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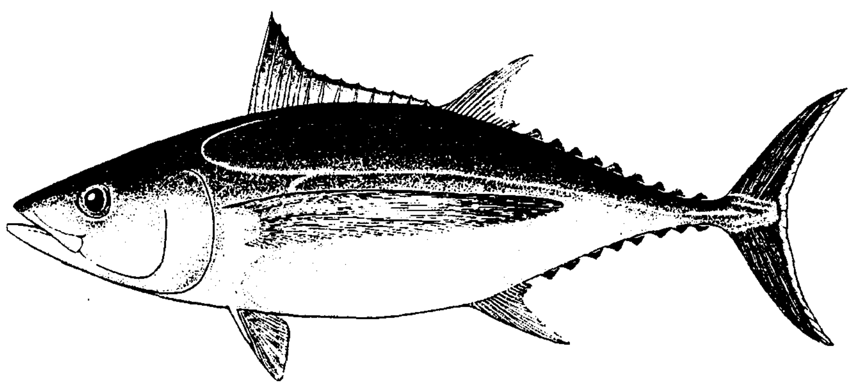

Sixth South Pacific Albacore Research Workshop
Working Paper N°. 3

Rarotonga, Cook Islands
March 5 – 7, 1996

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Introduction

Until the end of 1970's, the tagging of south Pacific albacore (*Thunnus alalunga*) concerned only a few individuals tagged incidentally or during small scale tagging programmes along the south-east coast of Australia and the coast of New Zealand (Roberts 1974, Matthews and Deguara 1992). The first high-seas tagging programme was carried out between 1986 and 1989 in the subtropical convergence zone (STCZ). It was done on board commercial troll fishing vessels with the assistance of scientists from the US National Marine Fisheries Service (NMFS) and the Institut Français de Recherche Scientifique pour le Développement en Coopération (ORSTOM). From 1990 to 1992, a second large scale tagging programme was initiated by the Tuna and Billfish Assessment Programme (TBAP) of the South Pacific Commission (SPC) in association with the Ministry of Agriculture and Fisheries (MAF) of New Zealand. This tagging took place throughout the south Pacific troll fishing ground. Since the implementation of those two programmes, the recoveries have been collected by the Oceanic Fisheries programmes (OFP) of the SPC. The objective of the present paper is to use these data in an analysis of movement patterns, growth and mortality rates of the south Pacific albacore population.

Tag releases and recoveries

Only a brief description of the tagging methods used and the spatio-temporal distribution of tagging effort is given in this paper. A more detailed description of the tagging procedures can be found in Labelle (1993).

Tagging methods

Tagging was conducted on board chartered and commercial troll fishing vessels during the commercial fishing season. The choice of this type of gear was dictated by the fact that large numbers of juvenile albacore in suitable condition could be obtained in this way. The main objectives of the tagging were to obtain information on movement, spatial distribution and mortality of albacore. Therefore, as many uninjured fish as possible covering all sizes and distributed throughout the surface fishing area and the fishing season were tagged. The tags used were yellow plastic tags with a single barbed nylon head. During tagging, the fork length measurement to the nearest lower centimeter was recorded with the associated date, time, tag number and location at release.

Tag recovery data were supplied to the OFP through voluntary returns by fishermen and fishing companies, and through systematic catch sampling programmes at canneries and landing sites throughout the South Pacific. Along with the tag number, tag finders were requested to provide the date, the location of recapture, the method of capture and the fork length and (or) the weight.

Spatial and temporal distribution of tagging

By the end of the tagging programme, a total of 17,226 albacore had been tagged and released. The number of tags released each year (Figure 1) shows that most of the tagging was conducted during the end of the tagging period with more than 60% of the tags released through the joint SPC—MAF tagging programme from 1990 to 1992. Each year, most of the tagging was conducted during the period December to late March when the fishery was in operation. 76% of the tagged fish were released on the principal albacore surface fishing ground, i.e., the Subtropical Convergence Zone (STCZ), in an area bounded by 35-47°S and 170-130°W. Some tagging occurred also along the New Zealand and Tasmanian coast and as far east as Easter Island (~110°W).

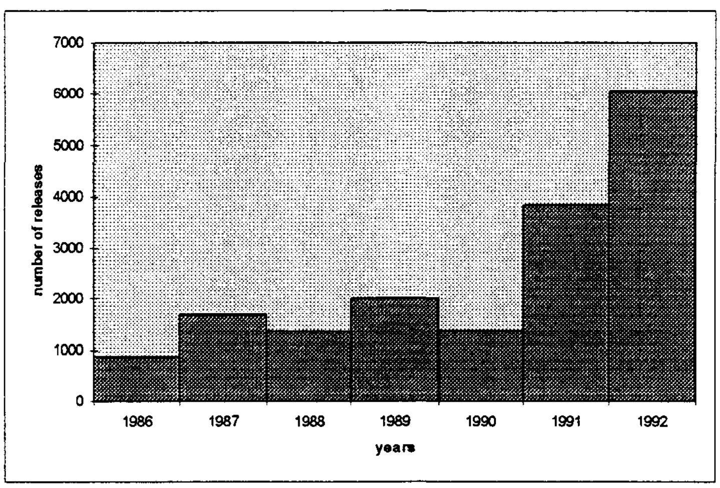

Figure 1. Number of albacore tagged and released per year during the tagging programme conducted jointly by SPC, MAF and NMFS from 1986 to 1992.

Tag recoveries

Of the 17,226 tags released, 168 (0.97%) have been recovered to date. Table 1 gives a summary of releases and returns, by release agency. Albacore have been recovered by several gears including driftnet, handline, longline and troll (Table 2). The vast majority of recoveries (~91%) has, however, been made by longliners. This may reflect to the relative exploitation rates of longline and surface fisheries, differential reporting rates by gear may also have occurred (Anonyme 1995). Furthermore, the fact that albacore caught and tagged from troll fishing vessels have been recaptured by longliners also indicates that potential interactions between those two fleets exist (Labelle 1993).

Table 1. South Pacific albacore tag release and return numbers, as at 31 January 1996.

Agency	Number released	Number of returns	Return rates(%)
MAF	578	4	0.69
NMFS	6803	27	0.39
SPC	9845	136	1.38
Total	17226	168	0.97

Table 2. Albacore tag return numbers, by recapture vessel gear and nationality, as at 31 January 1996.

