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CONVERSION FACTORS UPDATE FOR TROPICAL TUNAS CAUGHT WITH PURSE SEINE IN THE ATLANTIC OCEAN

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SUMMARY

Allometry relationships are essentials tools used in stock assessment. Among them, the most used are those relating weight to length. These relationships must be regularly reviewed to avoid bias in length conversion. In this paper, we proposed an update of the length weight relationship of major tunas caught by the purse seine fisheries. Based on a robust dataset, we not only demonstrated a change in the length-weight relationship, but we further test for additional predictors to improve its reliability. Sex, month, year and location of the fish had a limited effect on size even if they are significant. R² only increased very lightly between the two models from 0.001 to 0.004 and all were above 0.98 with only the knowledge of the fork length. Regarding the predictions of the two models, their relative differences were very small, 0.3% maximum on average for larger fish. For small and medium size fish, the mean differences were almost negligible. Consequently, the authors recommend using simple length-weight relationships to convert length to weight for the purse seine tropical fisheries.

RÉSUMÉ

Les relations d'allométrie sont des outils essentiels utilisés dans l'évaluation des stocks. Les plus utilisées sont celles mettant en relation le poids et la longueur. Ces relations doivent être régulièrement révisées afin d'éviter des biais dans la conversion de longueur. Dans ce document, nous proposons une actualisation de la relation longueur-poids des principaux thonidés capturés par les pêcheries de senneurs. Sur la base d'un jeu de données robuste, nous démontrons non seulement un changement de la relation longueur-poids mais nous testons également des prédicteurs supplémentaires pour améliorer sa fiabilité. Le sexe, le mois, l'année et la localisation des poissons avaient un effet limité sur la taille même s'ils sont significatifs. Les R² n'ont augmenté que très légèrement entre les deux modèles, de 0,001 à 0,004, se situant toutes au-delà de 0,98 avec la seule connaissance de la longueur à la fourche. En ce qui concerne les prédictions des deux modèles, leurs différences relatives étaient très faibles, un maximum de 0,3% en moyenne pour les plus grands poissons. Pour les poissons de petite et de moyenne taille, les différences moyennes étaient quasiment négligeables. Par conséquent, les auteurs recommandent d'utiliser de simples relations longueur-poids pour convertir la longueur en poids pour les pêcheries de senneurs tropicaux.

RESUMEN

Las relaciones alométricas son herramientas esenciales utilizadas en la evaluación de stocks. Entre ellas, las más utilizadas son las que relacionan el peso con la talla. Estas relaciones deben revisarse periódicamente para evitar sesgos en la conversión de tallas. En este documento, proponemos una actualización de la relación talla-peso de los principales túnidos capturados por las pesquerías de cerco. Basándonos en un conjunto de datos robusto, no sólo demostramos un cambio en la relación talla-peso, sino que además probamos predictores adicionales para mejorar su fiabilidad. El sexo, el mes, el año y la ubicación de los peces tuvieron un efecto limitado en la talla, aunque son significativos. Las R² sólo aumentaron muy ligeramente entre los dos modelos, de 0,001 a 0,004, y todas se situaron por encima de 0,98 sólo con el conocimiento de la longitud de la horquilla. En cuanto a las predicciones de los dos modelos, sus diferencias relativas fueron muy pequeñas, un 0,3 % como máximo de media para los peces de mayor tamaño. En el caso de los peces de tamaño pequeño y mediano, las diferencias medias fueron casi insignificantes. Por consiguiente, los autores recomiendan utilizar relaciones simples entre talla y peso para convertir la talla en peso en las pesquerías tropicales de cerco.

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KEYWORDS

Length-weight relationship, Yellowfin, skipjack, bigeye.

