring counts.

Ring count	Sample size	Length range	Mean length	Standard Deviation	Coefficient variation
1	7	45-51	47.2	2.21	4.68
2	79	44-65	50.1	4.23	8.38
3	71	46-72	57.1	6.86	12.03
4	68	48-78	65.9	6.63	10.01
5	61	57-95	73.6	8.01	10.88
6	53	58-99	79.6	8.74	10.98
7	54	70-105	85.1	8.42	9.89
8	26	73-102	88.9	7.34	8.25
9	20	80-101	95.0	4.58	4.81
10	32	88-110	96.6	4.61	4.77
11	20	92-107	97.6	3.69	3.78
12	2	103-108	105.5	3.53	3.35
13	1	107	107.0	n/a	n/a

Table 3. Estimates of growth parameters for various models (top), and regressions of predicted recovery sizes against actual recovery sizes for last three models (bottom). The models were: A. Murray and Bailey (1989); B-C. Present study; D. Hampton *et al.* (1990); E. Wetherall *et al.* (1989). No von Bertalanffy growth parameter estimates were generated from the later model. All growth rate estimates are for 80 cm fish. Predicted sizes were regressed against all available recovery sizes (all 8), or only the first five obtained prior to 1990 (first 5). Lower and upper bounds of the slope (LB-UB) correspond to the 95% confidence intervals.

Model: structure	Age groups	Size range	L_∞	K	T_0	Growth·month^{-1}
A: vertebrae	1-10	44-110	192.000	0.06	-3.300	~ 0.56 cm
B: vertebrae	1-13	44-102	126.883	0.117	-2.306	~ 0.45 cm
C: vertebrae	2-8	42-110	138.900	0.100	-2.455	~ 0.48 cm
D: fork length	1-6	47-104	102.000	0.280	n/a	~ 0.55 cm
E: sagittae	1-5	45-105	n/a	n/a	n/a	~ 1.00 cm
	Predicted rec. sizes	Regression intercept	Adjusted r^2	Regression slope	Slope LB	Slope UB
C: vertebrae	all 8	0.895	0.685	0.939	0.369	1.509
D: fork length	all 8	9.728	0.768	0.840	0.422	1.258
E: sagittae	all 8	-42.490	0.782	1.557	0.812	2.301
C: vertebrae	first 5	14.243	0.966	0.809	0.569	1.049
D: fork length	first 5	25.261	0.937	0.681	0.403	0.960
E: sagittae	first 5	-44.656	0.804	1.600	0.382	2.837

8. FIGURES

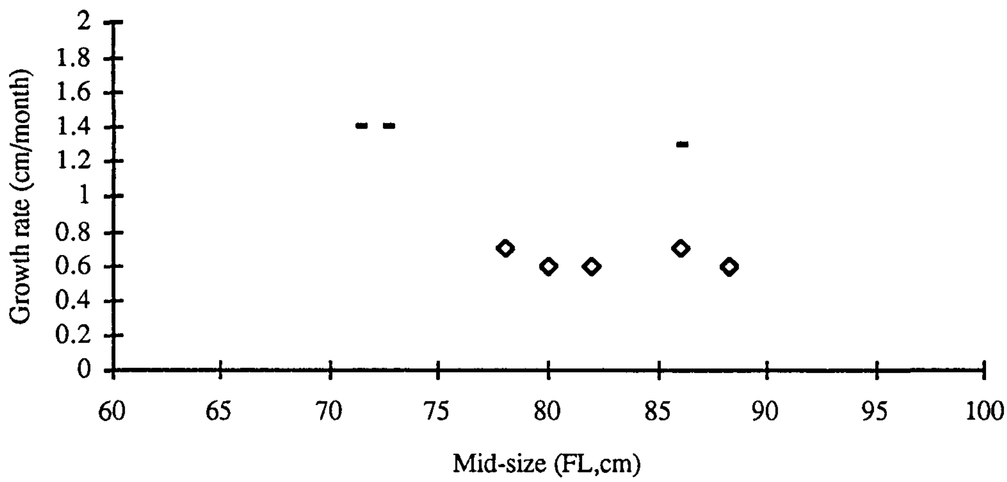

Figure 1. Average growth rates of South Pacific albacore based on data obtained from the 1986-1991 tagging programmes. The solid lines correspond to the growth rates of tagged fish for which the length at recovery was estimated from the weight at recovery. Open points correspond to the growth rates of individuals where the lengths at recovery were known. Mid-size is the average length between release and recovery.