Gear type	Nationality	No. of returns
Driftnet	Japan	2
	total	2
Handline	Australia	1
	French Polynesia	1
	total	2
Longline	Japan	15
	Korea	1
	New Zealand	3
	Taiwan	132
	USA	1
	total	152
Troll	Australia	1
	New Zealand	3
	USA	3
	total	7
Unknown	Japan	1
	New Zealand	1
	Unknown	3
	total	5
	grand total	168

Table 3 gives the aggregated returns by time at liberty. It shows that albacore tags have been returned up to 7+ years after release. The tags returns by longliners have been observed mainly during the second and third year at liberty suggesting that at the size at which the majority of the fish were tagged (~60-70cm), they were not immediately fully available to the longlines.

Table 3. Returns of tagged albacore by time at liberty and recapture gear.

Time at liberty (yr)	Surface	Longline	Unknown	Total
0 to 1	2	17	0	19
1 to 2	4	42	0	46
2 to 3	3	59	2	64
3 to 4	1	26	2	29
4 to 5	0	5	0	5
5 to 6	1	2	0	3
6 to 7	0	0	0	0
7 to 8	0	1	1	2

Movements

Albacore tagged from troll fishing vessels in the STCZ and along the coasts of New Zealand have shown extensive movements to the east, west and north (Figure 2). The average distance between release and recapture location is 950 nautical miles (NM). However, a large proportion of albacore have moved less than 600 nautical miles (Figure 3a). Fish tagged by game fishermen on the coast of Australia have shown for most of them (~80%) even more limited displacements, suggesting that this portion of the stock tends to spend more time in coastal area. No fish has been recovered south of the area of release (i.e., south of 45S). The plot of distance travelled by time at liberty (Figure 3b) shows a high individual variability of apparent movements rates. For instance, the fish with the longest time at liberty (more than 7 years) was recovered less than 500 NM from its location of release, while some fish were recovered more than 3,000 NM after about 1 year. Only one fish tagged in the STCZ has been recovered in the northern hemisphere (the vicinity of Marshall Island), but this isolated example is not sufficient so far to refute the hypothesis on the existence of two separate stocks in the North and South Pacific and of limited exchange between the two hemispheres.

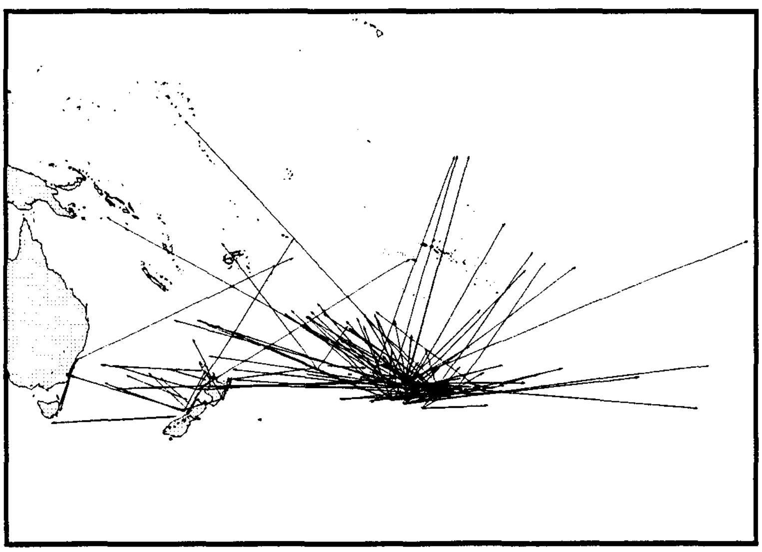

Figure 2. Movements of tagged albacore in the South Pacific

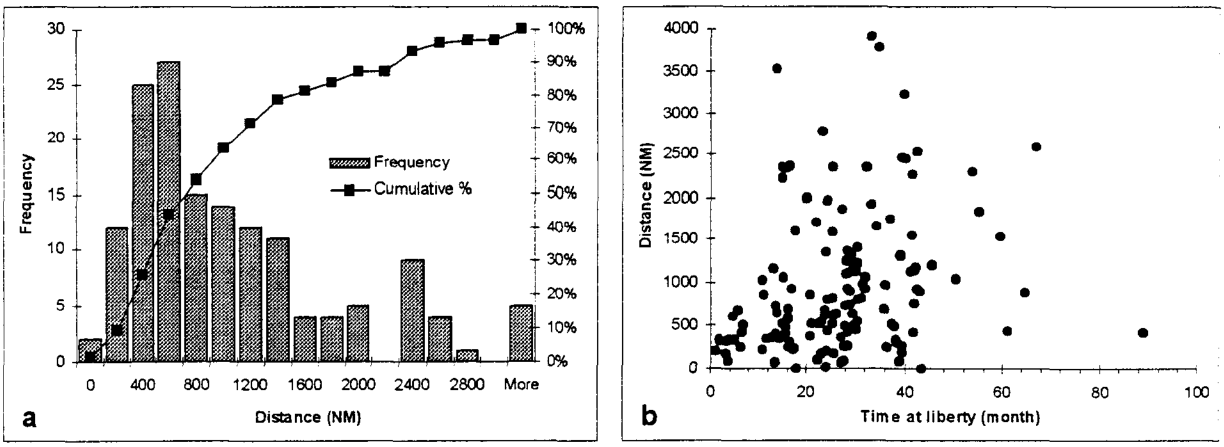

Figure 3. Movement of south Pacific tagged albacore. **a** Frequency and cumulative percentages of distance (nautical miles) travelled, **b** Distance travelled in relation to time at liberty

Growth

Information for each tag return is associated in the database with different credibility scales (Bailey et al. 1993). Those for date and length at recapture were used to make a data screening and to eliminate incomplete or clearly unreliable observations. The size distribution for the albacore tag recoveries ranges between 48 and 83 cm at release and between 49 and 111 cm at recapture. The time at liberty varies from 25 to 2660 days (7 years and 3.5 months). Out of 168 tag returns, 76 were rejected due to incomplete or clearly unreliable information (Table 4).

Table 4. Number of tagged fish released, recovered, rejected and accepted for analysis of albacore growth. Coefficient of reliability : 0 = incomplete or clearly unreliable information; 1 = only length or weight at recapture are available or measured length is outside of the confidence interval of the length-weight relationship; 2 = measured length is within the confidence interval of the length-weight relationship.