Introduction

Tuna fishery is one of the most important fisheries in the world in terms of catch and economic importance (FAO, 2022; Majkowski, 2007). Of the 5.1 million tons of tuna caught worldwide each year, 66% come from purse seiners (ISSF, 2023; Justel-Rubio and Recio, 2023; Majkowski, 2007; McKinney *et al*., 2020; Miyake *et al*., 2004). Purse seine fishing is a fishing technique that consists of targeting and catching entire fish schools in surface waters by encircling them with a fishing net called a seine. In the tropical oceans, purse seine (PS) is used extensively to target tropical tunas and specifically skipjack tuna (*Katsuwonus pelamis*), yellowfin tuna (*Thunnus albacares*) and bigeye tuna (*Thunnus obesus*) (Kaplan *et al*., 2014). Due to their catch volume, skipjack and yellowfin tunas are the two species that generate the highest revenue (FAO, 2011; ISSF, 2023; McKinney *et al.*, 2020). The strong economic stakes surrounding this exploitation have led to a sharp increase in pressure on these stocks (Pons *et al.*, 2017). To restore overfished stocks and preserve others from overexploitation, it is fundamental to evaluate fishing pressure and stock status for each exploited species. Stock assessments are based on several life history parameters such as growth, fecundity, and mortality. Acquiring biological information on the exploited species is essential to obtain these parameters. One of the biological parameters used for these models is allometry relationships. These relations are used to deal with fisheries data as a tool, for instance, to estimate size coverage, sampling rates and extrapolation to the population (Chassot *et al*., 2016). To give an example of data, the Tropical Tunas Treatment (Duparc *et al*., 2019) standardize length data on the same scale of measure through length conversion factors. Furthermore, this treatment uses other conversion factors to express length measures in weight measures.

Among all allometric relationships those relating weight to length remains one of the most used in fishery science. The study of allometric relationships has two main goals. The first is to describe mathematically the relation to convert one parameter into another. This is it most commonly use as fish length is often easier and more accurately measured than its weight in field studies. The second goal is to study the variation of an expected weight for a length of an individual (or group) as indicators of the well-being of the individuals (Froese, 2006; Le Cren, 1951). This well-known condition, calculated as a ratio between the observed weight and the one expected from the observed length, was used numerously among numerous fish species, including tuna (Ashida, 2020; Dupaix *et al*., 2023; Nøttestad *et al*., 2020). Assessment models are very sensitive to conversion factors (Langley *et al*., 2009; Minte-Vera *et al*., 2016). Indeed, it's crucial to use an appropriate relationship to process fisheries data. Kimmerer *et al*. (2005) demonstrate the bias associated with the use of an inappropriate length-weight relationship to estimate a modeling parameter. Numerous studies have also demonstrated that allometric rules can vary for a given species accordingly the seasonality or the location and between male and female (*Persica Fluviatilis*, Le Cren (1951), several Triglidae Olim and Borges (2006), Actinopterigii in Viana *et al.* (2016)). On the context of pelagic migratory species stock, as tuna, we could expect an important effect of these components on the allometry relationship.

Concerning the Atlantic Ocean, it's been almost 40 years since the International Commission for the Conservation of Atlantic Tuna (ICCAT) conversion factor was updated for the three major species (Caverivière, 1976; Cayré and laloë, 1986; Parks *et al*., 1982). Unfortunately, these studies can be biased because they were based on data collection which may not be representative of the entire tuna species population due to limited spatial coverage, size ranges or inadequate sampling. An alternative hypothesis is the evolution of these relationships due to natural or anthropic reasons. In such a condition, the reliability of the conversion factor is questionable and should be reviewed.

Since the 80's, IRD, the French Research Institute for the Development, has been monitoring the catches of French purse seiners in Atlantic and Indian ocean. Based on a robust dataset which covers the whole size distribution of catch and all the fishing ground of the EU purse seine fisheries over several decades, this paper aims to determine the optimal allometry relationships for major tropical tuna species by testing spatiotemporal effect on this relation, plus the sex effect. To do so, it first determined the optimal models of each relationship per species and estimated the size effect of each of the selected covariable. Then, compared this optimal model to the simple power model to estimate the gain in predictive power and impact on the prediction for small, medium and larger fish. This paper contributes to increasing knowledge of these exploited species and highlights the need to update the assessment model parameters.

1. Data and methods

1.1 Data source

The data uses for this study come from the Tunabio database (Guillou *et al.*, 2022). As it includes different projects since the 70's, the methodology between them may differ slightly. The protocol and the sampling plan slightly varied in effort among species, space and time but fish measurement remained similar and comparable. The fish from EU tropical purse seine fisheries (France and Spain) were sampled at the port landing, at the canneries or at the lab. Of 12,615 data, 98.7% come from a sampling routine in Abidjan port through the Data Collection Framework (Reg 2017/1004 and 2021/1167) funded by both IRD and the European Union. The remaining data (n=166) were collected under other IRD projects (Pecoraro *et al*., 2020).

