ESTIMATES OF LENGTH MEASUREMENT ERRORS FOR TAGGED SKIPJACK (*Katsuwonus pelamis*) FROM THE CENTRAL AND WESTERN PACIFIC OCEAN

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PREFACE

The Skipjack Survey and Assessment Programme, which commenced in August 1977 and concluded in September 1981, was an externally funded part of the work programme of the South Pacific Commission. The governments of Australia, France, Japan, New Zealand, United Kingdom and the United States of America provided funding for the Programme, which worked in the waters of all of the countries and territories within the area of the South Pacific Commission and in New Zealand and Australia.

The work described here is part of investigations begun by the Skipjack Programme to evaluate growth of skipjack using tag release and recapture data. Whatever measure of success achieved depends to a large extent on previous work (e.g. Skipjack Programme 1981). All members of the Tuna and Billfish Assessment Programme provided useful advice and criticism.

The staff of the Tuna Programme at the time of preparation of this report comprised the Programme Co-ordinator, R.E. Kearney; Research Scientists, A.W. Argue, C.P. Ellway, R.S. Farman, R.D. Gillett, J.P. Hallier, P. Kleiber, T.A. Lawson, C.A. Maynard, J.R. Sibert, W.A. Smith and M.J. Williams; Research Assistants, Veronica van Kouwen and Susan Van Lopik; and Programme Secretary, Carol Moulin. Most staff were involved to some extent in the fieldwork from which this report resulted and/or in the analysis of the data and preparation of the manuscript.

Tuna Programme
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ABSTRACT

Length measurement errors and growth increments for skipjack were examined from tagging data collected by the Skipjack Survey and Assessment Programme of the South Pacific Commission. Growth of skipjack at large for 0-7 days is negligible, therefore 0-7 day length increments are informative of release length measurement errors. The distribution of 0-7 day increments was long-tailed, with an average of 0.13 cm and a standard deviation 1.43; reliability of the data varied among tag recovery sources but not among taggers; and bias, related to size of fish, was present in recapture length measurements.

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1.0 INTRODUCTION

Tag and recapture data have been used to estimate the growth of skipjack (Katsuwonus pelamis) by a number of authors (Schaefer, Chatwin & Broadhead 1961; Rothschild 1966; Joseph & Calkins 1969; Josse et al. 1979). General reviews of skipjack biology (e.g. Joseph & Calkins 1969) point out wide variation in growth parameters. Whether this variation is due to geographic and temporal differences or to the effects of errors in the methods of analysing growth is unknown.

Tagged fish at large for short periods of time undergo negligible growth, therefore their apparent change in length may be informative of length measurement errors. The purpose of the work described here was to examine length increments of fish at large for short periods of time in an attempt to estimate the magnitude of length measurement errors.

2.0 METHODS

2.1 Data Sources

Data used in this analysis were tag and recapture data collected and compiled by the Skipjack Survey and Assessment Programme according to the methods described by Kearney & Gillett (1982) and Kleiber & Maynard (1982).

2.2 A Robust Estimator: the Biweight

Estimators that maintain high efficiency under conditions of skewness and kurtosis are referred to as "robust" estimators or "robust of efficiency". The sample mean, unfortunately, is not robust. Intuitively, a more efficient estimate for samples drawn from long-tailed distributions would be a weighted average that gave less weight to extreme values. Many kinds of weighted averages exist; the class of weighted averages to be used below are known as biweights. For a discussion of biweights and other robust estimates of location and spread, see Mosteller & Tukey (1977).

Biweights are implicitly defined as follows:

$$X^* = \Sigma W_i^2 X_i \ / \ \Sigma W_i^2 \qquad (1)$$

where X^* = the biweight,

X_i = the observed values,

$$W_i^2 = \begin{cases} (1-U_i^2)^2, & U_i^2 < 1 \\ 0 \ , & U_i^2 \geq 1 \end{cases} \qquad (2)$$

$$U_i = (X_i - X^*) \ / \ cQ \qquad (3)$$

Q = a measure of the spread of the X_i,

c = a constant,

and where summations include only terms for which $U_i^2 < 1$. An estimate of the variance of the biweight is given by:

