Age and Growth of South Pacific Albacore
Determined from Daily Otolith Increments

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INTRODUCTION

The South Pacific albacore stock has supported fisheries by Japanese, Taiwanese, and Korean tuna longline fleets since the 1960's. Recently, it has also been the target of extensive surface fishery developments by trollers from the United States, Canada, New Zealand, and French Polynesia, and by drift gill net (driftnet) vessels from Japan and Taiwan. In addition, several other South Pacific island states, including American Samoa, Cook Islands, Fiji, New Caledonia, Tonga, and Vanuatu have interests in South Pacific albacore. Some have longline fleets catching albacore, others earn substantial income from canning of albacore, and all regard the albacore resource as an important basis of future economic development.

However, the rapid expansion of surface fisheries, particularly by the large driftnet fleets, has prompted concerns over fishery interactions and possible overfishing, and underscored the need for more information on South Pacific albacore fishery biology and stock dynamics. In 1986, a cooperative international program (SPAR) was established by the United States (NMFS), New Zealand (MAF), France (ORSTOM), and the South Pacific Commission (SPC), to facilitate data exchange and research. Scientists from Taiwan, the Republic of Korea, Japan, and several South Pacific island countries or territories have also participated in the informal SPAR program. The research objectives include estimation of rates of growth, mortality, and recruitment, and modeling of distribution and migration patterns. The first three parameters are of particular significance, as they determine the productivity of the albacore resource and its capacity to sustain harvests by the competing fleets.

As part of a joint research effort with MAF and ORSTOM vessels and U.S. commercial trollers, in 1986 and 1987 the NOAA Ship Townsend Cromwell undertook oceanographic surveys of the albacore fishing grounds in the Subtropical Convergence Zone (STCZ), the same area being explored by U.S. jigboats. Albacore caught by the Cromwell and sampled from the landings of the U.S. trollers at Pago Pago, American Samoa, provided the basis for estimating the first model of South Pacific albacore age and growth. This paper describes the model's development, examines its results, and discusses its significance for albacore stock assessment.

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METHODS AND MODELS

Collection and Preparation of Data

In many teleosts, including several tuna species, the age of an individual fish can be determined by counting growth increments on suitable bony structures, such as vertebrae or sagittae, and multiplying such counts by the frequency of increment formation. The increment frequencies must be validated by experimentation. In the North Pacific, the daily formation of identifiable structures on albacore sagittae was demonstrated by counting the number of marginal increments on sagittae of 116 fish injected with oxytetracycline, tagged, released, and subsequently recaptured (Laurs, Nishimoto, and Wetherall 1985). A statistical model of age and growth for North Pacific albacore was developed from fork length (FL) measurements and complete otolith increment counts on 225 specimens (Wetherall, Laurs, Nishimoto, and Yong 1987).

Since 1986, several thousand South Pacific albacore have also been injected with oxytetracylcine, tagged, and released by research vessels from the U.S., New Zealand, and ORSTOM, and by U.S. commercial albacore trollers. Unfortunately, only 5 tagged albacore have been recovered, and no otoliths from them are available. Lacking a validation of daily increment formation in South Pacific albacore, in this analysis we simply assumed that the structures counted on the sagittae were daily increments, based on the North Pacific results.

Samples of sagittal otoliths were collected from albacore caught by trolling on the *Townsend Cromwell*'s 1986 survey, and from albacore landed at Pago Pago during the same year by the U.S. jig boats *Bald Eagle* and *Day Star*[3]. After cleaning in weak household bleach and distilled water, the otoliths were stored dry, and prepared and interpreted by techniques similar to those used by Wild and Foreman (1980).

Sagittae from all albacore were lightly etched with acid prior to reading. First, they were brushed on their distal side between the postrostrum and the primordium (nucleus) with 0.5 N or 2.0 N HCl. Large otoliths were also brushed with acid on their proximal side to reduce their thickness and allow more light to penetrate. After etching, all otoliths were rinsed in distilled water, cleansed with household bleach, and rinsed again. The process of etching and rinsing was repeated as necessary, but in no case resulted in loss of marginal increments. At the time of reading, etched otoliths were mounted whole on culture microslides, in immersion oil.