Year of tagging	No. tagged fish released	No. tagged fish recovered	Missing release length	Missing recovery date	Missing recovery size	Observations	
						Rejected	Accepted
1986	862	3	0	0	1	1	2
1987	1688	10	0	0	4	4	6
1988	1365	4	0	0	2	2	2
1989	2019	6	0	0	4	4	2
1990	1391	9	0	1	3	3	6
1991	3838	50	2	1	21	22	28
1992	6063	86	0	4	39	40	46
Total	17226	168	2	6	74	76	92

Growth rates

The growth rates have been plotted against the median fork length for the period at large (mid-size). The growth rates range from 0.03 to 1.64 cm/month with an average of 0.64 cm/month (Figure 4). That is the half of the values proposed by Wetherall et al. (1989) from the reading of otolith daily growth increments. As in the previous tagging analysis (Labelle, 1993), estimates of growth rates for south Pacific albacore smaller than 60 cm cannot be obtained because too few data are available. Despite a high variability, a trend seems to indicate that the growth rate increases with the size until 70 cm, then decline progressively afterwards.

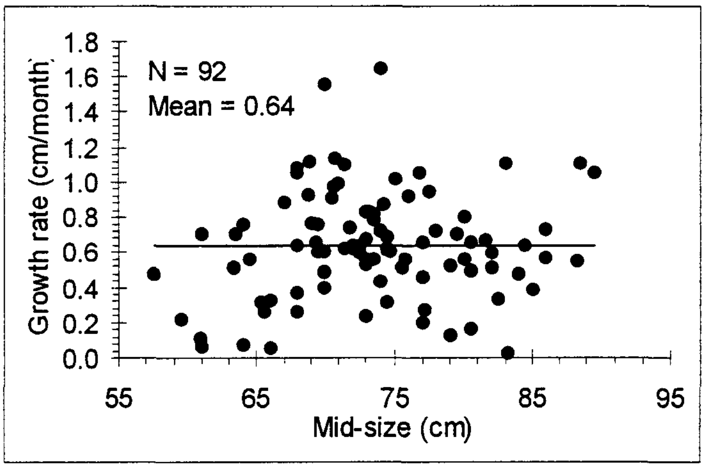

Figure 4. Individual growth rates of tagged south Pacific albacore according to the median fork length for the period at large (mid-size).

Growth parameters

Von Bertalanffy growth parameters from tagging data were estimated with the Fabens (1965) length increment model:

$$\Delta L_i = (L_\infty - L_i)(1 - e^{-K\Delta ti}) + e_i$$

where: L_i is the length at release for the i th tag return,

ΔL_i is the length increment,

Δt_i is the time at liberty,

e_i is an error term, normally distributed, having a mean of zero and variance σ^2.

As different authors have shown that the ordinary least squares fitting procedure tends to result in biased estimates of growth parameters (Chien and Condrey 1987, Kimura et al 1993), we used a maximum-likelihood procedure which automatically weights observations where the variance increases with time at liberty. According to Kimura (1980), the objective function (Φ) minimised to obtain the parameter estimates is:

$$\Phi = \frac{NLog(2\pi\sigma^2)}{2} + \frac{\sum_{i=1}^{N}\left(\Delta L_i - \Delta\hat{L}_i\right)^2}{2\sigma_i^2}$$

where: $\Delta L_i - \Delta\hat{L}_i$ is the difference between the observed and estimated length increment, and σ_i^2 is the variance of ΔL_i.

Different models were tested, either with an overall error term or specific error terms due to individual variation in L_∞, the measurement of release length (e_L) and on the observation at recapture (e_O). The variance $\sigma_{\Delta L}^2$ can be written (Hampton 1991) :

$$\sigma_{\Delta L}^2 = \sigma_{L\infty}^2\left(1-e^{-K\Delta t}\right)\ \sigma_L^2\ e^{-K\Delta t} + \sigma_o^2$$

With this error structure, the observation model becomes:

$$\Delta L_i = (L_\infty - L_i)(1-e^{-K\Delta ti}) + e_{L_\infty}(1-e^{-K\Delta ti}) + e_{L_i}\ e^{-K\Delta ti} + e_{oi}$$

Estimates of growth parameters are in Table 5. The model with an overall error term e_O is improved by adding an error term due to L_∞, as shown by the significant decrease of the objective function and the best adjusted R^2. On the other hand, the additional error term due to the measurement of the release length does not improve it. Therefore, the second model including an error term for L_∞ and an error term for the observation can be selected as the best one to fit the data. The 95% confidence interval (± 2 x standard deviation) include the values estimated from length frequency analysis with MULTIFAN (97.1cm and 0.239 yr^{-1} for L_∞ and K respectively; Labelle et al. 1993). On the other hand, the estimates obtained from vertebral-ring-counts (Labelle et al. 1993) give a higher L_∞ (121.0 cm) and a lower K (0.134 yr^{-1}).

The very large $\sigma_{L_\infty}^2$ estimates suggest that there is high individual variability in growth of south Pacific albacore. That variability increases with increasing time at liberty (Figure 5), probably because the probability that released fish encounter different environmental conditions increases with time. The linearised growth rate per year (G_{yr}) according to these estimates is given by the relation $G_{yr} = 28.3 - 0.289 * L_i$. That represents an increment length after one year of 13.85 cm and 5.18 cm for release lengths of 50 cm and 80 cm respectively.

Table 5. South Pacific albacore growth parameters estimates (standard deviation between brackets) by the maximum likelihood using the Fabens model and 3 different terms of error (σ_O^2 = variance on the observation, $\sigma_{L_\infty}^2$ = variance on L_∞, σ_L^2 = variance on release length, Φ = objective function of the maximum-likelihood procedure).

Model	K	L_∞	σ_O^2	$\sigma_{L_\infty}^2$	σ_L^2	Φ	Adjusted R^2
σ_O^2	0.273 (0.093)	102.48 (9.01)	65.76 (9.65)	-	-	326.61	0.532
$\sigma_O^2 + \sigma_{L_\infty}^2$	0.341 (0.097)	97.99 (6.16)	1.38 (2.45)	207.14 (75.8)	-	313.09	0.550
$\sigma_O^2 + \sigma_{L_\infty}^2 + \sigma_L^2$	0.339 (0.095)	98.09 (6.16)	0 -	211.23 (79.5)	1.85 (3.01)	313.08	0.544

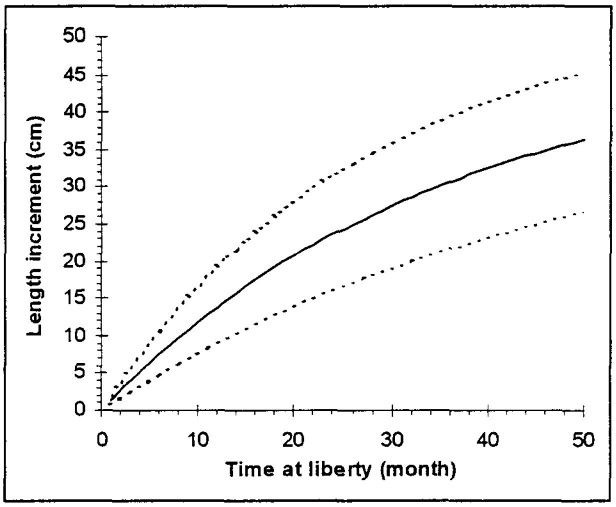

Figure 5. *Thunnus alalunga*. Growth increments based on a 50 cm release length. Dotted lines represent ± 1 standard deviation.

