ELSEVIER

Fisheries Research 41 (1999) 87–92

FISHERIES RESEARCH

Short communication

The length–weight relationship of Albacore, *Thunnus alalunga*, from the Indian Ocean

Chien-Chung Hsu*

Institute of Oceanography, National Taiwan University, PO Box 23-13, Taipei, Taiwan

Received 23 September 1997; accepted 30 November 1998

Abstract

To comply with the compilation of catch databases of Taiwanese gillnet fishery and stock assessment, a new length–weight relationship of albacore, *Thunnus alalunga*, from the Indian Ocean was determined using data from gillnet catches. Four different fitting algorithms were used. The four resultant formulae were not significantly different. However, the formula W=0.056907$FL^{2.7514}$, where W is the body weight in g and FL is the fork length in cm, estimated by least square of residuals excluding suspected outliers which were diagnosed by least median square of residuals, is considered as an acceptable and useful one. Consequently, the equation can be used to compile catch databases mainly from the surface gears and for other assessment purposes.

Keywords: Albacore; Length–weight relationship; Robust regression

1. Introduction

In the Indian Ocean, albacore, *Thunnus alalunga*, has been one of the target species for the Taiwanese longline fishery since the early seventies (Hsu and Liu, 1990), and for the large-scaled pelagic gillnet fishery from 1983 to 1992 (Hsu, 1993). The annual production of Indian albacore varied from about 10 000 mt in 1985 to about 32 300 mt in 1990 (Anon, 1996). From 60% to 90% of the annual production was caught by Taiwanese fishermen (Hsu, 1993). Since 1991, the Taiwanese longline fleet transferred their effort to bigeye tuna (*Thunnus obesius*) and Spanish, French and Ivory Coast surface fleets, usually targeting skipjack tuna (*Katsuwonus pelamis*) and yellowfin tuna (*Thunnus albacares*), began to catch significant amounts of albacore incidentally. Nevertheless, Taiwan is still the main nation of exploiting albacore in the Indian Ocean using longlines.

The relationship between body weight and length is a simple but important equation in fishery studies, which are at present concerned with building available catch databases transforming catch in number into catch in weight, and incorporating these into yield per recruit model analysis, and age-structured model analyses. As recognized, almost Taiwanese fleets fishing albacore unload their catches at baseports outside of home nation, and they do not weigh catches individually on board because the unsteady conditions at sea seriously affects the accuracy of weighing. However, the captains have the responsi-

*Tel: +886-2-2362-2987; fax: +886-2-2366-1198; e-mail: hsucc@ccms.ntu.edu.tw

0165-7836/99/$ – see front matter
PII: S0165-7836(99)00002-8

bility to count the fish caught, to measure the size, and to submit their measurements with logbooks to the fisheries management agency (Hsu and Lin, 1996). Under these circumstances, to accurately weigh the catch is hardly possible. A better and more reliable approach is using length–weight relationships and size composition to convert catch in number into catch in weight.

A length–weight relationship was therefore formulated using the samples caught mainly by longline fleets (Huang et al., 1990). This equation has been used in yield per recruit model analyses (Lee et al., 1991) and age-structured model analyses (Lee and Liu, 1996; Hsu, 1995). Unfortunately, these analyses were confounded by data uncertainty which might come from the length–weight conversion. The length–weight relationship used (Huang et al., 1990), which was formulated based on the data from longline gears, may not be appropriate over the entire size ranges. In the Indian Ocean, gillnet fleets operate at high latitudes inhabited by the immature albacore juveniles from November to March, and longline fleets fish at relatively low latitudes where the mature adults occur throughout the year. Thus if a length–weight relationship estimated from one fishery only was used for the other, a bias may be introduced, and this has been found in the Huang et al. (1990) equation, resulting in data uncertainty in age-structured model analyses. Hence, a project was required to collect length and weight data of Indian albacore landed from gillnets during heavy fishing period.

Therefore, in this paper, the data set sampled from Taiwanese gillnet vessels during the 1990–1991 fishing season was used to formulate the length–weight relationship for the Indian albacore stock. Moreover, to obtain the most reliable parameter estimation, instead of simple regression analysis, the robust regression algorithm was used to investigate possible outliers and to comparatively re-estimate the parameters of the relationship. The result may provide a useful key to length–weight equation for further catch data compilation and stock assessments.

