Length-weight relationships for tropical tunas caught with purse seine in the Indian Ocean: Update and lessons learned

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Abstract

Morphometric data for tropical tunas caught with purse seine have been collected in the Indian Ocean over the last decades through routine sampling at processing factories and research projects. We estimate the parameters of allometric relationships between fork length (cm) and total weight (kg) for bigeye (*Thunnus obesus*), skipjack (*Katsuwonus pelamis*), and yellowfin tuna (*Thunnus albacares*) caught with purse seine in the Indian Ocean. We show that relationships currently used in the IOTC underestimate weights at length for bigeye and skipjack with potential consequences for the estimates of purse seine catch and other datasets derived from fish numbers and size data. We question the use of gear-specific length-weight relationships for tropical tunas. We recommend to carefully and systematically collect morphometric data required for conversion factors and relationships and made them available to the IOTC Secretariat as they are key in data processing and can eventually affect the monitoring of the status of tuna and tuna-like stocks in the Indian Ocean.

Keywords: allometry, morphometry, species composition

1. Introduction

Morphometric data are instrumental in the processing of fisheries data to estimate sampling rates, reporting coverage, and extrapolate from samples to the population. In the case of European and Seychelles purse seine fisheries, length-weight relationships are particularly important as species composition of the catch is estimated through the conversion of fish sizes measured onboard the vessels at landing. Biased or inappropriate morphometric relationships have been shown to affect knowledge on the size structure of the catch in longline fisheries with potential impacts on stock assessments (Langley et al., 2006; Minte-Vera et al., 2016; Satoh et al., 2016). In the present analysis, we follow the work of Chassot et al. (2014) to update the length-weight relationships for yellowfin, skipjack, and bigeye tuna caught with purse seine in the Indian Ocean.

2. Materials & Methods

2.1. Data

About 30,000 tunas have been sampled during routine sampling conducted at the cannery 'Indian Ocean Tuna Ltd' (former 'Conserverie de l'Océan Indien') in Victoria (Seychelles) from 1986 following an agreement with the management staff in order to comply with health and quality manufacturer practices and not delay processing operations (Chassot et al., 2014). Sampling was dependent on fish available at processing and conducted opportunistically through close collaboration with process managers. In complement, 732 tunas were collected during IRD-SFA research projects conducted in Seychelles during 2013-2016, 190 tunas were collected through the Indian Ocean Tuna Tagging Programme, and 216 large bigeye were sampled in July 2015 at the factory 'Mer des Mascareignes' based in Port-Louis, Mauritius. The sampling protocol for length-weight data consisted in identifying the tuna species, which can be an issue for juveniles of yellowfin and bigeye $<$40 cm (Itano, 2004), measuring fish length (cm) with a caliper to the nearest 0.1 cm and mass (kg) to the nearest 0.1 g with a scale. Sex and sexual maturity stage were determined from visual examination of the gonads according to standard classification (Schaefer and Orange, 1956). Access to the IOT cannery was mainly restricted to the 'raw-pack' processing line of large yellowfin tuna for most years and no sampling operation was conducted during 1991-2002, which resulted in an unbalanced sampling design over time (Table 1).

2.2. Statistical modelling

For each species, a power regression assuming a multiplicative error term was used to model total fish weight (W_T) as a function of fork length F_L following:

$$W_T = a \times F_L^b \times \eta \tag{1}$$

Where η is a lognormally distributed multiplicative error term. We assumed that the thawing of the fish did not affect observations of weight although data collected for 93 tunas showed that a small but systematic size-dependent bias occurs due to water loss, reaching up 3% in tunas <5 kg (IOTC-2013-SC16-INF13). Sex was not included in the model as preliminary analysis showed that it did not explain a significant part of the variability observed in weight. Model parameters were estimated by applying a logarithmic transformation to equation (1):

$$\ln(W_T) = \ln(a) + b \times \ln(F_L) + \epsilon \tag{2}$$

Where ϵ is normally distributed and has mean zero and constant variance. Model parameters were estimated with linear regression models using the 'lm' function implemented in {R Core Team} (2016). Estimates of a were adjusted for bias following the method proposed by Neyman and Scott (1960) (Hayes et al., 1995). Gaussian error distribution and homoscedasticity hypotheses were checked using the residuals.