This paper focuses on the fork length which is the distance from the tip of the lower jaw to the shortest caudal ray (fork). Only two projects took the fork length to the nearest centimeter and the first dorsal length to the nearest half centimeter.

In addition to the length and weight variable, covariables included in the model were collected. If the sampling took place in the lab or at the cannery, sex was acquired following the methodology from Diaha *et al.* (2015). The present study covers the 2009-2022 period which represents 12,615 individuals in total.

The sampled fish cannot always be linked to a specific set, when the fish is, for example, collected at the factory. In that case, all possible set locations and fishing date of the corresponding trip were associated to one sample. Thus, the fishing month of a fish, used in the model, corresponds to the month of the identified set or the average fishing month of the corresponding trip. Regarding the spatial effect, we calculated the distance of each set of a trip to its centroid. Results demonstrated that 5° square is a reasonable scale to represent the spatial trip coverage (**Appendix 1**). We so include the 5° square id of the centroid of each trip as spatial covariable. In Atlantic Ocean the study area extends from Mauritania, 20°N, to Angola, 20°S and from 30°W to the West African coast.

1.2 Data screening

Outliers were detected using simultaneously two methods. The first one, the isolation forest (Liu *et al.*, 2008) detected outliers by splitting randomly and repeatedly the dataset according to some feature until rarer values end up alone in one branch (Cortes, 2023). Each data gets a score according to the distance of isolation, i.e., number of splits needed to isolate an observation. The second method is the prediction interval from a linear model using a prediction at 99%. Finally, the selected data were observations included simultaneously in the 99% prediction interval and in the 99% quantile of the isolation tree scores.

This cleaning was carried out by species. On average per species, 0.7% (0.69 - 0.73%) of the data were removed per relationship. The **Table 1** resumes the data set for the following study.

1.3 Statistical modeling

Models

The allometric relationships are commonly modeled using a power function (Eq1), log transformed in its linear form (Eq2) to simplify the modeling approach (Keys, 1928; Le Cren, 1951; Pélabon *et al*., 2014).

$$W = aL^b \qquad \text{Equation (1)}$$

Where, W is the whole-body wet weight (kg), L is the fish length (here Fork length, cm), a and b the parameters.

$$\log(W) = \log(a) + b\log(L) \qquad \text{Equation (2)}$$

Following the recommendations of Froese *et al.* (2011) and Pélabon *et al*. (2014), we aim to compare two linear models. The "simple model" is defined as the direct relationship between the response variable (W) without any other covariable than the length (L), whereas the full model included the sex of each individual, the 5° square id (CWP) as spatial predictors, fishing months and fishing year, as temporal predictors. All predictors were in interaction with the length considering that the allometry relationship can vary. No interaction between space and time was included.

Regarding the full model, predictor selection was performed using backward selection based on Akaike's information criterion (AIC). Two models with more than two values of AIC (ΔAIC) were considered significantly different (Anderson and Burnham, 2002). When ΔAIC between two models was inferior to two, the simplest model in terms of degrees of freedom was selected. The best-fit model was referred to as the "optimal model".

Size effect

We estimate the size effect of each predictor calculating the Coefficient of variation (CV) of their estimated marginal means (EMM) in a reference grid as described by Lenth *et al.* (2023). The reference grid consists of the set of all combinations of predictor levels (sex, 5° square id, month and year) and estimated marginal means were the prediction values from the model of interest (optimal model). We computed the EMM for quartile 25, 50 and 75% of the length distribution to estimate the size effect for small, medium and large fish. We calculated the coefficient of variation as the effect size of each predictor.

Such marginally averaged predictions are useful for describing the results of fitting a model, particularly in presenting the effects of factors. Indeed, the function of EMM is to average groups together with equal weights which give a balanced representation of the effect. EMM is also very useful for heading off Simpson's paradox situation in evaluating the effects of a factor.

Model comparison

We aimed to estimate the variation of the variable response according to the prediction of the simple model or the optimal model. To do so, we computed relative deviation (Rdev) of predictive values between these two models.

$$\text{Rdev} = \frac{\bar{X}_{optimal} - \bar{X}_{simple}}{X_{obs}} \quad \text{Equation (3)}$$

Where X_{obs} is the observed response variable value, $\bar{X}_{simple}$ is the predicted value of the simple model and $\bar{X}_{optimal}$ the predicted value of the optimal model.