2. Materials and methods

2.1. Data used

The fishing season for Taiwanese gillnetters operating in the Indian Ocean (Fig. 1) is from November to March (Hsu and Liu, 1990). The samples were selected randomly and measured from catch unloaded

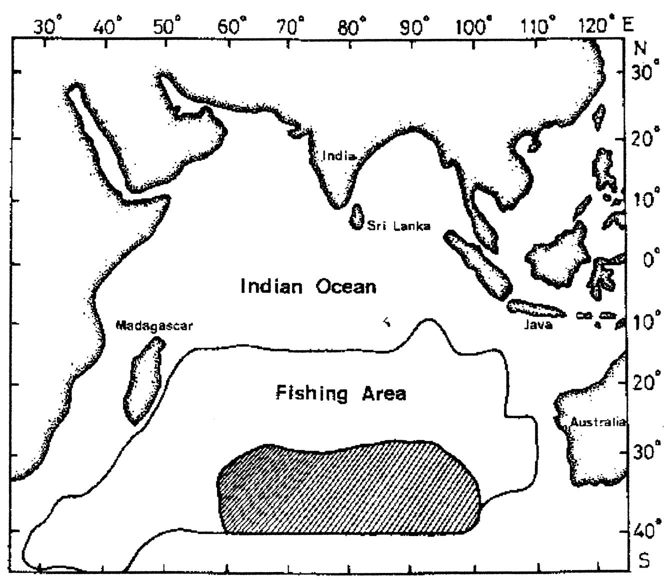

Fig. 1. Location of the major albacore fishing ground for Taiwanese longline (whole area) and gillnet fisheries (hatched area) in the Indian Ocean. The hatched area indicates the fishing ground where the data were collected in the present study.

at Kaohsiung Fishing Port, which is the largest fishing port at southern Taiwan, from the 1990–1991 fishing season. The sex of the samples was not determined, since a previous report indicates that there is no significant difference in the morphometric characteristics between sexes (Huang et al., 1990). The body length was measured as fork length to the nearest 1/10 cm by wooden calibers, and the body was weighed in frozen condition including gills and entrails to the nearest g.

2.2. Parameters estimation

The length–weight relationship is $W=a\ L^b$, where W is the round weight in g, L the fork length in cm, and a and b are parameters to be estimated.

As usual, there are two approaches to estimate the parameters a and b, i.e., transform length–weight equation into a linear form through logarithm and then derive the unbiased least square (LS) estimates of a and b and use the nonlinear regression analysis (NLS). However, the logarithmic transformation may not always improve the quality of data and guarantee the conditions in regression analysis with respect to the normal error and constant variance, but it was used herein for LS as opposed to NLS.

Normally before statistical estimation, the scatter-plot was a priori made to justify the length–weight relationship, though the visual inspection is subjective. Further a regression diagnostic technique may be used to identify the possible outliers because these outliers are perhaps difficult to examine visually for the 2499 observations in a scatter-plot. Also it is difficult to identify outliers from a residual plot, because outliers always pull the regression line towards themselves (Sen and Srivastava, 1990). Therefore, for comparison, an approach less sensitive to outliers compared with LS and NLS method, called robust regression analysis (RR), was used to estimate a and b.

The least median of squares (LMS, Rousseeuw, 1984; Rousseeuw and Leory, 1987) was chosen for diagnosing outliers, because simulated tests and field data have revealed that LMS gives the least sensitive results for both outliers in dependent and independent variables (Chen et al., 1994). Thus, a robust least square (RLS) fitting algorithm including three steps was followed: (1) the observations were diagnosed for possible outliers by LMS, (2) the detected outliers were excluded from data set, and (3) the new data set was used to estimate the parameters a and b by LS. Then S-plus software (ver. 3.3, Venables and Ripley, 1994) programmed for this procedure was used to estimate the slope and intercept of the length–weight relationship. Marquardt's algorithm was used for the NLS to estimate the parameters (Marquardt, 1963; Draper and Smith, 1980).

3. Results and discussion

Altogether 2499 specimens were measured (Table 1), from random samples of about 0.5% of total catches of each sampled vessel. Fig. 2 indicated that an exponential relation between length and weight was appropriate. However some data points which departed from the concentrated group were concerned before parameters fitting analysis.