3/ The *Bald Eagle* and *Day Star* were supported partially by Saltonstall-Kennedy funds administered by the Pacific Fisheries Development Foundation and granted to the American Fishermen's Research Foundation, an association of U.S. albacore trollers and canners.

Each otolith was surveyed microscopically to discover a path, leading from the tip of the postrostrum to the primordium, along which increments could be counted most easily and completely. Such exploratory counting was repeated until the entire record of growth was included. Counts were made from the margin to the nucleus under magnifications of 150-600X. The lower powers were used near the nucleus or on smaller otoliths where average increment width was greater.

Once the optimum reading path was defined, 4 final replicate counts were made, and the average increment count was computed. The age of the fish in days was estimated by multiplying the mean count by 1.05 to correct for undercounting, assuming the same rate of undercounting as in the North Pacific albacore experiments (Laurs, Nishimoto, and Wetherall 1985). The fork length measurements were then plotted against estimated age, and a single outlier was removed. The final data set contained 144 observations, including 61 from albacore taken by the Townsend Cromwell and measured fresh, and 83 from albacore caught by the commercial trollers, brine-frozen, and measured on the day of landing after thawing.

Fitting Growth Models

Our objective was to estimate mathematical relationships between fork length and age, for two purposes:

(1) computing the age of an albacore given a measurement of its fork length, and

(2) calculating the fork length of an albacore given a determination of its age.

To model the relationships of length to age, and age to length, we chose a simple, non-linear interpolator, defined on the interval [XMIN, XMAX], of the form:

$$Y = A + B\ [(X - XMIN)/(XMAX - XMIN)]^{C}$$

where XMIN and XMAX are, respectively, the minimum and maximum values of the specified independent variable in the data set under study, and A, B, and C are parameters to be estimated. In choosing this function, rather than the widely-used von Bertalanffy growth function, we sought to avoid a common problem with the latter, viz., tempting the reader to assign biological significance to the parameters. Our only purpose was to describe statistical relationships between observations of fork length and age within the ranges of the data. One drawback to our interpolator is numerical instability near the lower bound of the X range. But this is only a minor annoyance, and does not affect the function's utility.

Assuming the dependent variable (length or age) had an additive error with zero mean and homogeneous variance, we fit the interpolator to each data set by iterative least squares. In each case, we assumed that the independent variable was measured or determined without error. The models fit in this manner provided estimates of expected fork length at age, and mean age at fork length, within observed ranges of these variables. [The bias and precision of the interpolations are being estimated empirically using bootstrap methods, based on 1,000 pseudo-random samples drawn with replacement from the underlying joint distribution. This work is still in progress.]

RESULTS

The estimated age and growth models are displayed in Figure 1, along with the observations, and interpolations based on the fitted models are given in Tables 1 and 2. The models fit well, in the sense that they account for over 90% of the variation in the dependent variable, and the residuals are reasonably well-behaved.

The fitted models indicate faster growth than expected for albacore. Because of the limited scope of our sample, we couldn't estimate the mean fork length at the first birthday. However, our interpolation model indicates a mean fork length of 54.9 cm at 1.5 yr, 64.4 cm at 2.0 yr, 72.1 cm at 2.5 yr, 78.9 cm at 3.0 yr, and 85.1 cm at 3.5 yr. These translate to monthly growth rates ranging from about 1.6 cm for albacore between 55 and 65 cm (1.5-2.0 yr olds), to about 1.0 cm for albacore between 80 and 85 cm fork length (3.0-3.5 yr olds).