The Rdev is a percentage of deviance relatively to the true value observed. We so computed the mean Rdev for small, medium and large fish dividing the size range in three categories of equal length to estimate the percentage of deviance all along the relationship.

We also checked for eventual bias in prediction of the simple model by representing the residual of the simple model against the predictors of the optimal model.

2. Results and discussion

Length weight relationship was significantly different among months and years whichever species (**Table 2**). However, the temporal variation observed does not follow a specific pattern. Spatial effect was also significant for all species but intercept only for the YFT. Thus, in some specific areas fish are heavier or lighter for a similar length but again without general gradient across the ocean. The question of zones with specifically highly nutritive richness or better condition for tuna is so raised but seems not to have a strong effect at the population level. Finally, sex was only significant for YFT.

The relative importance of predictors was confirmed by effect size looking at the coefficient of variation computed from EMM (**Table 3**). The sex had the smallest effect with only 1.2% of variation on average between male and female. Other predictors had similar effect sizes from 2% to 12% depending on the variable and species. Regarding species, the BET relationship was the most affected by predictors specifically on small individuals.

At the end, the different indicators demonstrated a very limited gain by the addition of predictors to the simple model. Indeed, R^2 only increased very lightly between the two models from 0.001 to 0.004 and were all above 0.98 with only the knowledge of the fork length (**Table 2**). Regarding the predictions of the two models, their relative differences were very small, 0.3% maximum on average for the larger fish (**Table 3**). For the small and medium size, the mean differences were almost negligible, almost always lower than 0.1% whichever the species.

At the end, the length-weight relationship can so be considered highly similar (**Table 4**). In comparison the current relationships used by the ICCAT were very different, raising the question of the reasons leading to this shift. Indeed, ICCAT relationship systematically underestimates the tuna weight compared to our results. This systematic shift could be explained by several hypotheses. The stock representativeness of the dataset can be biased if the fish measurement were performed in a limited area or during a short period of time. For instance, the authors noted a lack of data in several spatiotemporal strata in the analyses of BET allometry that explained the variation in the results (Parks *et al.,* 1982). We found that a spatio-temporality can affect the allometry relationship as it was found in several studies (Le Cren, 1951; Olim and Borges, 2006; Parks *et al*., 1982; Viana *et al*., 2016). However, these effects were very limited and do not fully explain the observed differences.

The second hypothesis is that the length-weight relationships of tunas have evolved in 60 years. Our data covered only the last two decades, whereas data used for ICCAT relationship covered the period 1957 – 1983 (Caverivière, 1976; Cayré and laloë, 1986; Parks *et al*., 1982) according to the species. With the increase of the ocean temperature, many studies have predicted an enrichment of the trophic system in favor of the tropical tunas (Cheung *et al.*, 2013; Erauskin-Extramiana *et al.*, 2019). The tuna could be heavier for a similar fork length compared to 4 or 5 decades ago because of the increase of the sea surface temperature which boosted ocean productivity. The fact that we did not find any pattern of such response during the last decade and so our result does not support this hypothesis, but it would be interesting to recover the historical dataset (if possible) to test this assumption over a longer period.

3. Conclusions

Considering the weak gain in prediction and the very limited bias by using a simple model compared to more complex model including many more predictors, the authors recommend the use of simple length-weight relation to convert length to weight for the purse seine tropical fisheries (**Table 5**).

The authors also recommend the identical approach for all other fisheries targeting tropical tuna with different gears or fishing ground for comparison and to avoid any bias in using these up-to-date relationships.

The authors finally recommend a regular review of the allometry relationship based on continuing and robust sampling to identify possible long-term changes.