$$\text{variance } X^* = \frac{\Sigma W_i^2 (X_i - X^*)^2}{\{\Sigma W_i(1-5U_i^2)\}\ \{-1+\Sigma W_i(1-5U_i^2)\}} \qquad (4)$$

and where, again, summations include only terms for which $U_i^2 < 1$. Biweights must be calculated by iteration, since X^* cannot be found until the W_i are known and the W_i cannot be found until X^* is known. The procedure starts with an initial estimate, for example, the median. From the initial estimate, the U_i and W_i are computed from Equations 3 and 2, and a new estimate is calculated from Equation 1. Using the new estimate, the U_i and W_i are again computed, the next value of the estimate is calculated, and so on. The final value of the biweight is taken when subsequent iterations do not change the estimate by some small value specified beforehand. The variance of the biweight is estimated from Equation 4 using the final value of the biweight, and the variance of the observed values is estimated by the product of the biweight variance and the sample size.

For biweights reported below, the initial estimate was the median, Q = half the interquartile range, c = 6, and the final estimate was taken when the next iteration did not change the estimate by more than 0.0001 per cent. Where biweights are given, the associated standard error of the estimate and the standard deviation of the observed values are based on the biweight variance.

To illustrate its statistical properties, the biweight was evaluated in a Monte Carlo-type study. For several distributions of varying degrees of departure from normality, the performance of the biweight and the mean were compared on the basis of 1000 computer-generated random samples, each consisting of 20 observations. Four mixed-normal distributions were examined, and were intended to reflect the range of conditions for the 0-7 day increments. In one of the mixed distributions, 95 per cent of the observations were drawn from a normal distribution of mean zero and standard deviation 1.0, and the remaining 5 per cent, the contaminating values, from a normal distribution of mean zero and standard deviation 5.0. The other three were constructed either by increasing the level of contamination to 10 per cent, or by increasing the standard deviation of the contaminating distribution to 10.0, or both.

The results (Table 1) show that even under low contamination conditions, the standard error of the mean was 17 per cent higher than for the biweight; under worst conditions, it was twice as high. In other words, over the range of conditions likely to be encountered in our data, the biweight will most often be the more efficient estimate.

The number and magnitude of extreme values present in a sample will vary, and when there is none the mean will be the more efficient estimate. To guard against this possibility, for data presented below, the estimate with the smallest standard error was taken as the "best" estimate, except for samples of less than eight observations, for which the mean was used.

TABLE 1. RESULTS OF THE MONTE CARLO EVALUATION OF THE BIWEIGHT, EXPRESSED AS THE RATIO OF THE STANDARD ERROR OF THE MEAN TO THE STANDARD ERROR OF THE BIWEIGHT. Under perfect normality, the ratio is 0.76.

	Standard Deviation of Contaminating Distribution	
	5.0	10.0
Level of Contamination		
5%	1.17	2.04
10%	1.41	2.61

2.3 Variance in 0-7 Day Increments

The variance of 0-7 day increments was examined by tagger and recovery source to check for differences in reliability of subsets of the data. Twenty-one taggers were involved in tagging, although 66 per cent of the fish were tagged by four people; the 17 remaining taggers were grouped into an "others" category. Upon receipt of tag returns, "credibility" codes were assigned to each recapture length on the basis of its source and on whether weight was available to verify the length. Ten credibility codes were used, though four codes were assigned to 92 per cent of the returns. These represented tags recovered by the Skipjack Programme research vessel, local joint-venture vessels based in the Commission region, various other reliable sources (mostly including tags returned from a reliable source in New Zealand), and weight-verified data (including many returns from Japan-based pole-and-line vessels fishing in the Commission region). For the purposes here, the remaining six codes were aggregated to form an "others" category.

