LENGTH-FREQUENCY COMPOSITIONS AND WEIGHT–LENGTH RELATIONS FOR BIGEYE TUNA, YELLOWFIN TUNA, AND ALBACORE (PERCIFORMES: SCOMBRINAE) IN THE ATLANTIC, INDIAN, AND EASTERN PACIFIC OCEANS

Guoping *ZHU* [1, 2, 3], Liuxiong *XU* [1, 2] *, Yingqi *ZHOU* [1, 2], and Xiaojie *DAI* [1, 2, 3]

[1] *The Key Laboratory of Shanghai Education Commission for Oceanic Fisheries Resources Exploitation, College of Marine Sciences, Shanghai Ocean University, Shanghai 201306, China*

[2] *The Key Laboratory of Sustainable Exploitation of Oceanic Fisheries Resources (Shanghai Ocean University), Ministry of Education, Shanghai 201306, China*

[3] *Tuna Fishery Technical Working Group of China, Shanghai 201306, China*

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Background. Bigeye tuna, *Thunnus obesus* (Lowe, 1839); yellowfin tuna, *Thunnus albacares* (Bonnaterre, 1788); and albacore, *Thunnus alalunga* (Bonnaterre, 1788), are very important species for world fisheries. It is crucial to the future existence of those economically important species that the best possible biological data on the species is provided to fisheries managers.
Materials and Methods. The weight–length relations (WLRs) for bigeye tuna, yellowfin tuna, and albacore, collected in the Atlantic, Indian, and eastern Pacific oceans were studied using commonly accepted methodology.
Results. Significant differences can be found from the fork length distributions and the WLRs of the above 3 tuna species and the relations of gilled-gutted and whole weight of bigeye and yellowfin tunas collected from the Atlantic, Indian, and Eastern Pacific Oceans. Significant differences of fork length distributions can be found for bigeye tuna, yellowfin tuna, and albacore from the three areas. The growth exponents (*b*) of bigeye tuna, yellowfin tuna, and albacore collected from the Atlantic, Indian, and eastern Pacific oceans register significant deviations from isometric value of 3.
Conclusion. The date collected will be useful for the fisheries management of the three species studied.

Keywords: bigeye tuna, yellowfin tuna, albacore, weight–length relation, *Thunnus*

INTRODUCTION

The weight–length relation (WLR) is an important tool in fish biology, physiology, ecology, and fisheries assessment and has been originally used to provide information on the condition of fish and determine whether somatic growth is isometric or allometric (Ricker 1975, Oscoz et al. 2005). WLRs are useful in determining weight and biomass when only length measurements are available, as indications of condition and to allow for comparisons of species growth between different regions (Koutrakis and Tsikliras 2003).

Bigeye tuna, *Thunnus obesus* (Lowe, 1839); yellowfin tuna, *Thunnus albacares* (Bonnaterre, 1788); and albacore, *Thunnus alalunga* (Bonnaterre, 1788), are the important commercial species in the tropical and subtropical waters of the Atlantic, Indian, and Pacific oceans (Driggers et al. 1999, Sun et al. 2001, Miao and Huang 2003, Farley et al. 2006). It constitutes an extremely valuable fishery resource intensively exploited by Asian longliners, and US and European purse seiners, at various stages of its life cycle (Stéquert and Conand 2000). However, the stocks of the above tuna species, especially bigeye tuna, are almost on the verge of over-exploitation and may soon be regarded as overfished (Joseph 2003). It is crucial to the future existence of this economically important species that the best possible biological data on the species is provided to fisheries managers (Manooch and Hinkley 1991). This study contributes to the knowledge of the WLRs of bigeye tuna, yellowfin tuna and albacore of the Atlantic, Indian, and Pacific Oceans.

* Correspondence: Professor Liuxiong XU, Dean, College of Marine Sciences, Shanghai Ocean University, 999 Huchenghuan Road, Lingang New City, Shanghai 201306, China, phone: 86-21-61900301, e-mail: *lxxu@shou.edu.cn*