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Table 1. Summary of the dataset use in LWR relationships per species. FL: Fork length (cm), W: Total weight.(kg).

effective	*min FL*	*max FL*	*min W*	*max W*	*min year*	*max year*
YFT						
5 127	36	173	0.96	111.4	2010	2022
SKJ						
2 745	30.3	71	0.5	9.2	2008	2022
BET						
1 054	39.3	172.6	1.3	117.25	2014	2022

Table 2. Model result.

model	*formula*	*df*	*AIC*	*R²*
YFT				
Simple	log.W ~ log.FL	6338	-18861,9	0,996
Optimal	log.W ~ CWP + log.FL * Sex + log.FL * FishingMonth + log.FL* FishingYear	6268	-17434,0	0,997
SKJ				
Simple	log.W ~ log.FL	2743	-7442,5	0,983
Optimal	log.W ~ FishingYear + log.FL * CWP + log.FL* FishingMonth	2665	-6830,1	0,987
BET				
Simple	log.W ~ log.FL	1052	-3153,7	0,997
Optimal	log.W ~ log.FL * CWP + log.FL * FishingMonth + log.FL * FishingYear	982	-2947,4	0,998

Table 3. Effect size (CV) of covariables computed from Estimated marginal mean for 3 Fork length values (quantile 25, 50 75%) per species.

FL	*min W*	*max W*	*μ W*	*SD*	*CV*	*covariable*
YFT						
106.7	24.8	25.1	24.9	0.21	0.008	sex
128.8	43	43.7	43.3	0.52	0.012	
142.9	58.2	59.4	58.8	0.83	0.014	
106.7	24.2	25.7	24.9	0.46	0.018	month
128.8	42.4	44.9	43.3	0.74	0.017	
142.9	57.1	61.4	58.8	1.11	0.019	
106.7	23.9	26.3	24.9	0.63	0.025	year
128.8	41.1	44.9	43.3	1.08	0.025	
142.9	55.4	60.2	58.8	1.72	0.029	
106.7	22.9	28.5	24.9	0.92	0.037	cwp5
128.8	40.2	46.4	43.3	1.09	0.025	
142.9	54.9	61.3	58.8	1.35	0.023	
SKJ						
42	1.4	1.6	1.5	0.053	0.034	month
46	1.9	2.2	2.1	0.082	0.040	
51	2.6	3.1	2.9	0.14	0.047	
42	1.4	1.7	1.5	0.09	0.060	year
46	1.9	2.3	2.1	0.12	0.060	
51	2.7	3.2	2.9	0.17	0.060	
42	1.4	1.7	1.5	0.058	0.038	cwp5
46	1.9	2.3	2.1	0.075	0.036	
51	2.7	3.2	2.9	0.12	0.040	
BET						
63.3	5.1	6.2	5.8	0.30	0.053	month
81.5	10.8	13.2	12.3	0.65	0.053	
114.2	29.2	35.7	33.3	1.76	0.053	
63.3	5.1	6.9	5.8	0.59	0.101	year
81.5	11.1	13.7	12.3	0.82	0.066	
114.2	31.8	34.4	33.3	0.86	0.026	
63.3	4	7.1	5.8	0.70	0.120	cwp5
81.5	9.5	14.3	12.3	1.11	0.09	
114.2	29.3	37.6	33.3	1.89	0.057	

Table 4. Mean and standard error of the relative error in weight between the simple and the optimal model by size categories and species. Min FL and Max FL represent the minimum and maximum fork length of each size category (size class).

size class	*min FL*	*max FL*	*Rdev*	*se*
YFT				
small	36	81.6	0,00055	1,71E-06
medium	81.7	127.3	-0,0034	2,59E-06
large	127.4	173	0,0031	4,20E-06
SKJ				
small	30.3	43.8	0,00019	1,23E-06
medium	43.9	57.4	-0,00034	1,12E-06
large	57.5	71	0,0014	1,02E-05
BET				
small	39.3	83.7	-0,00037	5,13E-06
medium	83.9	127.9	0,00015	3,09E-05
large	128.5	172.6	0,0017	7,42E-05

Table 5. Parameters a and b of the length weight relationship estimated from the simple model. Min FL and Max FL represent the minimum and maximum fork length.

effective	*min FL*	*max FL*	*intercept*	*intercept IC*	*slope*	*slope IC*	*adj R²*
YFT							
5123	36	173	2.016e-05	[1.97e-05 ; 2.06e-05]	3.004	[2.999 ; 3.009]	0.996
SKJ							
2745	30.3	71	5.517e-06	[5.18e-06 ; 5.88e-06]	3.352	[3.335 ; 3.368]	0.983
BET							
1054	39.3	172.6	2.210e-05	[2.12e-05 ; 2.31e-05]	3.007	[2.997 ; 3.016]	0.997