2.4 Length Measurement Bias and Size of Fish

On the basis of other studies of length measurement errors (Rothschild 1966; Joseph & Calkins 1969; Josse et al. 1979), it was suspected that bias related to size of fish was present in the data. This possibility was investigated using a method based on the following length measurement bias model. Assuming that bias can be represented as a linear function of fish length, we have:

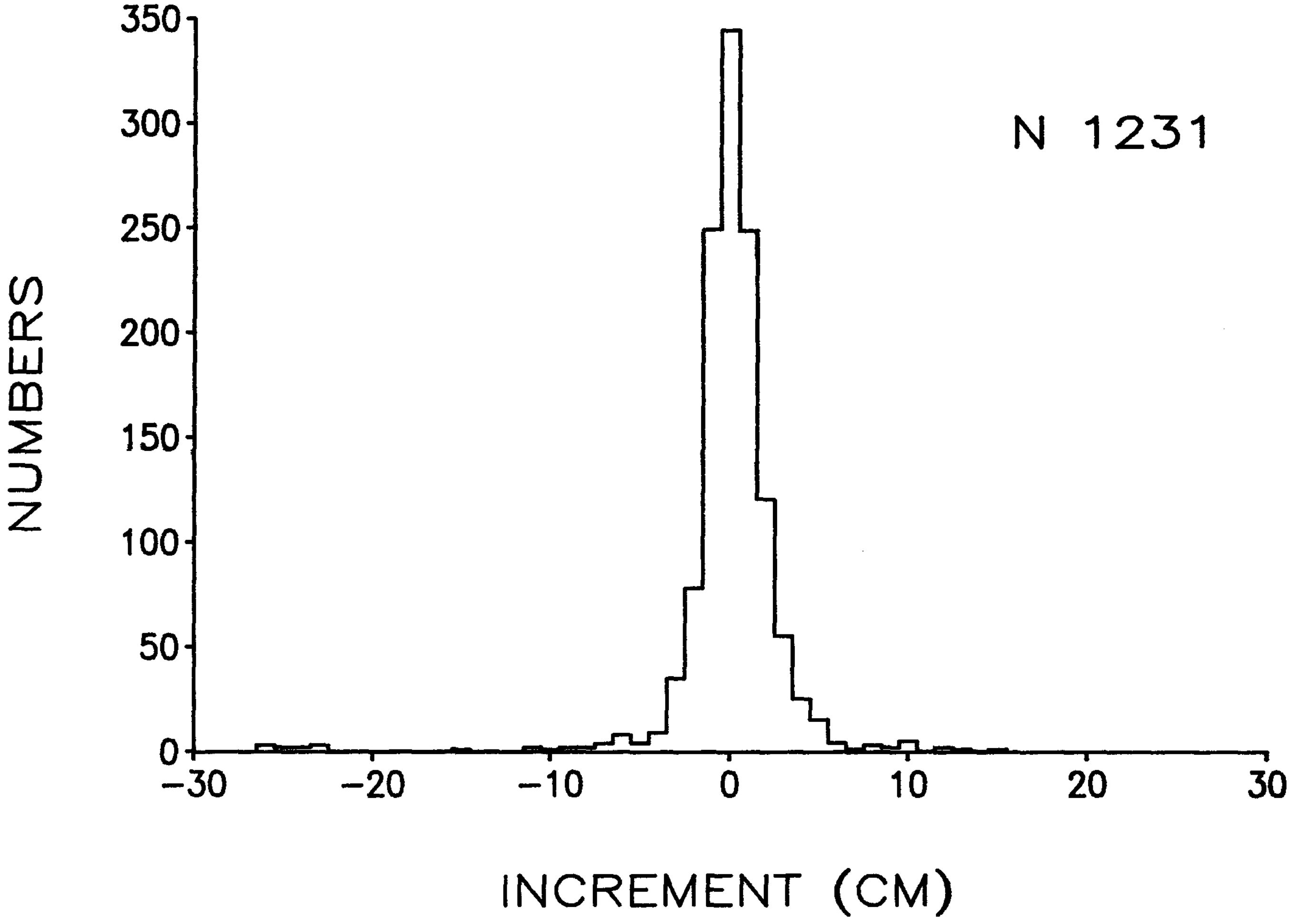
$$L_1 = a_1 + b_1\hat{L}_1 + e_1 \tag{5}$$

$$L_2 = a_2 + b_2\hat{L}_2 + e_2 \tag{6}$$

where L_1 and $\hat{L}_1$ are true and observed lengths at release respectively; L_2 and $\hat{L}_2$ are true and observed lengths at recapture respectively; a_1, b_1, a_2, and b_2 are constants; and e_1 and e_2 are error terms. If $L_1 = L_2$ for fish at large 0-7 days, then:

$$\hat{L}_1 = A + B\hat{L}_2 + E \tag{7}$$

FIGURE 1. DISTRIBUTION OF LENGTH INCREMENTS FOR SKIPJACK AT LARGE 0-7 DAYS



where $A = (a_2 - a_1) / b_1$

$B = b_2 / b_1$

and $E = (e_2 - e_1) / b_1$

When a_1 and b_1 are known, a_2 and b_2 can be calculated from regression estimates of A and B. Similarly, if a_2 and b_2 are known then a_1 and b_1 can be calculated.