Mortality rates

Description of the model

The model used to estimate mortality is a tag attrition model dealing with the decline in the rate of tag recapture as the population of tagged fish at large also declines. Predictions of tag recoveries were made using a catch equation. The parameters of the model, specifically catchability and natural mortality, were estimated by fitting the model to the observed recoveries through the maximisation of a multinomial likelihood function. The probabilities associated with the fates of each tag were calculated using the following equations:

$$p_i = \frac{\alpha F_i}{F_i + M}(1 - e^{-(F_i+M)})\prod_{k=1}^{i-1} e^{-(F_k+M)}$$

where p_i is the probability of a tag being recaptured in time period i, F_i is the fishing mortality over the same time period, M is the natural mortality rate, which is assumed to be constant over time, and α combines the instantaneous survival from being tagged and the proportion of recaptured tags that were actually returned.

The probability, p_{NR}, of a tag not being returned due to various reasons such as, death, survival past the end of the period analysed, non-reporting, recaptures made after the period analysed and tag slippage, is given by :

$$p_{NR} = 1 - \sum_{i=1}^{n} p_i$$

where n is the total number of time intervals included in the analysis.

Fishing mortality (F_i) in the model is calculated using the following equation:

$$F_i = qE_i$$

where E_i is the fishing effort and q is the catchability (one of the parameters estimated by the model).

For simplicity, the model we used in this first estimation is spatially aggregated and consequently does not incorporate fish movement and spatial variability in tag recoveries. The maximum of the likelihood function was found using an iterative searching algorithm, the Nelder-Mead simplex algorithm (Press *et al.*, 1992).

Preparation of the data

Recoveries have been observed over a period of 10 years (from 1986 to 1995). Thus, to limit the number of time intervals in the analysis, quarterly time steps are used. As shown before in Table 2, recoveries have been obtained by several gears. However, the vast majority (more than 90%) have been made by longliners and only those recoveries are treated in this analysis. As a consequence, recoveries made by the other fleets were added to the non-recovered category. Due to the low overall recovery rate (<2%) leading to a low number of recoveries (152 by longliners), an initial fit was conducted on an aggregated data set, grouping categories of tags released at different periods in the same time at liberty. In that case, constant fishing effort by time period has to be assumed, as it is not possible to know which effort applied to each time period. To see if the use of variable fishing effort in time could have an impact on the estimates, a second fit was conducted on several release sets. The model used in this second analysis is referred as the "non-aggregated model". Fifteen release sets are defined, corresponding to release quarters starting in the first quarter of 1986 and ending in the second quarter of 1992. The analytical model assumes that the fish are released at the beginning of each quarters. Therefore, the dates of release are rounded to the closest "first-of-the-quarter". Figure 6 shows the total number of fish tagged and recovered. By quarterly release set.

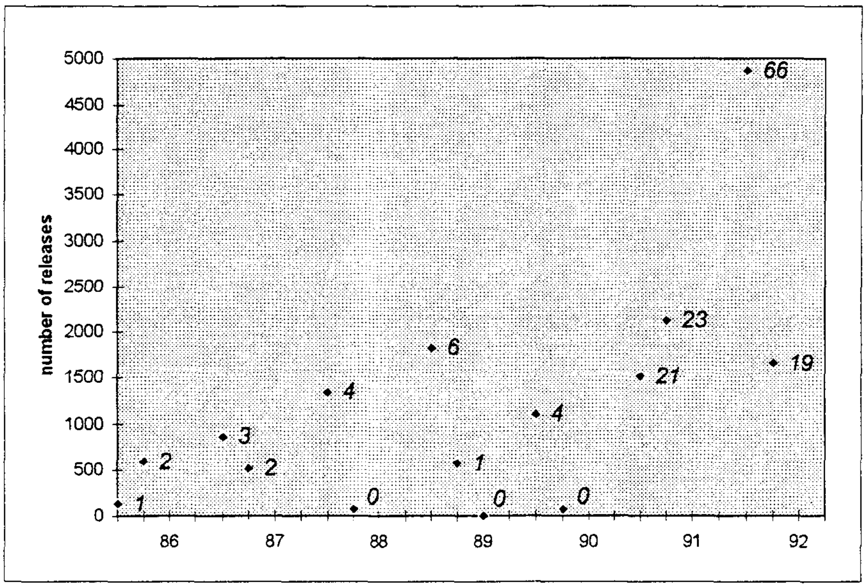

Figure 6. Total numbers of albacore released by quarter (black dots) during the tagging programme with the number of recoveries obtained from each quarterly release set in italics.

The longline fleet fishing in the South Pacific consists mainly of Japanese, Korean and Taiwanese vessels. To aggregate the fishing effort of those fleets to obtain one series of fishing effort to include in our model, it was first necessary to standardise the effort series. This was done by using one series as a standard and calculating the relative fishing power of the other two (the ratio between their CPUEs , in number of fish caught by hundred hooks, and the CPUE of the standard fleet). Taiwanese vessels which have consistently targeted albacore over a long period, were chosen as the standard. This is therefore the fleet for which we can assume a relatively constant fishing power directed against albacore. Quarterly fishing efforts estimates for the entire South Pacific used in the analysis are plotted in Figure 7.

The returns were also aggregated by quarter of recovery. As the model assumes that recoveries occur during the whole quarters following release dates, the aggregation was done by simply truncating the date of recovery to each corresponding quarter. Release and recovery data are given in table 6.