3. Results & discussion

A total of 29304 L_F-W_T data were used to derived the species-specific length weight relationships, i.e. 2156, 1762 and 25386 for bigeye, skipjack, and yellowfin, respectively. Model residuals showed that assumptions of equal variance and normal distribution of log-transformed weights at length were met for each species. Length-weight parameters derived from maximum likelihood estimates of the parameters of equation 2 are provided in Table 2.

Mean regression models fitted to the bigeye and skipjack data were found to significantly differ from the relationships currently in use in IOTC and available from IOTC-2016-WPTT18-DATA10. The current IOTC length-weight relationship underestimates the weights at length for both bigeye and skipjack (Figs. 1-2). The length-weight relationship for bigeye was estimated in the early-1980s from about 90 L_F-W_T data points encompassing the size range 30-140 cm fork length (see Fig. 8 of Cort (1986)). The absence of fish in the sample for large sizes may have biased the relationship and resulted in weight underestimation.

For skipjack, parameters of the current IOTC relationship were derived from data collected in the Atlantic Ocean during 1977-1983 (Cayré and Laloë, 1986). Interestingly, data collected in the Atlantic Ocean in recent years still indicate smaller weights at length in the Atlantic Ocean than in the Indian Ocean (IRD, unpublished data). Differences in weight might reflect differences in prey availability and energetic expenses stemming from differences in oceanographic productivity and environmental conditions (e.g. temperature and seasonality) between the Atlantic and Indian Oceans (Druon et al., 2016). Such differences affect stock productivity and expected production per recruit and call for comparative analyses to better understand tuna plasticity and ability to adapt to environmental changes such as global warming (Dueri et al., 2012).

The large underestimation of individual skipjack weight likely resulted in the underestimation of skipjack in the purse seine catch, and consequent overestimation of proportion of yellowfin and bigeye. A simple simulation could be performed to assess the expected changes in purse seine species composition resulting from the update of the skipjack and bigeye length-weight relationships. For yellowfin, the relationship was very similar to the current IOTC one used for purse seine since this latter was derived from the same dataset covering 1986-2014 (Chassot et al., 2014). A full re-processing of the purse seine data in the Indian Ocean might be required to update the annual time series of catch for the 3 species, at least for the period 2001-2014. This could be combined with changes in post-stratification (i.e. smaller time-area strata) that have been recently envisaged to improve the estimation of the composition of purse seine catch (Fonteneau et al., 2016).

Our results also show that length-weight relationships used for bigeye and yellowfin tunas caught with longline differ from the ones used for purse seine, suggesting that tunas caught by longliners would weigh less at similar sizes (Figs. 1-3). Although the hypothesis of vertical habitat partioning by large tunas in the pelagic realm cannot be ruled out, pop-up satellite tags deployed in all oceans over the last decades show typical vertical behaviour with deep dives that suggest frequent exchanges between vertical water layers (e.g. Dagorn et al., 2006). In addition, yellowfin and bigeye tunas are known to aggregate for spawning in warm surface waters where they are caught by purse seiners, supporting a mixing between vertical components of the populations. Analyses should be conducted to test for the effect of gear on length-weight relationships in Indian Ocean tunas to determine whether gear-independent relationships should be adopted by the IOTC as in the Atlantic Ocean (e.g. Parks et al., 1982). Morphometric data used for determining conversion factors and relationships should be carefully collected, described and made available to the IOTC Secretariat and scientific Community since they are key in data curation and preparation of data inputs for stock assessments models.

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Tables

Table 1: Annual number of tunas by species for which fork length (cm) and total weight (kg) were available and used in the present analysis. BET = bigeye tuna; SKJ = skipjack tuna; YFT = yellowfin tuna

	BET	SKJ	YFT	ALB	FRI
1987	23	0	611	0	0
1988	240	0	700	0	0
1989	68	0	478	0	0
1990	480	0	893	0	0
2003	24	0	304	0	0
2004	0	0	1051	0	0
2005	0	0	1240	0	0
2006	4	0	4273	0	0
2007	91	0	1514	0	0
2008	29	0	1071	0	0
2009	2	2	2335	0	0
2010	10	22	1200	0	0
2011	49	0	2316	0	0
2012	29	0	3366	0	0
2013	204	178	1860	0	0
2014	358	826	1056	0	0
2015	545	734	1118	0	0

Table 2: Maximum likelihood estimates of the parameters for the length-weight relationships for bigeye tuna (BET), skipjack tuna (SKJ), and yellowfin tuna (YFT). SE = Standard error