Table 1
Sampling information of albacore in the Indian Ocean used for body weight and length measurements in the present study

Sampling vessels	Fishing period	Sample size	Range of fork length (cm)	Mean of fork length (cm)
1	Nov 1990–Mar 1991	356	50.3–104.0	75.9
2	Nov 1990–Feb 1991	463	51.3–97.9	76.2
3	Nov 1990	285	46.2–94.7	70.4
4	Nov 1990–Dec 1990	314	52.9–93.7	74.7
5	Nov 1990–Feb 1991	409	56.0–110.0	73.6
6	Nov 1990–Mar 1991	405	46.5–98.2	76.7
7	Jan 1991	267	50.0–112.0	75.1
Total		2499	46.2–112.0	74.8

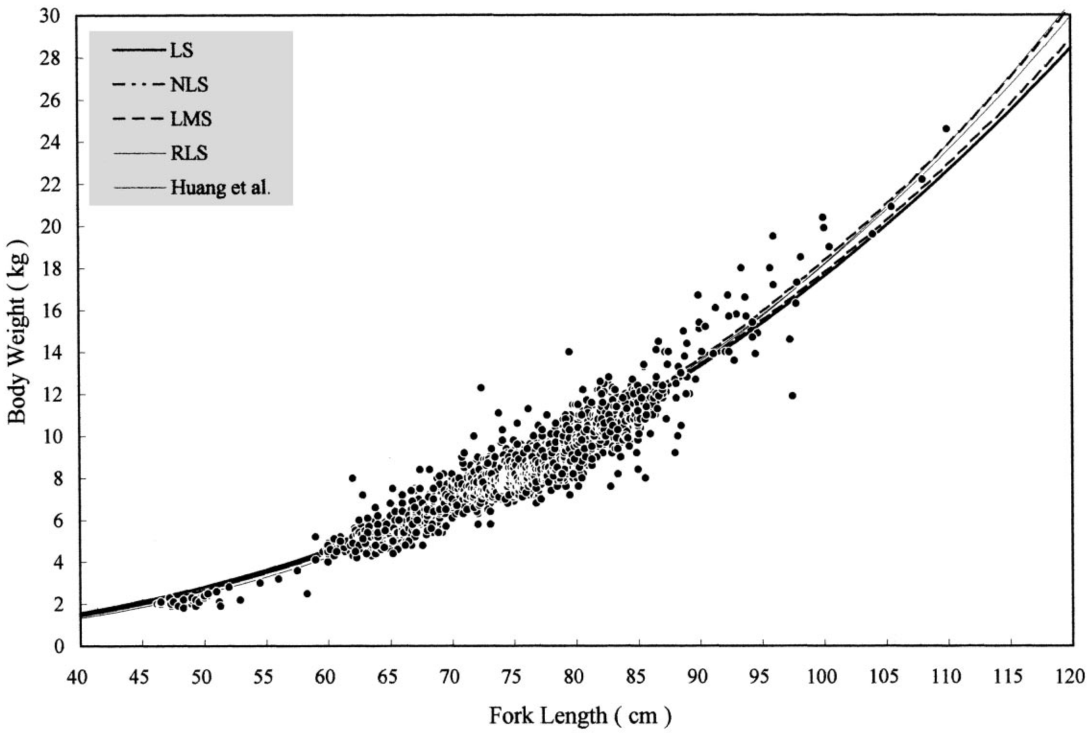

Fig. 2. The scatter plot of 2499 pairs of length vs. weight of albacore from the Indian Ocean. The length–weight relationships of the four formulae estimated by the present study, in which a comparable Huang et al. (1990) equation was also present.

The results obtained from performing LMS of natural logarithmic transformation of weight on natural logarithmic transformation of length indicate that the slope and intercept of equation are 2.7787 and 0.05068 (R^2=0.7833, $P \ll 0.001$). The slope and intercept of RLS which excluded 84 detected outliers investigated by LMS and then fitted by LS are 2.7514 and 0.056907 (R^2=0.9185, $P \ll 0.001$), respectively.