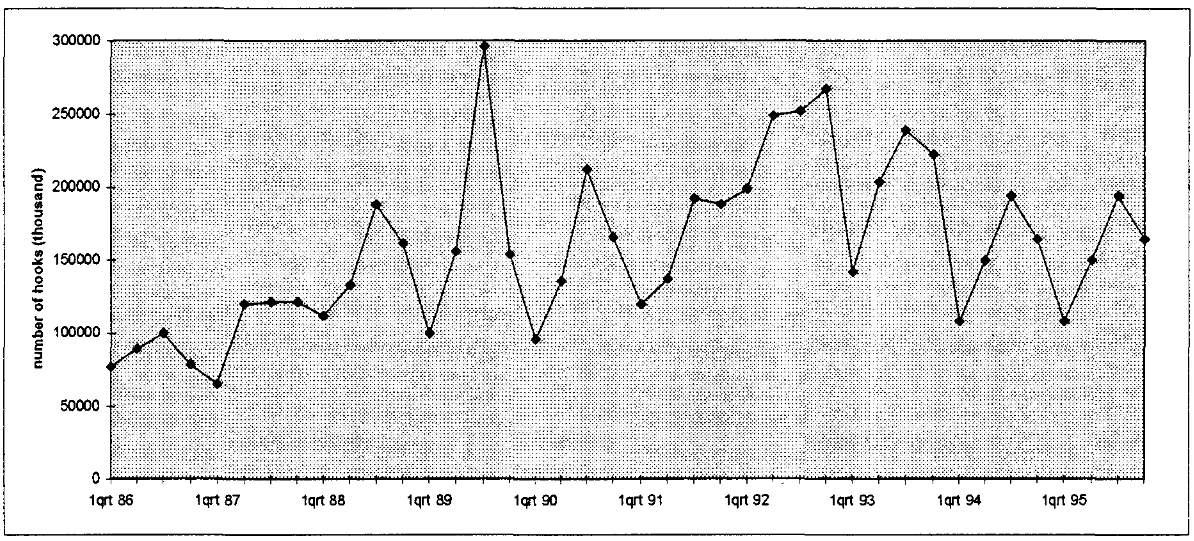

Figure 7. Aggregated longline fishing effort of the Japanese, Korean and Taiwanese fleets for 40 quarters of years 1986-1995 and for the area 10°N to 50°S and 145°W to 90°E. Fishing effort is expressed in Taiwanese units (see text for the standardisation procedure used). Data for 1994 and 1995 (not available to date) have been estimated using the monthly average over the period 1986-1993.

Table 6. Albacore tag data used in the "non-aggregated" version of the tag-attrition model. The numbers of recoveries per quarter assigned to each release set are shown together with the numbers of non-recovered albacore (see text for various reasons of non-recoveries).

release set	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
date of release	1/86	2/86	1/87	2/87	1/88	2/88	1/89	2/89	3/89	1/90	2/90	1/91	2/91	1/92	2/92
nb. of release	127	597	857	522	1330	77	1832	577	3	1093	67	1509	2116	4864	1656
date of recovery															
1/86	0														
2/86	0	0													
3/86	0	0													
4/86	0	0													
1/87	0	0	0												
2/87	0	1	0	1											
3/87	0	0	0	1											
4/87	0	0	0	0											
1/88	0	0	0	0	0										
2/88	0	0	1	0	0	0									
3/88	0	1	0	0	0	0									
4/88	0	0	0	0	0	0									
1/89	0	0	0	0	0	0	1								
2/89	0	0	0	0	0	0	0	0							
3/89	0	0	0	0	0	0	0	0	0						
4/89	0	0	0	0	0	0	0	0	0						
1/90	0	0	0	0	0	0	0	0	0	0					
2/90	0	0	0	0	0	0	0	0	0	0	0				
3/90	0	0	0	0	0	0	0	0	0	0	0				
4/90	1	0	0	0	0	0	0	0	0	0	0				
1/91	0	0	0	0	1	0	0	0	0	0	0	0			
2/91	0	0	0	0	1	0	1	0	0	1	0	0	2		
3/91	0	0	1	0	1	0	1	0	0	0	0	1	0		
4/91	0	0	0	0	1	0	0	0	0	0	0	0	0		
1/92	0	0	0	0	0	0	0	0	0	0	0	0	0	3	
2/92	0	0	0	0	0	0	0	0	0	1	0	4	1	5	0
3/92	0	0	0	0	0	0	1	0	0	0	0	1	0	1	0
4/92	0	0	0	0	0	0	0	0	0	0	0	1	4	1	1
1/93	0	0	0	0	0	0	1	0	0	0	0	2	3	4	1
2/93	0	0	0	0	0	0	0	0	0	1	0	3	2	10	2
3/93	0	0	0	0	0	0	0	0	0	0	0	2	0	3	1
4/93	0	0	0	0	0	0	0	0	0	0	0	2	1	2	0
1/94	0	0	0	0	0	0	0	1	0	0	0	2	2	7	3
2/94	0	0	1	0	0	0	1	0	0	0	0	2	5	13	1
3/94	0	0	0	0	0	0	0	0	0	0	0	1	2	8	5
4/94	0	0	0	0	0	0	0	0	0	1	0	0	0	3	1
1/95	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
2/95	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
3/95	0	0	0	0	0	0	0	0	0	0	0	0	1	4	2
returns	1	2	3	2	4	0	6	1	0	4	0	21	23	66	19
non-returns	126	595	854	520	1326	77	1826	576	3	1089	67	1488	2093	4798	1637

Results

The model converges readily in both the "aggregated" and "non-aggregated" forms. Figures 8 and 9 present predicted and observed tag returns by time at liberty. As mentioned before, most returns by longliners occurred during the second and third year at liberty. This phenomenon is probably due to the size of "full recruitment" to the longline fishery being larger than the average size of the fish when they were tagged. To account for this, the catchability coefficients of the first 4 quarters are set to zero. Results obtained with both models are similar (Table 9), although the "aggregated" fit gave a total mortality rate somewhat higher than the "non-aggregated" fit. One reason for this might be linked to the fact that the aggregated version combines release-sets for which some recoveries are still to be expected. Once those recoveries will be made, the results of this version of the model will probably become closer to the "non-aggregated" form.