MATERIALS AND METHODS

Study area and data sampling. Specimens were caught using longline and randomly sampled on board the Chinese longline vessels operating in the Atlantic (from October 2002 to April 2006), Indian (from January 2003 to December 2005), and Eastern Pacific (from July 2003 to November 2006) Oceans (Fig. 1) on a daily basis. For each sampled fish, fork length (FL) was measured to the nearest 1 cm and grouped in 5 cm fork length classes. Whole weight (RW) and gilled-gutted weight (DW) were measured with electronic platform balances to the nearest 1 g.
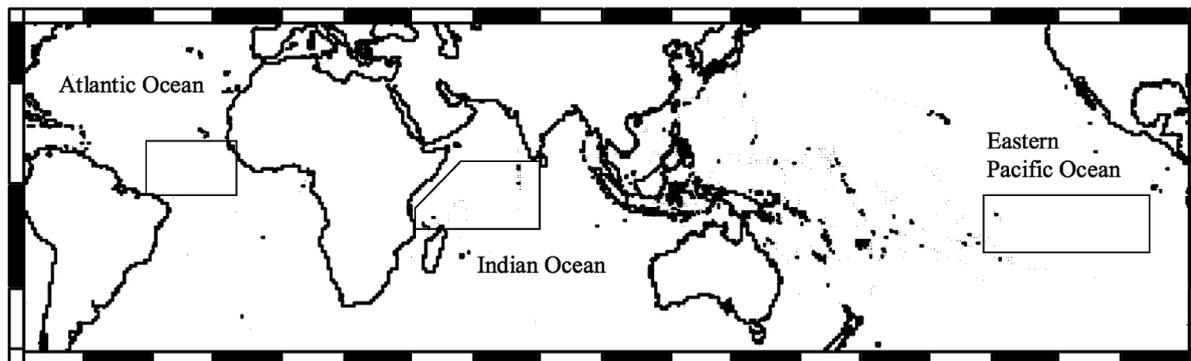

Fig. 1. Map of the areas studied

Length–weight relations. The differences of FL distribution of tuna species among areas were tested by Kruskal–Wallis one-way analysis of variance (K–W test).

The length–weight relations was quantified with an exponential regression equation

$$W = aL^b e^\varepsilon, \ \varepsilon \sim N\ (0, \sigma^2),$$

where: W was the gilled-gutted weight (DW) or the whole weight (RW) [g],

L the fork length (FL) [cm], b the growth exponent or length–weight factor, and a was a constant. The parameters (a and b), the coefficient of determination (r^2) and the 95% confidence limits (CL) were estimated over the entire period by least squares regression using the log transformed weights and sizes.

The WLRs were tested for significant difference among areas by means of analysis of covariance (ANCOVA). In order to confirm whether b-values obtained in the linear regressions were significantly different from the isometric value (3), Student's t-test (H_0: $b = 3$) was applied (Sokal and Rohlf 1987).

RESULTS AND DISCUSSIONS

The FL range and mean FL of bigeye-, yellowfin tuna, and albacore from the Atlantic, Indian, and eastern Pacific oceans were given in Table 1. The K–W test showed that significant differences of FL distributions could be found for bigeye tuna ($H = 80.7991$, $P < 0.001$), yellowfin tuna ($H = 181.2648$, $P < 0.001$) and albacore ($H = 77.3503$, $P < 0.001$) from the three areas (Fig. 2).

The relations between gilled-gutted weight and whole weight were showed in Table 2. The ANCOVA analysis showed that significant differences of the relations of gilled-gutted and whole weight could be found among areas for bigeye tuna ($F = 173.4808$, $df = 3555$, $P < 0.001$) and yellowfin tuna ($F = 5.3132$, $df = 1370$, $P < 0.001$).

The details of weight–length relations of bigeye-, yellowfin tuna, and albacore from the Atlantic, Indian, and eastern Pacific oceans were given in Table 1. The values of the parameter b were well within the normal range of 2.5 to 3.5 (Carlander 1969) and the range given by Tesch (1971) (between 2 and 4). Carlander (1977) indicated that values of $b < 2.5$ or >3.5 are often derived from samples with narrow size ranges, so narrow size range (93.0–119 cm) and limited samples (88) may be contributed to the reason why b value = 2.343 (< 2.5) was low for albacore in the Indian Ocean. The results of Student's t-test showed that regression coefficients of bigeye tuna, yellowfin tuna, and albacore collected from the Atlantic, Indian, and eastern Pacific oceans register significant deviations from isometric value of 3 (Table 1). The Student's t-test also shows that b values of bigeye tuna among the Atlantic, Indian, and eastern Pacific oceans show no significant differences, and the similar results can be found for yellowfin tuna and albacore. However, with the limited size ranges or the number of samples, particularly albacore, in the present study, further works should be done for comparing the differences of b values of bigeye tuna, yellowfin tuna, and albacore among the Atlantic, Indian, and eastern Pacific oceans, such as the differences in condition between small and large individuals in the respective area at that point in time and more WLR estimates should be considered (Froese 2006). The ANCOVA analysis shows that significant differences of the WLRs can be found among the Atlantic, Indian and Eastern Pacific Oceans for bigeye tuna ($F = 334.4317$, $df = 5216$, $P < 0.001$), yellowfin tuna ($F = 141.4433$, $df = 1850$, $P < 0.001$), and albacore ($F = 66.7288$, $df = 329$, $P < 0.001$), respectively.