Moreover, the model to interpolate age as a function of fork length predicts that the time intervals between the modes in typical length frequency distributions are about 6 mo, rather than 1 yr, as is usually assumed. Length frequency samples taken recently from the STCZ surface fishery catches by staff of NMFS and SPC illustrate this:

Source	Fork Length Modes (cm)	Estimated Age (yr)	Estimated Interval (yr)
New Zealand troll	58	1.73	
South Pacific			0.46
Jan-Feb 1989	67	2.19	
			0.55
	76	2.74	
Japanese driftnet	60	1.82	
Tasman Sea			0.49
Jan-Feb 1989	69	2.31	
			0.49
	77	2.80	
United States troll	62	1.92	
South Pacific			0.57
1988	72	2.49	
			0.51
	80	3.00	

These results are somewhat inconsistent with the only available direct evidence of South Pacific albacore growth rates, viz., tag returns. Of the 5 returns to date, 4 are accompanied by information on initial and final length. The tagged albacore grew at an average rate of 0.6-0.7 cm per month, considerably less than the 1.0 cm per month which our otolith-based growth model would have predicted.

Since the Townsend Cromwell albacore were fresh when measured, whereas albacore landed by the Day Star and Bald Eagle had been brine-frozen and then thawed before measurements were taken, we wondered whether our results might have been biased. In particular, we thought there might have been a tendency to underestimate the "fresh" fork lengths of the frozen albacore. However, no consistent difference was apparent between the two groups of fish in average length-at-age. In addition, we tested the effects of a bias due to freezing and thawing by fitting the interpolator first to the raw commercial jigboat data and then to the same data with 2% and 5% upward adjustments made to fork length. Our basic results were unaffected; we still estimated surprisingly fast growth rates and intervals of about 6 mo between adjacent modes in the length frequency distributions.

INFERENCES

Our tentative growth models based on daily otolith increment counts are controversial, because they suggest that cohorts of South Pacific albacore are generated every 6 months rather than once per year. A number of questions must be answered before we can accept these results with confidence. First, because the apparent growth rates are faster than expected for albacore, and faster than shown by tag recoveries, one may suspect that the otolith structures counted as daily increments actually have a lower-than-daily frequency. Alternatively, the increments could in fact be deposited daily, but be undercounted.

Because no otoliths have been recovered from the 5 tagged and tetracycline-injected South Pacific albacore recaptured so far, we have no direct means of checking the validity of the assumption on daily increment formation and accurate counting (since these processes are confounded, we cannot judge them separately). Nevertheless, we are confident that otolith increments were deposited daily and that excessive, systematic undercounting was unlikely. The person (R.N.) who made the South Pacific albacore increment counts also processed the sagittae for the North Pacific albacore growth model, and interpreted the marginal otolith increments for the 116 recoveries of tetracycline-injected albacore. The tetracycline experiment showed that an average of 0.95 "daily" increments were identifiable on North Pacific albacore sagittae per day at liberty (hence our 5% upward adjustment of otolith increment counts). The North Pacific albacore tetracycline validation applied to fish above about 50 cm fork length; the frequency of otolith structures counted as "daily" increments was not determined for smaller albacore. Thus, there is a possibility that when the whole otolith counts (margin to core) were made, the otolith microstructure during the early-growth period (i.e., up to 50 cm fork length) was misinterpreted.

If systematic errors in interpreting the early-growth otolith structures were independent of fish length there would be no difference in our estimates of growth rate; the growth curve would simply be shifted a constant distance along the age axis. But if the bias were proportional to length of the albacore, then the steepness of the growth curve would be affected, too. Misinterpretation would be most likely to occur with with otoliths from larger albacore, where early-growth structure might be obscured in the thicker otoliths. In this event, whether the duration of the early-growth period was underestimated or overestimated, corrected growth curves would be flatter and growth rates would be lower than we predicted.

If the otolith-based age and growth model is correct, then it would appear from the length-frequency distributions of the surface catches that the South Pacific albacore stock exploited in the STCZ is a mixture of two or more groups of albacore with birthdate distributions about 6 mo apart. These groups could arise from a single population with semestral spawning, or from two populations with annual spawning cycles 6 mo out of phase with each other. The evidence for spawning season and periodicity in South Pacific albacore is meager and ambiguous. In their recent compilation of scombroid larval distributions, Nishikawa, Honma, Ueyanagi, and Kikawa (1985) reported relatively few plankton net tows in the South Pacific. Samples were taken in all quarters of the year, but were spatially uneven. During October-December, when sampling was most intense in the South Pacific, albacore larvae were found over a broad region between the longitudes of about 143 W and 146 E, and the latitudes of 7 S and 25 S. Albacore larvae were also taken over the same region in January-March, and a few were found in April-June near 164 W and 25 S. None were taken in July-September.