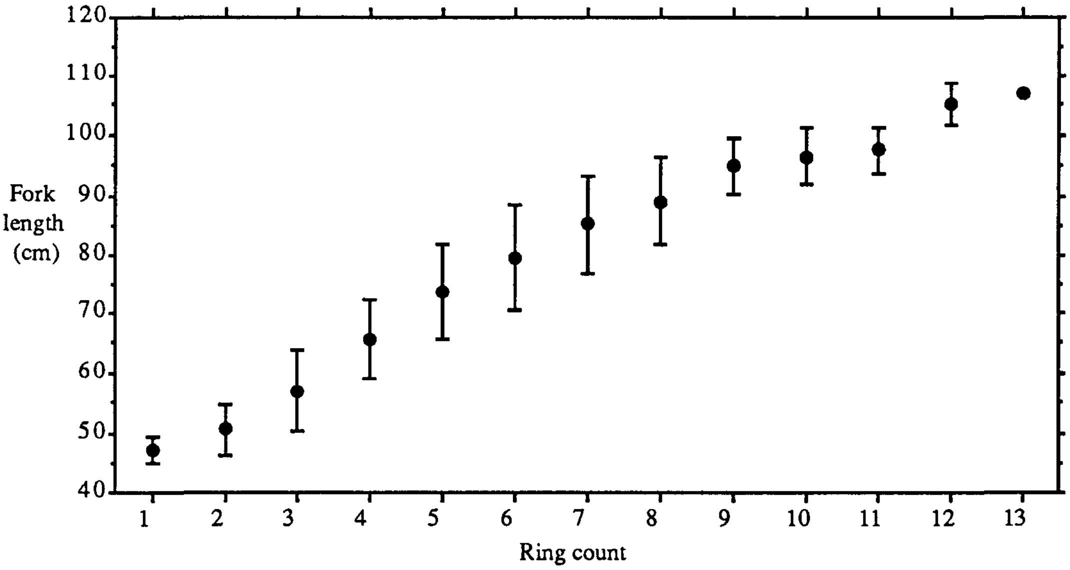

Figure 2. Lengths of albacore sampled by vertebrae ring count category. The average fork length (mid dot) ± 1 standard deviation (vertical bars) are given for each ring count category.

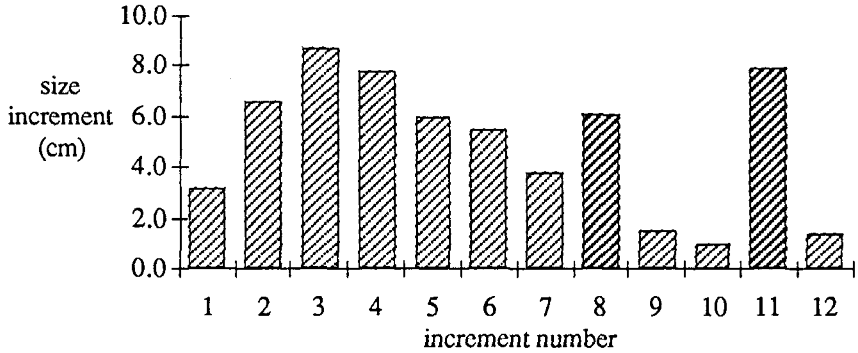

Figure 3. Difference in average size between successive age classes.