If none of these constants is known beforehand, some assumptions must be made. Here it was assumed that recapture lengths measured by Skipjack Programme scientists on board the research vessel (measured to the half centimetre on a measuring board after immediate fishing operations had ceased, usually during relative tranquility) were unbiased; i.e., for this particular recapture source, $a_1 = 0$ and $b_1 = 1$. This assumption enabled bias coefficients for each of the taggers to be estimated. Once the coefficients for taggers were known, those for the remaining recapture credibility categories could be estimated.

3.0 RESULTS AND DISCUSSION

3.1 Distribution of 0-7 Day Increments

Statistical properties and quality of the data were evaluated by considering the distribution of increments for fish recaptured within seven days of tagging (Figure 1). The range of increments for this group was large, -26.0 cm to 14.9 cm. The mean was 0.02 cm and the median 0.00 cm, indicating that the combined release and recapture measurement errors, averaged over all sizes of fish, were unbiased. The sample standard deviation for the 0-7 day increments was 3.11 cm. This estimate exaggerates the spread, however, as positive kurtosis, evident in Figure 1, was present in the data. A variety of statistics confirmed the presence of kurtosis (sample kurtosis, the ratio of the 95 per cent range to the 67 per cent range, and others), and a chi-square goodness-of-fit test rejected the hypothesis of normality at $p<0.001$. Though often ignored, the presence of kurtosis has ill effects on the usual estimate of average value; this problem is addressed below.

The biweight of 0-7 day increments was 0.13 cm. The standard deviation based on the biweight variance was 1.43 cm, compared to the sample standard deviation of 3.11 cm, illustrating how the latter value exaggerated the spread of the major portion of the data due to the presence of a relatively small number of large values. The degree of "contamination" of the sample by large values can be estimated from the proportion of observations greater than two standard deviations based on the biweight variance. This proportion was nine per cent; since the expectation under normality is only five per cent, this suggests at least a four per cent level of contamination. The standard deviation based on the biweight variance is itself, however, affected by extreme values (though to a lesser extent than the sample standard deviation); hence the standard deviation of the (ideally) uncontaminated 0-7 day increments is probably smaller than 1.43 cm and the level of contamination higher, possibly 5-10 per cent.

3.2 Patterns in 0-7 Day Increment Variance by Taggers and Recovery Sources

Table 2 gives the average (either the mean or the biweight) and standard deviation of the 0-7 day increments by tagger and recapture length credibility code. Standard deviations varied from 0.47 cm to 13.43 cm, suggesting that data for some tagger-credibility code combinations are more precise than for others. Recapture lengths measured by scientists on board the Skipjack Programme research vessel were consistently more precise, and those of the "others" category were poor. Those from "local joint ventures", "other reliable sources", and "weight verified" were intermediate. No differences in the reliability of release length measurements were evident among taggers, except "A" who was generally more precise.

TABLE 2. SUMMARY OF 0-7 DAY INCREMENTS BY TAGGER AND RECAPTURE "CREDIBILITY" CODE. Sample size (n), average increment (x) in cm, and standard deviation (sd) in cm are shown. Biweights are marked with an asterisk.