Species	a	b
BET	0.00002217	3.01211
SKJ	0.00000497	3.39292
YFT	0.00002459	2.96670

Figures

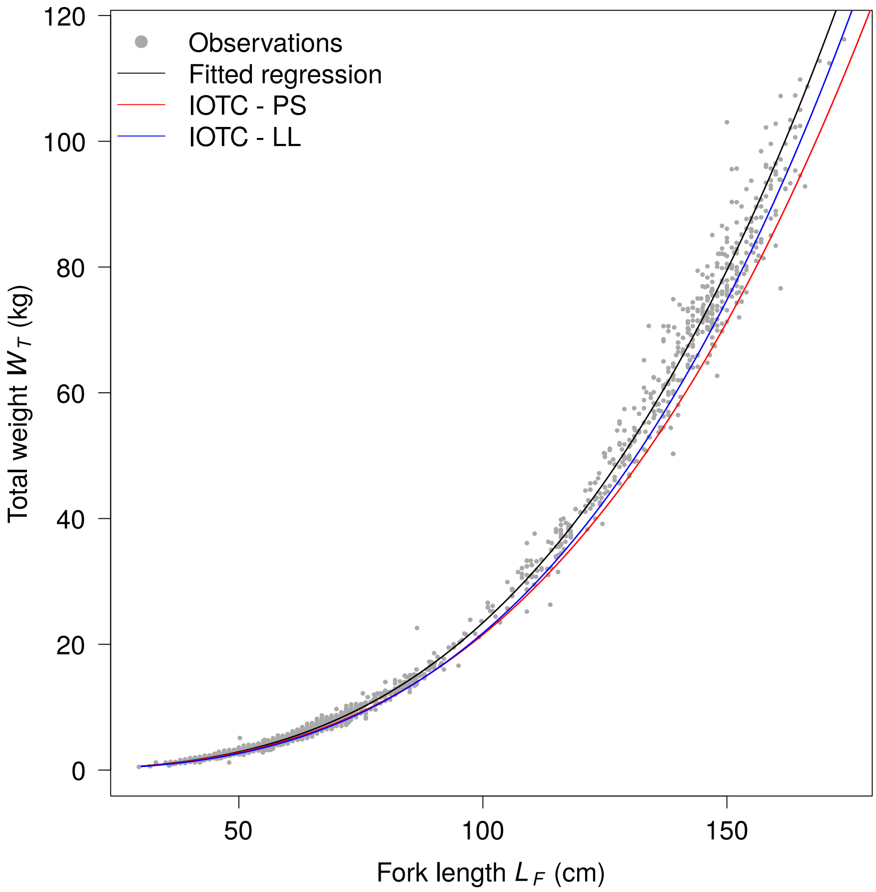

Figure 1: Relationship between fork length and total weitht of bigeye tuna (*Thunnus obesus*) caught with purse seine in the Indian Ocean. Solid line indicates mean regression model fitted to the data. IOTC-PS and IOTC-LL indicate official IOTC length-weight relationships for purse seine and longline, respectively