Another source of information on the time and place of South Pacific albacore spawning is the report by Argue, Conand, and Whyman (1983) which documents the occurrence of juvenile albacore in stomachs of skipjack tuna. These data show that juvenile albacore are present in the South Pacific from November-May, at least, in a broad area from the Tuamotu Islands to Queensland, Australia.

If the otolith-based growth model is correct, the consequences are significant for modeling of stock dynamics, estimation of yield potentials, and assessment of fishery interactions. Yield per recruit considerations suggest that surface fishery yield potentials should be proportional to average growth rate, and stock production and recovery rates in general should be greater if age at maturity is 3.5-4.0 yr, rather than 5.0-6.0 yr, as usually is assumed in albacore. Fishery interaction assessments are also affected by growth rate assumptions. In particular, faster growth means a shorter time lag between increased harvest rates in the surface fisheries and measurable impacts in the longline fishery.

REFERENCES

Argue, A.W., F. Conand, and D. Whyman
1983. Spatial and temporal distribution of juvenile tunas from stomachs of tunas caught by pole-and-line gear in the central and western Pacific Ocean. South Pacific Commission, Tuna and Billfish Assesement Program, Tech. Rep. No. 9, 47pp.

Laurs, R.M., R. Nishimoto, and J.A. Wetherall
1985. Frequency of increment formation on sagittae of North Pacific albacore (Thunnus alalunga). Can. J. Fish. Aquat. Sci. 41:1552-1555.

Nishikawa, Y. M. Honma, S. Ueyanagi, and S. Kikawa
1985. Average distribution of larvae of oceanic species of scombroid fishes, 1956-1981. Far Seas Fisheris Research Laboratory, Contribution No. 236.

Wetherall, J.A., R.M. Laurs, R.N. Nishimoto, and M.Y.Y. Yong
1987. Growth variation and stock structure in North Pacific albacore. Working Paper, 10th North Pacific Albacore Workshop, Shimizu, Japan, 11-13 1987 [unpublished].

Wild, A. and T.J. Foreman
1980. The relationship between otolith increments and time for yellowfin and skipjack tuna marked with tetracycline [in Engl. and Span.] Inter-Am. Trop. Tuna Comm. Bull. 17: 509-560.

Table 1. Interpolated fork length (cm) as a function of age (yrs) for South Pacific albacore, based on the daily otolith increment growth model. Data from U.S. albacore jigboats and Townsend Cromwell.

Assumed Age (yrs)	Estimated Fork Length (cm)
1.25	48.2
1.50	54.9
1.75	60.0
2.00	64.4
2.25	68.4
2.50	72.1
2.75	75.6
3.00	78.9
3.25	82.1
3.50	85.1
3.75	88.0
4.00	90.9
4.25	93.6

Table 2. Interpolated age (yrs) as a function of fork length (cm) for South Pacific albacore, based on the daily otolith increment growth models. Data from U.S. albacore jigboats and *Townsend Cromwell*.

Fork Length (cm)	Estimated Age (yrs)
46	1.30
48	1.35
50	1.40
52	1.47
54	1.55
56	1.64
58	1.73
60	1.82
62	1.92
64	2.03
66	2.14
68	2.25
70	2.37
72	2.49
74	2.61
76	2.74
78	2.87
80	3.00
82	3.14
84	3.28
86	3.42
88	3.57
90	3.71
92	3.86
94	4.01
96	4.17
98	4.33
100	4.49
102	4.65
104	4.81