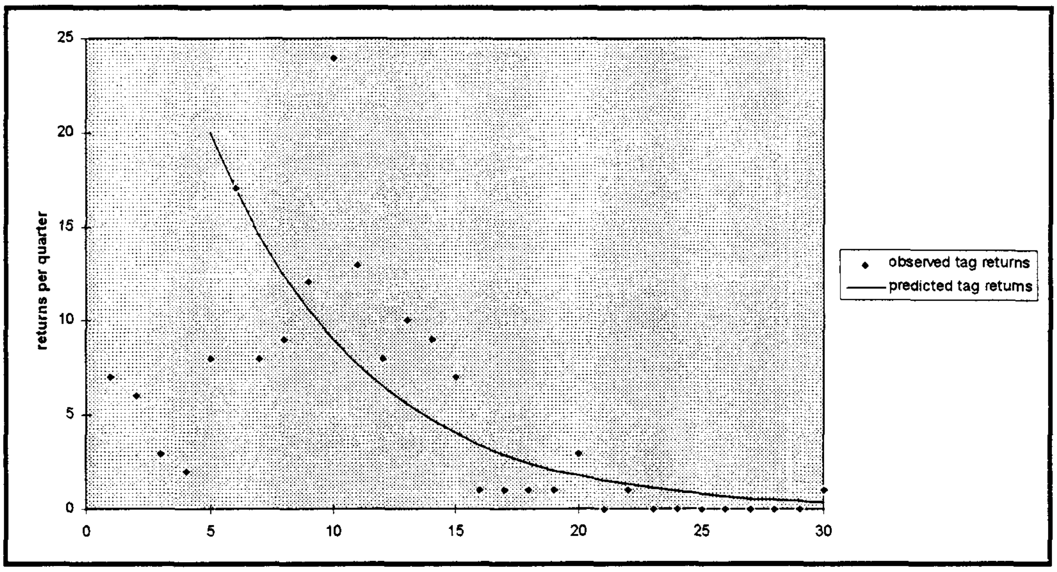

Figure 8. Predicted (solid line) and observed (dots) tag returns per quarter at liberty as obtained with the "aggregated" version of the model. For this fit, the parameter α was set to 0.5.

Table 9. Results of fitting two versions of the tag-attrition model with a series of values for α. The catchability coefficient q is expressed in effort $^{-1}$, the natural mortality coefficient M in year^{-1}, the total mortality Z in year^{-1} and the exploitation rate E is calculated using equation 4 (see text).

	"aggregated"				"non-aggregated"			
alpha	q	M	Z_{yearly}	E	q	M	Z_{yearly}	E
0.1	3.32E-06	0.541	0.625	0.134	7.87E-06	0.385	0.434	0.114
0.2	1.71E-06	0.584	0.627	0.069	4.02E-06	0.413	0.439	0.058
0.3	1.19E-06	0.598	0.628	0.048	2.71E-06	0.425	0.442	0.038
0.4	9.04E-07	0.614	0.637	0.036	2.03E-06	0.428	0.441	0.029
0.5	7.27E-07	0.623	0.642	0.028	1.64E-06	0.433	0.444	0.023
0.6	6.02E-07	0.612	0.627	0.024	1.37E-06	0.434	0.443	0.019
0.7	5.28E-07	0.625	0.638	0.021	1.17E-06	0.435	0.443	0.016
0.8	4.66E-07	0.629	0.641	0.018	1.02E-06	0.437	0.443	0.014
0.9	4.09E-07	0.623	0.633	0.016	9.16E-07	0.438	0.444	0.013
1	3.66E-07	0.621	0.631	0.014	8.23E-07	0.438	0.444	0.011

No quantification of the parameter α is possible as no tag seeding experiments have been conducted so far. Fits are thus conducted over a large range of α (0.1 to 1). For each version of the model, this does not affect the estimates of total mortality rate. However, as expected, α has an effect on the estimates of exploitation rate, calculated as follows:

$$E = \frac{\overline{F}}{\overline{F} + M}$$

Its effect is steeper when its values are low. This leads to large uncertainty on the exploitation rate if we assume that the return rate is low (Figure 10).

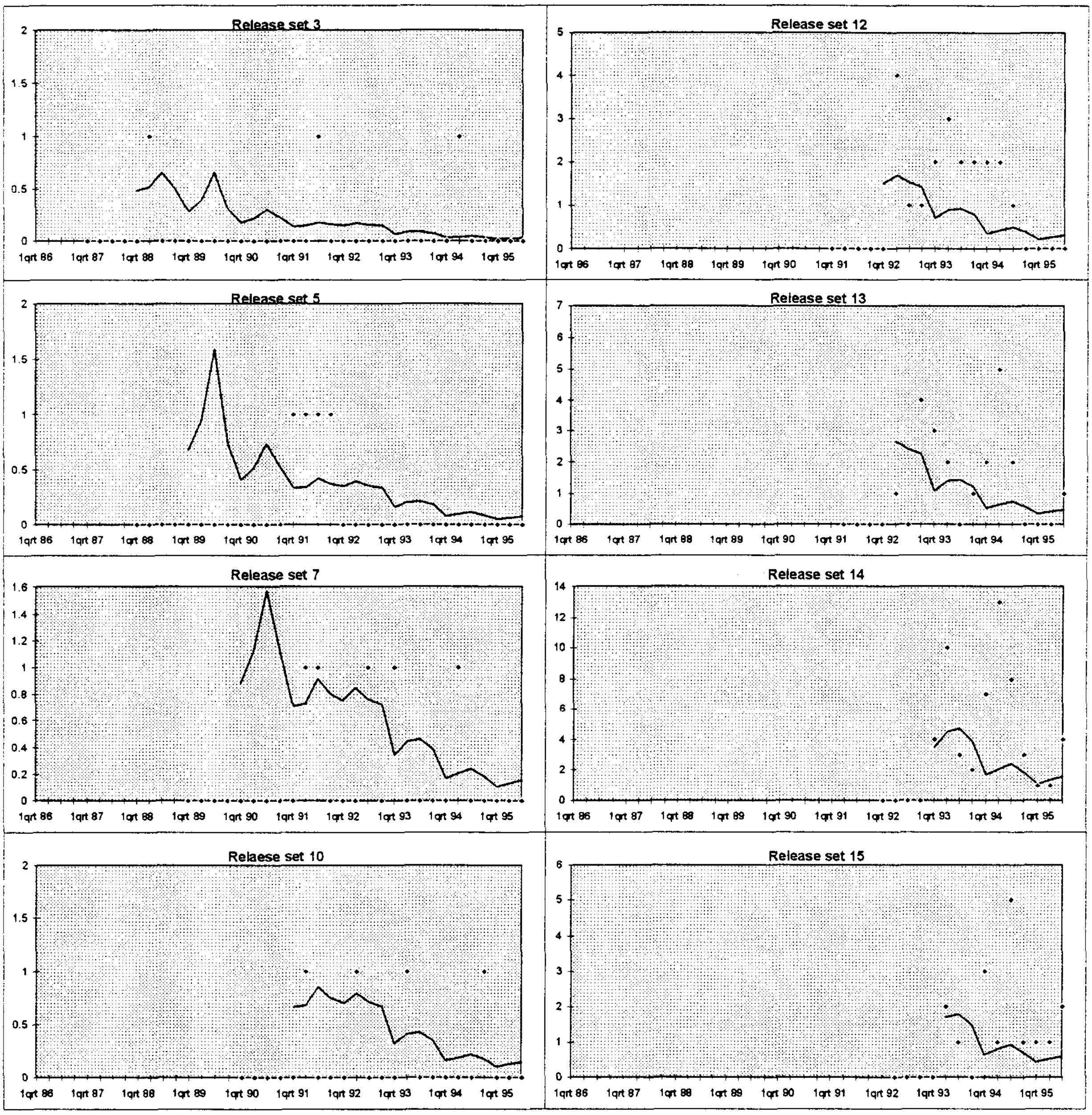

Figure 9. Predicted (solid lines) and observed tag returns for the 8 main release sets (in terms of number of releases and recoveries). Predicted results are based on parameter estimates using a value of 0.5 for α.