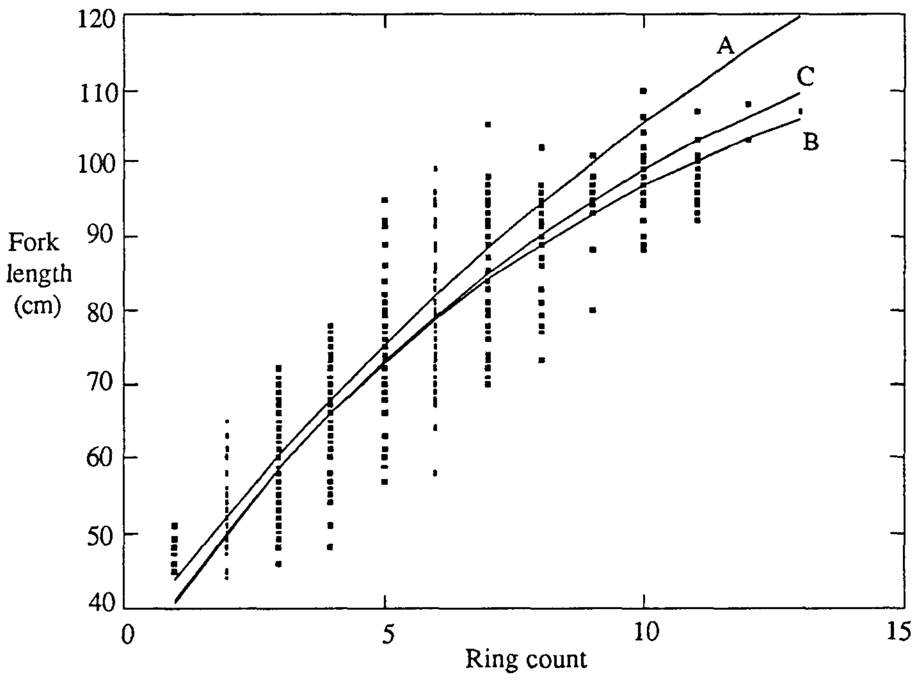

Figure 4. Actual sizes (dots) against predicted sizes (line) from von Bertalanffy growth models based on the three analyses of vertebrae ring counts. The predicted values associated with line A were from Murray and Bailey (1989), while those of lines B and C were based on the data sets with 13 and 7 age groups respectively.