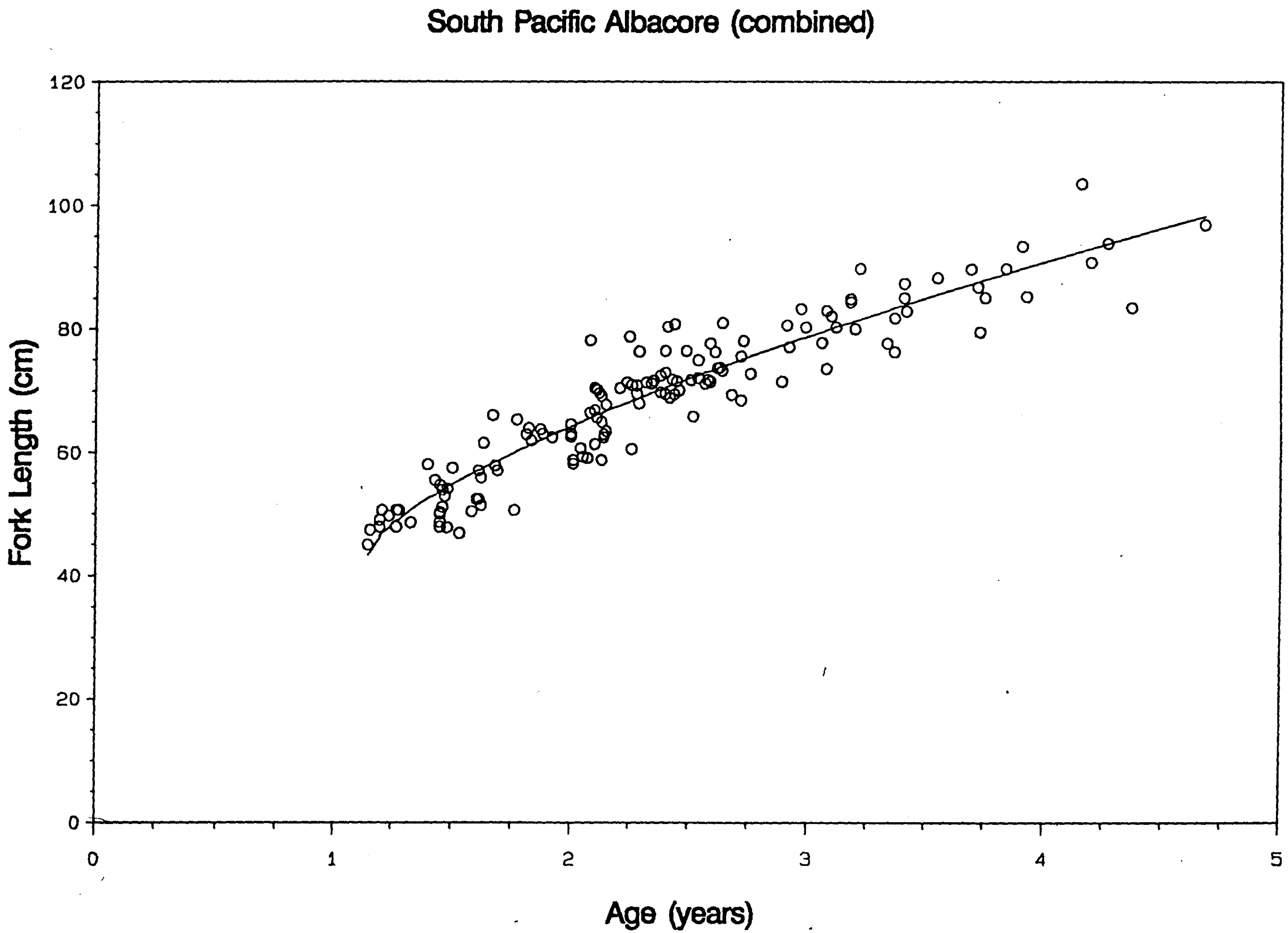

Figure 1. Observed fork length and estimated age for 144 South Pacific albacore (circles), and fitted interpolation model (line).