Longline fishery targets larger albacore, bigeye-, and yellowfin tuna, however, purse seiners take a small, but significant, by-catch of bigeye tuna (Hampton 2006). Tantivala (2000) set up the length–weight relation of $DW = 0.082FL^{2.6480}$ ($r^2 = 0.99$, $n = 232$) for the juvenile bigeye tuna (30–82 cm) and $DW = 0.031FL^{2.8580}$ ($r^2 = 0.97$, $n = 368$) for the juvenile yellowfin tuna (28–84 cm) collected from purse seine in the eastern Indian Ocean. Due
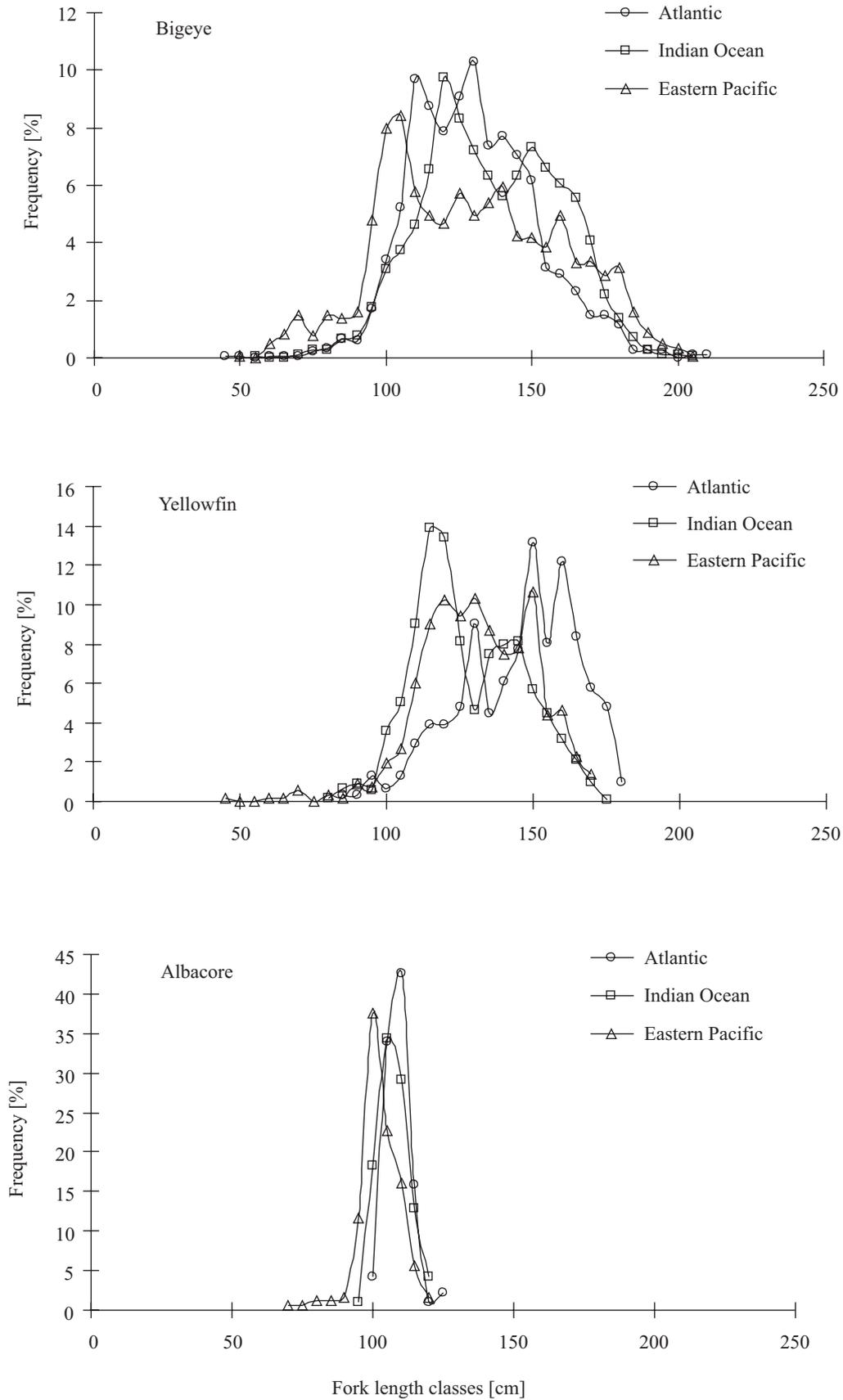
Fig. 2. The fork length distributions of bigeye tuna, yellowfin tuna, and albacore collected from the Atlantic, Indian, and eastern Pacific oceans