		Recapture Code				
Taggers		SPC Research Vessel	Local Joint Ventures	Other Reliable Sources	Weight Verified	Others
	n	29	13	3	28	0
A	x	-0.15*	0.15	-2.70	-0.32*	-
	sd	0.47	1.61	3.57	1.03	-
	n	58	64	46	40	3
B	x	-0.10*	0.38*	-0.13	0.04	-2.83
	sd	0.85	2.24	1.02	1.13	0.29
	n	60	94	90	46	1
C	x	-0.31*	0.33*	-0.15*	-0.56	-6.00
	sd	0.81	1.80	1.42	1.57	-
	n	82	115	145	48	14
D	x	0.16*	0.99	0.38*	0.36*	-9.85
	sd	0.97	2.13	1.21	1.22	13.43
	n	50	161	0	29	12
Others	x	0.06*	0.14*	-	0.41	-1.96*
	sd	0.84	1.89	-	1.11	10.51

3.3 Release Length Measurement Bias and Size of Fish

During preliminary fits to the measurement bias model, it was discovered that skewness in the extreme 0-7 day increments, the direction of which was found to change with size of fish, was confounding the results. When the data were treated by eliminating all increments greater in absolute value than four centimetres, skewness was substantially reduced. If these data were not excluded, it would have been impossible to distinguish, from the regression coefficients, between bias due to regularly occurring events and bias due to low probability but radically erroneous measurements. Since the biweight places less weight on extreme values in general, the omission of extreme 0-7 day increments from the study of bias did not have serious consequences for the estimation of growth rates.

Model fits were re-calculated to determine tagger bias in several locations for which data were available, with increments greater in absolute value than four centimetres excluded, and the presence or absence of bias was determined by testing the slope in Equation 7 for departures from unity. Assuming that recapture lengths measured on board the research vessel were unbiased, it appears that all taggers were unbiased in all locations except New Zealand. In New Zealand, each of the three taggers for which data existed showed significant bias.

3.4 Recapture Length Measurement Bias and Size of Fish

Recapture length bias for the "other reliable sources" category was evaluated under two conditions, as all but one of the 0-7 day fish with recapture lengths in this category were tagged in New Zealand. Assuming that taggers in New Zealand were biased, L_2 was regressed on adjusted values of L_1; assuming that taggers were unbiased, the same data were used in the regression but without adjustment. Both cases resulted in significant bias (Table 3).

TABLE 3. LENGTH MEASUREMENT BIAS COEFFICIENTS FOR RECAPTURE LENGTH "CREDIBILITY" CODES, AND PREDICTED BIAS. Bias for "other reliable sources" was determined both with data adjusted and unadjusted for possible tagger bias in New Zealand.

Recapture Length Credibility Code	Sample Size	a_2	b_2	Predicted Bias ($\hat{L}_2 - L_2$) by Recapture Length (cm)				
				30	40	50	60	70
Other reliable sources, adjusted	223	-21.80	1.45	8.27	3.76	-0.75	-5.26	-9.77
Other reliable sources unadjusted	223	-11.89	1.25	4.45	1.97	-0.51	-2.99	-5.47
Local joint ventures	399	-4.21	1.08	1.96	1.21	0.46	-0.29	-1.04
Weight verified	189	-3.26	1.06	1.34	0.70	0.06	-0.58	-1.22

Biases for the "local joint ventures" and "weight verified" categories were determined by regressing $\hat{L}_1$ and $\hat{L}_2$, under the assumption that taggers were unbiased, as few of these fish were tagged in New Zealand. Both cases resulted in significant bias (Table 3).

For the three biased recapture length credibility categories and the three biased taggers in New Zealand, assuming that their bias was genuine, the direction of bias was always the same. Table 3 shows that fish larger than 50 cm are generally underestimated, while fish smaller than 50 cm are overestimated. Given that the mean length of fish tagged was 50.4 cm, the effect is one of "central tendency".

4.0 CONCLUSIONS

Length increments for fish at large 0-7 days were found to be unbiased with a standard deviation of 1.43 cm. About 5-10 per cent of the data showed much larger errors and were asymmetrically distributed with respect to length. The biweight was suggested as a more efficient estimator of central tendency than the mean under these conditions, and a simulation study showed that this was indeed the case. Precision of the recapture length measurements was shown to vary generally between recapture sources, the most precise being those of Skipjack Programme scientists. Release measurement bias by taggers was not significant, except possibly in New Zealand. Recapture length measurement bias, on the other hand, was significant for all recapture categories other than those by the Skipjack Programme research vessel. In all cases of significant bias, the effect was to minimise the apparent increase in length.

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