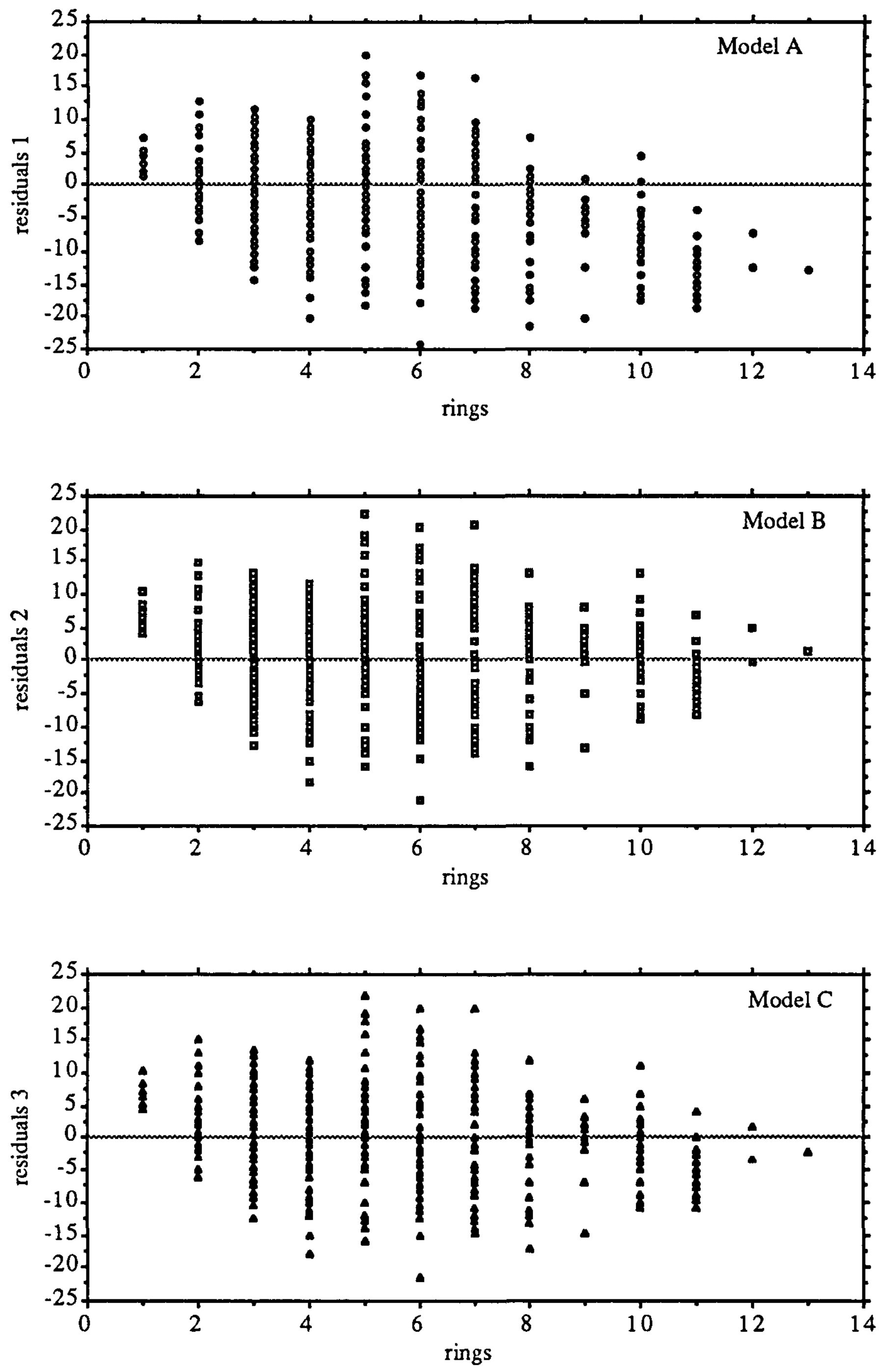

Figure 5. Plots of residuals (difference between actual and predicted lengths-at-age) associated with the three von Bertalanffy models based on vertebrae ring counts. Model A is from Wetherall *et al.* (1989), while Models B and C are from the present study of vertebrae growth ring patterns.

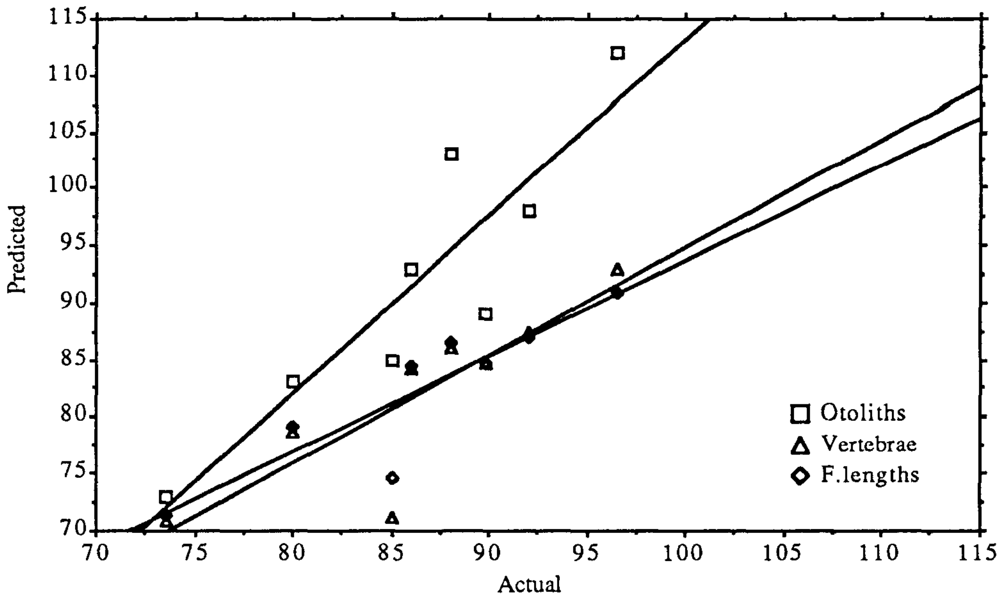

Figure 6. Predicted lengths-at-recovery against actual lengths-at-recovery for growth models based on distinct types of data used; namely otoliths (Model E, Wetherall *et al.* 1989), vertebrae (Model C, present study) and histograms of fork lengths (Model D, Hampton *et al.* 1990).