The comparison of the present estimation obtained from LS, NLS, LMS and RLS and the estimation of Huang et al. (1990) is illustrated in Table 2. The discrepancy increases with increasing fork length, particularly at lengths greater than about 95 cm. The results obtained by LS and NLS were lower than those of LMS and RLS. The formula of Huang et al. (1990) appears similar to that from LMS (Fig. 2).

The parameters 2.7514 and 0.056907 are for slope and intercept, respectively, obtained by RLS in the present study were acceptable for the length–weight relationship of albacore in the Indian Ocean. Although the largest value of R^2 (=0.995) was found from the

Table 2
Length vs. weight relationship of albacore in the Indian Ocean, estimated by least square (LS), nonlinear least square (NLS), least median of square residuals (LMS), and least square of residuals excluding outliers detected by LMS (RLS)

Estimation methods	Intercept	Slope	R^2
LS[a]	0.094	2.636	0.896
NLS	0.081	2.670	0.995
LMS	0.05068	2.7787	0.783
RLS	0.056907	2.7514	0.919

[a]The comparable formula: $W=0.03505L^{2.857}$ (R^2=0.970) is estimated by Huang et al. (1990).

estimation by NLS (Table 2), in principle, the fitting of length–weight relationship may be the best one. Further, the estimation obtained by Huang et al. (1990), using a different data set obtained mainly from longline vessels, showed large R^2 (=0.970), but with much steeper slope and smaller intercept among all formulae (Table 2). Both results with large R^2 were estimated from different data sets with possible outliers in it. Outliers always distort the curves much more towards themselves (Sen and Srivastava, 1990), even though the outliers may not be relevant to the large sample sizes in regression analysis. Basically, a goodness-of-fit may have a large R^2, however, a large R^2 does not necessarily imply that the fitted model is a useful one (Neter et al., 1989). All the results estimated herein therefore may be acceptable and explanatory for the length–weight relationship of albacore caught by gillnets in the Indian Ocean, and the estimates from RLS may be considered as the preferred one, even though a smaller R^2 (=0.919) was obtained. And the formula of Huang et al. (1990) may be acceptable for longline gears.

The length–weight relationship of Indian albacore stock, as calculated here, was very different from those from the northern and southern Atlantic albacore stocks. Penny (1994) found $W{=}0.013718FL^{3.0973}$ for the southern Atlantic stock; and Santiago (1993) found $W{=}0.01339FL^{3.1066}$ for the northern Atlantic stock. While these relationships may come from different stocks, the discrepancy between regression obtained by Huang et al. (1990) and those in the present study may be due to the different sample sizes and different estimation methods. The new regression proposed in this analysis is based on data distributed homogeneously within a range wider or atleast comparable to those of Huang et al. (1990). However, both of these formulae have limitations regarding seasonal or length-range coverage. It is noted that all length–weight formulae may give similar results for fish smaller than 100 cm, but tend to diverge up to 110 cm fork length for albacore in the Atlantic (Penny, 1994). Similarly, the formula obtained by the present study seems generally applicable (Fig. 2). However, the length of albacore catch from Indian Ocean may range from 40 to 120 cm, and few are over 110 cm. Therefore, the length–weight formula developed in this study is somewhat different from that of Huang et al. (1990), predicting slightly higher weights from fish smaller than 99 cm fork length, but lower weights thereafter.

The annual catches in weight of Indian albacore by Taiwanese fisheries, i.e., longline and gillnet fisheries, were based on landings reported by trade agencies and logbooks submitted by the captains (Hsu and Lin, 1996). There may be under-reporting in the trade reports, and inaccuracy can exist with on board weighing. The relationship provided here is a useful tool for converting catch in number to catch in weight incorporating size composition, mainly for the gillnet catches. Moreover, assessments provided by ad hoc VPA (Lee and Liu, 1996), age-structured production model (Hsu, 1995) and yield per recruit model analysis (Lee et al., 1991) may not provide enough information of the current stock status due to uncertainty of compiling catch data. The data uncertainty is not coincident between catches in weight and in number that were transformed by actual size distribution. Those errors may result from converting mean length to mean weight because slight variations of the length–weight formula used for this purpose always cause significant errors (Nielsen and Schoch, 1980). The current length–weight formula should permit the calculation of the catch-at-size, and thus perhaps the catch-at-age table for the catch data from gillnets and longliners, respectively. Hence, the data transformation may improve the assessments of the albacore stock in the future.