Table 1

Descriptive statistics and Length–weight relation parameters for bigeye tuna, yellowfin tuna,
and albacore from the Atlantic, Indian, and eastern Pacific oceans

Species	Area	FL range [m]	Mean FL [cm]	Mean W [g]	n	a	b	95% CL of b	r^2	t value	P value
BET	Atlantic	43.2–206.0	128.0	36546.2	2280	0.0158	2.997	2.968–3.026	0.9471	9.837	< 0.001
YFT	Atlantic	83.0–176.8	143.2	45309.0	299	0.0166	2.969	2.884–3.054	0.9412	12.411	< 0.001
ALB	Atlantic	99.1–125.0	107.2	23985.1*	94	0.0438*	2.825*	2.499–3.151	0.7628	10.338	< 0.001
BET	Indian Ocean	54.8–201.0	134.0	45195.7	1052	0.0247	2.926	2.898–2.954	0.9649	199.492	< 0.001
YFT	Indian Ocean	78.0–171.0	125.9	32267.9	1033	0.0163	2.985	2.953–3.017	0.9696	29.149	< 0.001
ALB	Indian Ocean	93.0–119.0	105.7	24045.5	88	0.434	2.343	2.066–2.620	0.7644	44.196	< 0.001
BET	Eastern Pacific	60.0–202.0	127.3	41723.5	1436	0.0132	3.043	1.841–3.728	0.9742	123.717	< 0.001
YFT	Eastern Pacific	93.0–170.0	129.5	33211.5	520	0.00418	3.244	3.176–3.312	0.9449	161.705	< 0.001
ALB	Eastern Pacific	70.0–118.0	100.7	18846.9	147	0.0542	2.760	2.552–2.968	0.8256	27.609	< 0.001

* Weight is whole weight [g]; BET = bigeye tuna; YFT = yellowfin tuna; ALB = albacore; n: sample size; FL: fork length [cm]; W: gilled-gutted weight [g]; CL = confidence limit; a = the parameter in the W–L relation; b = slope; r^2 = coefficient of determination.

Table 2

Descriptive statistics and the parameters in the relation between gilled-gutted weight and whole weight
for bigeye- and yellowfin tunas from the Atlantic, Indian, and eastern Pacific oceans

Species	Area	Slope (SE)	Intercept (SE)	n	r^2
Bigeye tuna	Atlantic	1.146 (0.002)	1.557 (0.077)	1180	0.9956
Yellowfin tuna	Atlantic	1.084 (0.004)	2.439 (0.169)	299	0.9969
Bigeye tuna	Indian Ocean	1.128 (0.005)	1.254 (0.241)	1177	0.9812
Yellowfin tuna	Indian Ocean	1.149 (0.003)	0.087 (0.088)	881	0.9959
Bigeye tuna	Eastern Pacific	1.085 (0.009)	2.784 (0.480)	580	0.9906
Yellowfin tuna	Eastern Pacific	1.097 (0.008)	1.817 (0.313)	192	0.9895

SE = standard error; n = sample size; r^2 = coefficient of determination.

to the fishing gear size selectivity, most samples in the present study do not include juveniles or very small individuals (such as albacore). In this context, and according to Petrakis and Stergiou (1995), the use of these WLRs should be rigorously limited to the size ranges applied in the estimation of the linear regression parameters. For this reason, it is particularly dangerous to extrapolate data to fish larvae (Pepin 1995), juveniles (Safran 1992), or immature stages (Bagenal and Tesch 1978).

The WLR in fishes is affected by a number of factors including season, habitat, food availability, feeding rate, gonad development, sex, spawning period, health, preservation techniques, and locality (Tesch 1971, Bagenal and Tesch 1978, Froese 2006); and these factors were not considered in the present study. However, unlike the parameter a, which may vary daily, seasonally, and/or between different habitats, the parameter b is characteristic of the species (Mayrat 1970) and generally does not vary significantly throughout the year (Bagenal and Tesch 1978).

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