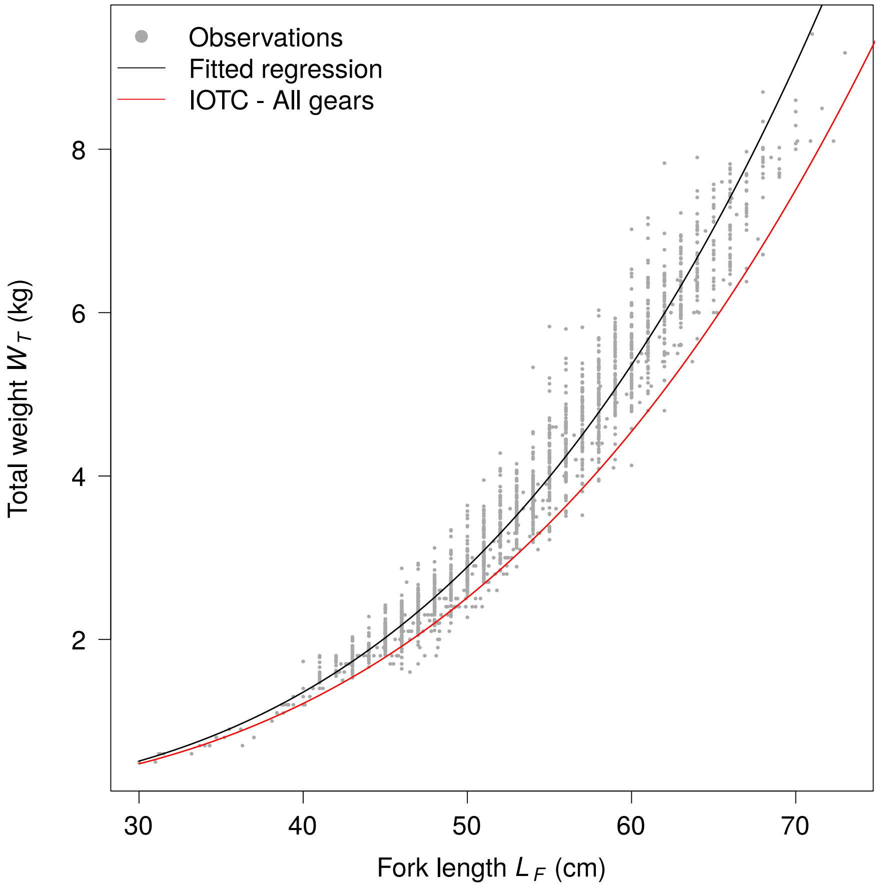

Figure 2: Relationship between fork length and total weight of skipjack tuna (*Katsuwonus pelamis*) caught with purse seine in the Indian Ocean. Solid line indicates mean regression model fitted to the data. IOTC-All gears indicates official IOTC length-weight relationship for all gears

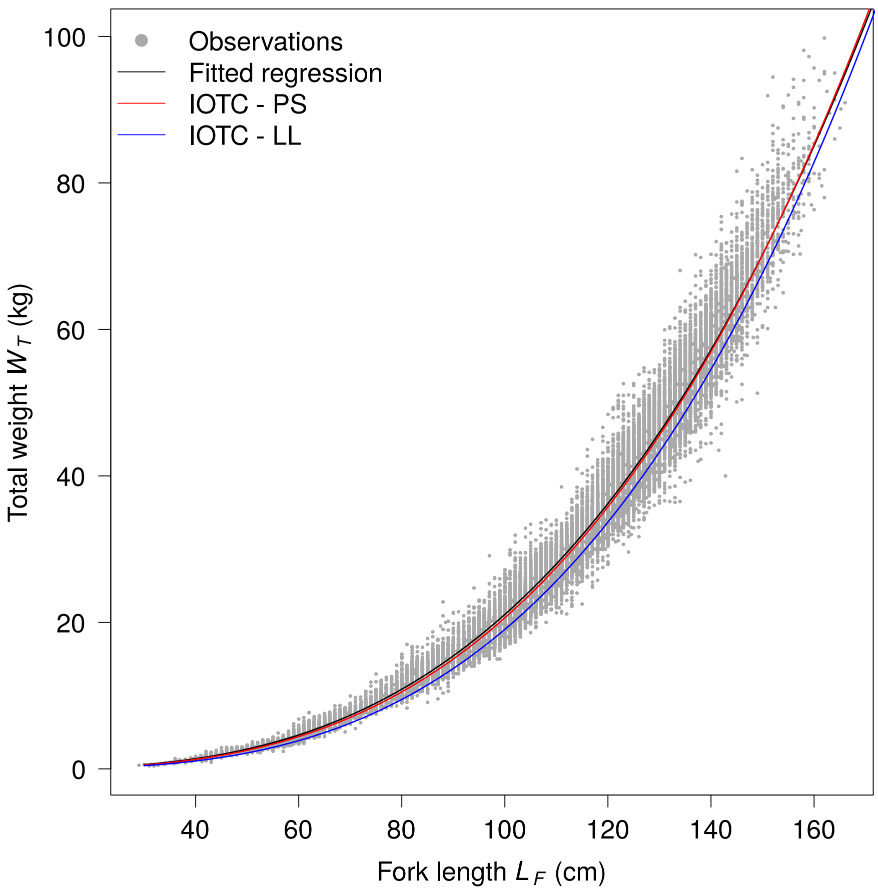

Figure 3: Relationship between fork length and total weight of yellowfin tuna (*Thunnus albacares*) caught with purse seine in the Indian Ocean. Solid line indicates mean regression model fitted to the data. IOTC-PS and IOTC-LL indicate official IOTC length-weight relationships for purse seine and longline, respectively