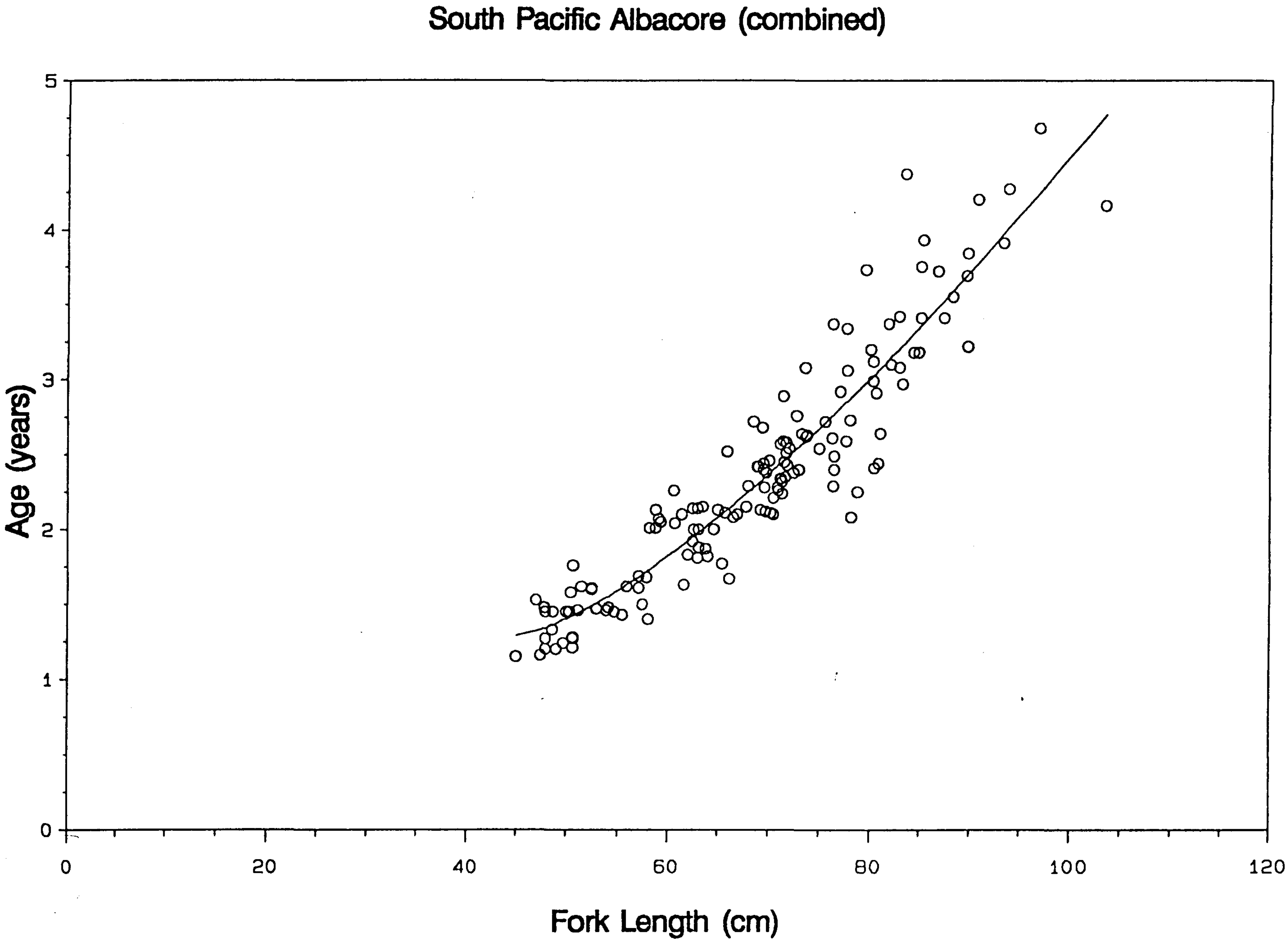

Figure 2. Estimated age and observed fork length for 144 South Pacific albacore (circles), and fitted interpolation model (line).