Acknowledgements

I thank Misses Y.M. Yeh and H.C. Chang for computational assistance, Mr. C.T. Ma for summarizing literatures. The help of staff of Tuna Research Center, Institute of Oceanography, National Taiwan University in measuring fish at fish market is greatly appreciated. And especially, I would like to thank two anonymous referees for reviewing and criticizing the manuscript.

References

Anon, 1996. Indian Ocean Tuna Fisheries Data Summary for 1984–1994. Indo-Pacific Tuna Development and Management Programme, Colombo, Sri Lanka.

Chen, Y., Jackson, D.A., Paloheimo, J.E., 1994. Robust regression approach to analyzing fisheries data. Can. J. Fish. Aquat. Sci. 51, 1420–1429.

Draper, N.R., Smith, H., 1980. Applied Regression Analysis. Wiley, New York.

Hsu, C.C., 1993. The status of Indian Ocean albacore stock – A review of previous work. Proceedings of the Fifth Expert Consult. on Indian Ocean Tunas. Indo-Pacific Tuna Development and Management Programme, Coll. Vol Work. Doc. 8, pp. 117–124.

Hsu, C.C., 1995. Stock assessment of albacore in the Indian Ocean by age-structured production model. J. Fish. Soc. Taiwan 22(1), 1–13.

Hsu, C.C., Lin, M.C., 1996. The recent catch estimating procedures of Taiwanese longline fisheries. International Commission for the Conservation of Atlantic Tunas, Coll. Vol. Sci. Pap. 43, pp. 175–177.

Hsu, C.C., Liu, H.C., 1990. Taiwanese longline and gillnet fishery in the Indian. Indo-Pacific Tuna Development and Management Programme, Coll. Vol. Work. Doc. 4, pp. 244–258.

Huang, C.S., Wu, C.L., Kuo, C.L., Su, W.C., 1990. Age and growth of the Indian Ocean albacore, *Thunnus alalunga*. Indo-Pacific Tuna Development and Management Programme, Coll. Vol. Work. Doc. 4, pp. 111–122.

Lee, Y.C., Liu, H.C., 1996. An updated virtual population analysis of the Indian Ocean albacore stock, 1980–1992. Proceedings of the Sixth Expert Consult. on Indian Ocean Tunas. pp. 267–278. Indo-Pacific Tuna Development and Management Programme, Colombo, Sri Lanka, 373 pp.

Lee, Y.C., Hsu, C.C., Chang, S.K., Liu, H.C., 1991. Yield per recruit analysis of the Indian albacore stock, Indo-Pacific Tuna Development and Management Programme, Coll. Vol. Work. Doc. 4, pp. 136–147.

Marquardt, D.W., 1963. An algorithm for least-squares estimation of nonlinear parameters. J. Soc. Ind. Appl. Math. 11(2), 431–441.

Neter, J., Wasserman, W., Kutner, M.H., 1989. Applied Regression Models. Richard D. Irwin, Boston, MA, p. 241.

Nielsen, L.A., Schoch, W.F., 1980. Errors in estimating mean weight and other statistics from mean length. Trans. Am. Fish. Soc. 109, 319–322.

Penny, A.J., 1994. Morphometric relationships, annual catches and catch-at-size for south African caught south Atlantic albacore (*Thunnus alalunga*). International Commission for the Conservation of Atlantic Tunas, Coll. Vol. Sci. Pap. 42(1), 371–382.

Rousseeuw, P.J., 1984. Least median of squares regression. J. Am. Stat. Assoc. 79, 871–880.

Rousseeuw, P.J., Leory, A.M., 1987. Robust Regression and Outlier Detection. Wiley, New York.

Santiago, J., 1993. A new length–weight relationship for the north Atlantic albacore. International Commission for the Conservation of Atlantic Tunas, Coll. Vol. Sci. Pap. 40(2), 316–319.

Sen, A.K., Srivastava, M.S., 1990. Regression Analysis: Theory, Methods and Applications. Springer. New York.

Venables, W.N., Ripley, B.D., 1994. Modern Applied Statistics with S-plus. Spinger. New York, 462 pp.