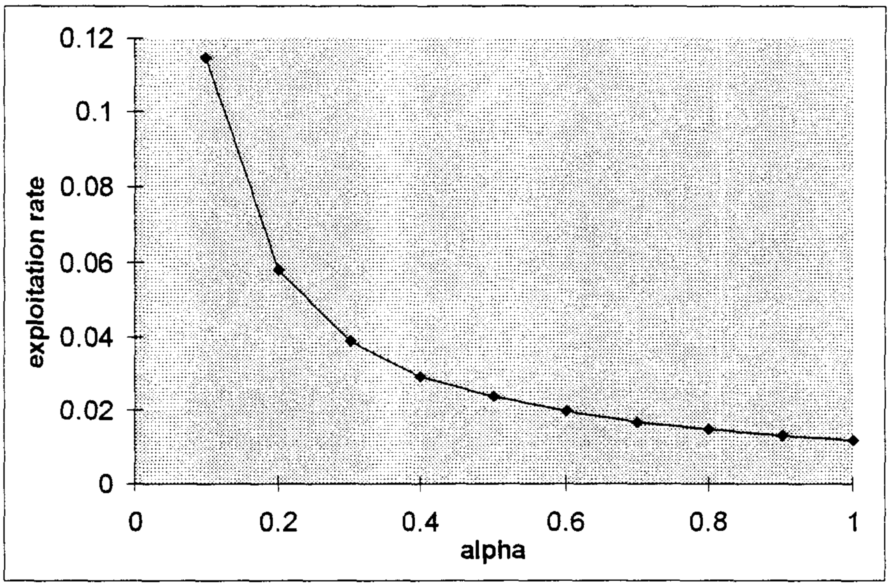

Figure 10. Effect of assumed values of α on the exploitation rate estimated with the "non-aggregated" form of the tag-attrition model.

Confidence intervals on the parameter estimates were calculated using the percentile method (Efron, 1982; Buckland, 1984). 500 synthetic data sets were stochastically generated using the probabilities calculated from the fit of the "non-aggregated" form of the model with α set at 0.5. 500 estimates of M and q were calculated by fitting the tag attrition model to the synthetic data sets. The joint distribution of the parameters M and q are presented in Figure 11 together with their frequency distributions (the frequency distribution of the exploitation rate E has also been added to the figure). It shows a strong dependency between M and q and a low dispersion of values around the mean confirmed by the estimates of standard deviations and coefficient of variations given in Table 10. 95% Monte Carlo confidence bounds are also calculated by simply taking the 2.5% and 97.5% quantiles from the distribution of values obtained by the stochastic process.

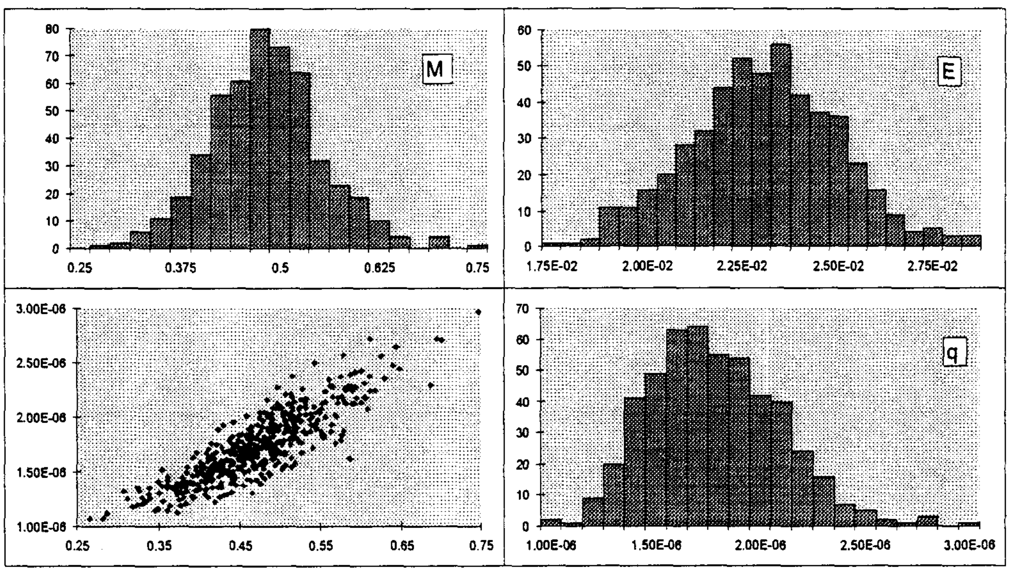

Figure 11. Joint distribution of M and q estimated from 500 simulated Monte Carlo data sets. Distribution of each parameter together with the exploitation rate E are also given.

Table 10. 95% confidence limits, standard deviation and coefficient of variation on the parameters as estimated using 500 Monte Carlo synthetic data sets (see text for a description of the method).

Estimates	*M*	*q*	*E*
Average	0.470	$1.735E^{-6}$	0.0227
Std deviation.	0.070	3.172E-7	0.0019
Coefficient of variation	0.149	0.182	0.086
95% confidence interval	0.333 — 0.611	$1.203E^{-6}$ — $2.418E^{-6}$	0.0188 — 0.0266

Discussion

No changes in the interpretation of tagged albacore movements presented in previous analyses (Labelle 1993, Anonyme 1995a, 1995b) are proposed on the basis of this study. With the exception of some fish tagged by game fishermen off the east coast of Australia, tagged albacore have shown extensive movements to the east, north and west of their release locations. The apparent movement patterns are, however, obviously conditioned by the longline, driftnet and troll fishing effort distributions, which are concentrated north of 40S and west of 130W. This fact might explain why no tagged albacore have shown southerly displacements. Despite the single recovery (and possibly a second) made in the northern hemisphere, the hypothesis of essentially separate stocks in the northern and southern Pacific, with low exchange rates probably remains valid. The fact that fish tagged in the commercial troll fishery have been recovered mostly in the longline fishery confirms the potential for interaction between these fisheries, as mentioned by Murray (1993) and Labelle (1993).