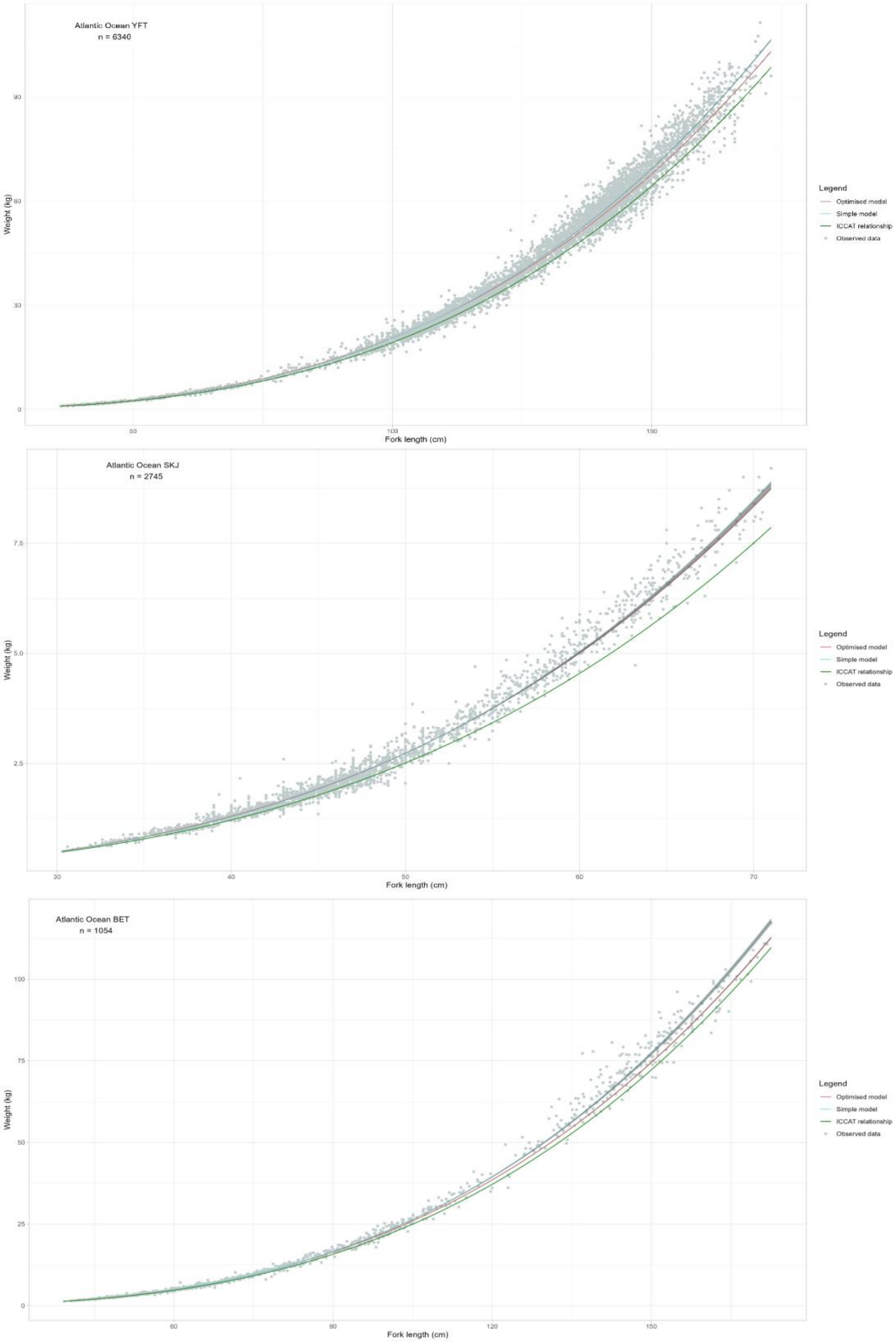

Figure 1. Length weight relationship of the three major tuna, YFT, SKJ and BET respectively. Grey dots are the observed data, the blue line is the simple model estimates and the red one the optimized one. The green line is the length weight relationship currently used by ICCAT.

Appendix 1

As the data cannot always be linked to a specific set, several positions of the trip can be associated to a fish. To determine the appropriate scale for this study, we calculate the centroid of the group of positions for each fish. Then the distance was calculated between the centroid and each position. **Figure I** illustrates the distribution for the three species of the study. Being close to the equator, one degree of latitude is equivalent to about 111 km. That is why the authors decide to use the 5° square scale to study the spatial effect of the model.

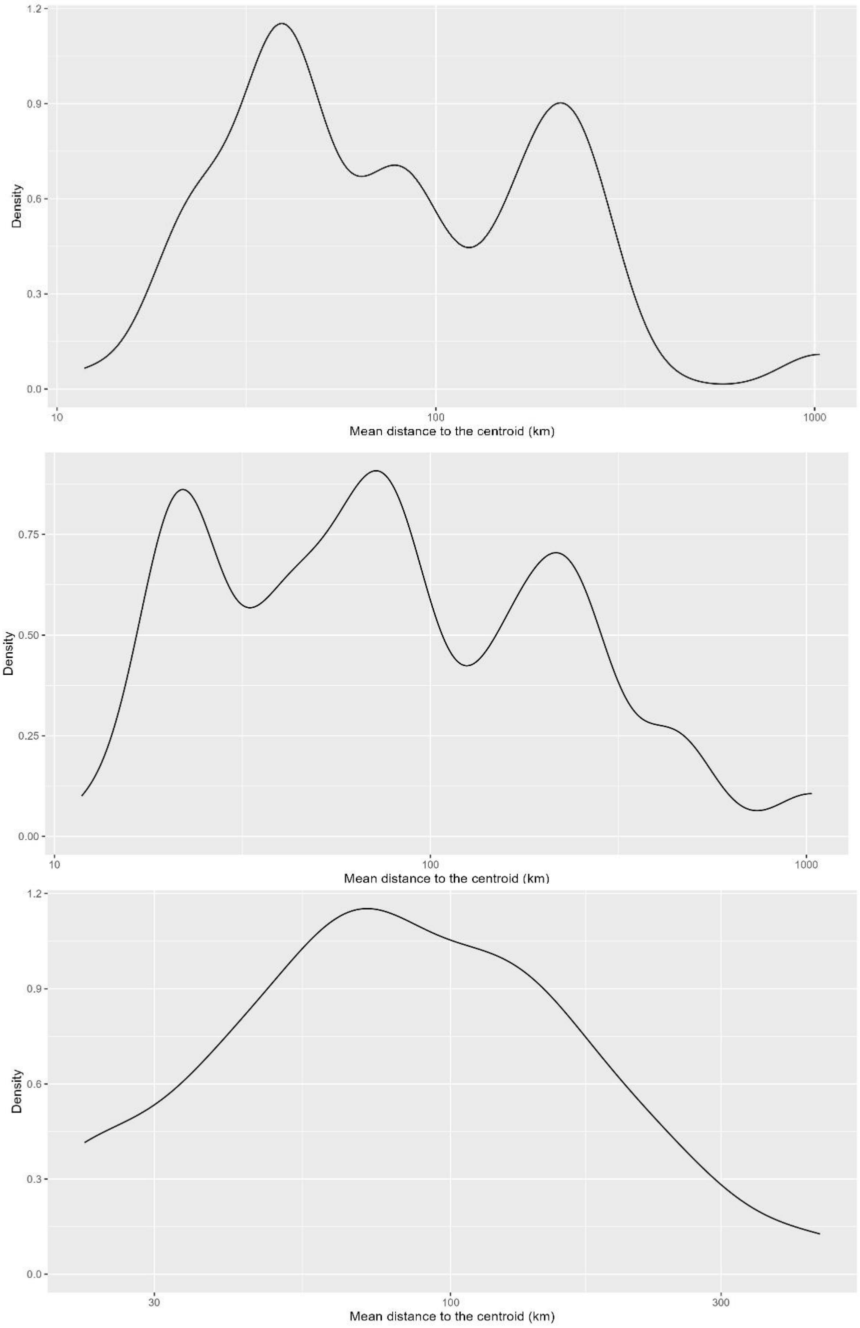

Figure I. Distribution of the distance to the centroid. From top to bottom : YFT, SKJ and BET.