Growth rates of south Pacific albacore have been estimated from caudal vertebrae (Murray and Bailey 1989), otolith increments (Wetherall et al. 1989), length frequency data (Hampton et al. 1990) and from tag returns (Labelle 1991). The results of previous analyses were discussed and compared by Labelle et al. (1993). They show the correspondence between growth rates estimated using caudal vertebrae, length frequency (under the hypothesis of annual cohorts) and the small number of tag returns available at the time, while they underline the conflicting results obtained from daily growth increment counts on otoliths. The present tagging analysis, which uses a larger number of tag returns, supports the view that the growth rates proposed by Wetherall et al. (1989) from increments counts of otoliths are too high of an order of 2. The estimates of L_∞ and K are consistent with the estimates obtained from length frequency analysis but the individual variability appears very high and increases with time at liberty. One difficulty with estimating growth parameters from the albacore tagging data was the virtual absence of returns during the first year at liberty, which are required to estimate release length measurements error.

The low level of returns from the albacore tagging experiment and the uncertainty over the reporting rate were the main reasons that a tag attrition model had not previously been fit to the albacore tagging data (Labelle, 1993). The number of recoveries is now large enough to give at least some indication of mortality rates, and the present attempt should be viewed as a first tentative step in that direction. Two approaches were used to analyse the data set. Splitting the data to use variable fishing effort in time gives probably better results as it takes account of the fact that some recoveries are still to be expected from the last release-sets.

As mentioned by Murray (1993), few studies have dealt with population dynamics of South Pacific albacore and the estimation of related parameters. The results obtained with this model, i.e., total mortality estimates of 0.4 — 0.6 $year^{-1}$, are in the range of the assumptions made by Hampton (1990), based on a likely longevity of albacore around 9 years (few age 9+ fish appear in the longline catch).

The preliminary results of this study have also shown the importance of the parameter α. For low values, let say below 0.3, small variations in this parameter can have a strong impact on the estimates of exploitation rates obtained by the tag-attrition model. An attempt to estimate α with the non-aggregated version of the model was made. No satisfactory results were obtained and the model converged to the maximum possible value, namely 1. This is probably due to the lack of enough contrast in the fishing effort data. Estimating α independently would be another possibility. This however would require the implementation of tag seeding experiments with all the logistic difficulties and costs associated with them and would be possible only if another tagging project were carried out.

Setting a value of one year at liberty after release for full-recruitment to the longline fishery is somewhat arbitrary. In fact, if we look at the recoveries by time at liberty, a value of 9 quarters would have been even better as the maximum number of recoveries occurs after slightly more than two years at liberty. We had however to find a compromise between increasing the "time at liberty for full-recruitment" and not decreasing to much the number of recoveries to be included in the analysis. A more satisfactory approach would be to test a series of several values.

Obviously, the estimates of mortality obtained from our analysis incorporate emigration from the fishing areas. We have seen that fishing effort is mainly concentrated in the western part of South Pacific and it is possible that an unknown proportion of the population move out of this area. Assessing the role played by emigration would necessitate the use of a more complex model incorporating explicitly fish movements. However, this would be impossible with the level of returns observed during this tagging experiment.

References

Anonyme, 1995a. Oceanic Fisheries Programme. Work Programme Review 1994-95 and Work Plan 1995-96. Eighth Standing Committee on Tuna and Billfish, 16-18 August 1995, Noumea, New Caledonia. SPC, WP5: 44 pp.

Anonyme, 1995b. SPAR News. October 1995. n°2

Bailey K., Williams P., Price R., 1993. A manual for the tagging database system of the regional tuna tagging project. South Pacific Commission, Noumea, New Caledonia, TBAP, Tech. Rep. 30: 49 pp.

Buckland, S. T. (1984). Monte Carlo confidence intervals. Biometrics 40, p811 — 817.

Efron, B. 1982. The Jackknife, the Bootstrap and other Resampling Plans. Philadelphia: Society for Industrial and Applied Mathematics. 92p.

Fabens A.J., 1965. Properties and fitting of the Von Bertalanffy growth curve. Growth 29: 265-289

Foreman T.J., 1980. Synopsis of biological data on the albacore tuna, *Thunnus alalunga* (Bonaterre, 1788), in the Pacific ocean. Spec. Rep. I-IATTC, (2):17-70

Fournier D.A., Sibert J.R., Majkowski J., Hampton J., 1990. MULTIFAN a likelyhood-based method for estimating growth parameters and age composition from multiple length frequency data sets illustrated using data for southern bluefin tuna (Thunnus maccoyii). Can. J. Fish. Aquat. Sci. 47:301-317

Hampton J., Fournier D.A., Sibert J.R., 1990. MULTIFAN analysis of South Pacific albacore length-frequency data collected by observers, 1989-1990. Paper presented at the Third South Pacific Albacore Research (SPAR) Workshop, 9-12 October 1990. South Pacific Commission, WP/1

Labelle M., 1991. Estimates of age and growth for south Pacific albacore. Paper presented at the fourth South Pacific Albacore Research (SPAR) Workshop, 4-8 November 1991. South Pacific Commission., WP/5

Labelle M., 1993. A review of albacore tagging in the South Pacific. South Pacific Commission, Noumea, New Caledonia, TBAP, Tech. Rep. 33

Labelle M., Hampton J., Bailey K., Murray T., Fournier D.A., Sibert J.R., 1993. Determination of age and growth of South Pacific albacore (*Thunnus alalunga*) using three methodologies. Fish. Bull. 91: 649-663.

Murray T., 1994. A review of the biology and fisheries for albacore, Thunnus alalunga, in the south Pacific ocean. In Shomura R.S., Majkowski J., Langi S. (ed.), Interactions of Pacific tuna fisheries, vol.2, Papers on biology and fisheries. FAO Fisheries Technical Paper, 336(2): 188-206.

Murray T., Bailey K., 1989. Preliminary report on age determination of South Pacific albacore using caudal vertebrae. Paper presented at the second South Pacific albacore Research (SPAR) Workshop, 14-16 June 1989, Suva, Fiji. South Pacific Commission, WP/20

Press W.H., Teukolsky S.A., Vetterling W.T., Flannery B.P., 1992. Numerical recipes in C. The art of scientific computing. Second edition. Cambridge University Press. 994 pp.

Wetherall J.A., Nishimoto R.N., Yong M.Y.Y., 1989. Age and growth of South Pacific albacore determined from daily otolith increments. Paper presented at the Second South Pacific Albacore Research (SPAR) Workshop, 14-16 June 1989, Suva, Fiji, South Pacific Commission, WP/18