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# LIFE HISTORY TRAITS OF THE SKIPJACK TUNA IN THE SOUTHWEST ATLANTIC

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## *SUMMARY*

*We investigated skipjack tuna (SKJ) population parameters in the southwestern Atlantic Ocean (SWA), off the Brazilian coast. Between January 2017 and August 2018, samples from pole and line commercial catch landings were taken at the ports of Rio Grande and Niterói. In each occasion, 100 to 300 individuals were randomly sampled for fork-length measurement. For each sample, a subsample of 15 to 30 individuals was randomly drawn to evaluate the size-structure of the catches, patterns of reproductive dynamics, and feeding ecology. Our results show that a single SKJ stock uses shelf break and slope waters off the Brazilian coast. This unique stock unit in the SWA has bioecological peculiarities that corroborate behavioral patterns described in the literature for the region, but share similarities with studies from other oceanic areas, influenced by different environmental conditions and fishing effort. Such results provide updated information on the SKJ population attributes in the SWA and allow integrated analyzes in different current and historical perspectives, supporting management measures aimed at the sustainability of the SKJ stocks.*

## *RÉSUMÉ*

*Nous avons étudié les paramètres de population du listao (SKJ) dans le Sud-Ouest de l'océan Atlantique (SWA), au large de la côte brésilienne. Entre janvier 2017 et août 2018, des échantillons provenant de débarquements de captures commerciales réalisées à la canne et au moulinet été prélevés dans les ports de Rio Grande et de Niterói. À chaque occasion, 100 à 300 spécimens ont été échantillonnés au hasard pour mesurer la longueur à la fourche. Pour chaque échantillon, un sous-échantillon de 15 à 30 spécimens a été tiré au sort pour évaluer la structure de taille des captures, les modèles de dynamique de reproduction et l'écologie alimentaire. Nos résultats montrent qu'un seul stock de SKJ utilise les eaux du plateau et du talus au large des côtes brésiliennes. Cette unité de stock unique dans la SWA présente des particularités bioécologiques qui corroborent les schémas comportementaux décrits dans la littérature pour la région, mais partagent des similitudes avec les études d'autres zones océaniques, influencées par des conditions environnementales et un effort de pêche différents. Ces résultats fournissent des informations actualisées sur les attributs de la population de SKJ dans la SWA et permettent des analyses intégrées dans différentes perspectives actuelles et historiques, soutenant les mesures de gestion visant à la durabilité des stocks de SKJ.*

## *RESUMEN*

*Investigamos los parámetros de población del listado (SKJ) en el suroeste del océano Atlántico (SWA), en aguas frente a la costa brasileña. Entre enero de 2017 y agosto de 2018, se tomaron muestras de desembarques de capturas comerciales con caña y línea en los puertos de Río Grande y Niterói. En cada ocasión, se tomaron muestras aleatorias de 100 a 300 individuos para medir la longitud de la horquilla. Para cada muestra, se extrajo al azar una submuestra de 15 a 30 individuos para evaluar la estructura de la talla de las capturas, los patrones de la dinámica reproductiva y la ecología de la alimentación. Nuestros resultados muestran que un único stock de listado utiliza las aguas de la plataforma y del talud continental de la costa brasileña. Esta*

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*unidad de stock única en el SWA tiene peculiaridades bioecológicas que corroboran los patrones de comportamiento descritos en la bibliografía para la región, pero comparten similitudes con estudios de otras áreas oceánicas, influenciadas por diferentes condiciones ambientales y esfuerzo pesquero. Estos resultados proporcionan información actualizada sobre los atributos de la población de listado en el SWA y permiten realizar análisis integrados en diferentes perspectivas actuales e históricas, apoyando las medidas de ordenación dirigidas a la sostenibilidad de las poblaciones de listado.*

*KEYWORDS*

*Size structure, Growth, Reproduction, Pole and line, Feeding ecology*

## 1. Introduction

Skipjack tuna (*Katsuwonus pelamis*, SKJ) is a cosmopolitan migratory pelagic species with worldwide distribution in tropical and subtropical waters. The species is carnivorous, feeding on a variety of prey, including zooplankton, pelagic fish and cephalopods (Castello 2000). It shows an opportunistic spawning behavior with synchronized spawning (Castello 2000; Andrade 2006) and a reproductive period occurring between the austral spring and summer seasons, with a peak in January off the southeastern Brazilian coast (Soares *et al.* 2019).

The skipjack tuna is among the top five marine resources captured in the world. The species ranked in third place for nine consecutive years, with landings around 3.2 million tons (FAO 2020). In the southwestern Atlantic Ocean (SWA), the species sustains a pole and line fishery of high social and economic relevance for fishers, producers, and the tuna canning industry in Brazil. Catches averaged 23,566 t/year from 2000 to 2018, reaching a peak of 32,438 t in 2013 followed by a 56% decrease to 18,133 t two years later (ICCAT 2019), as a consequence of extreme sea surface temperature heating anomalies in the SWA (Coletto *et al.* 2021).

We investigated SKJ population parameters in the SWA, off the Brazilian coast, evaluating the size-structure of the catches, patterns of reproductive dynamics, and feeding ecology between January 2017 and August 2018. Our results provide updated information on the SKJ population attributes in the southwestern Atlantic that may be used for productivity assessments and management of the stock.

## 2. Materials and Methods

Catches of the skipjack tuna by pole and line in the SWA are distributed roughly between 20° S and 35° S, mostly at the edge of the continental shelf and upper slope areas. The area is characterized in two portions of the continental shelf, based on geomorphological characteristics (Rossi-Wongtschowski and Madureira 2006). The Southern Continental Shelf (SCS), is located between Cabo de Santa Marta Grande (28°36'S and 48°48'W) and the Brazil-Uruguay ocean border (34°44’S and 53°22’W), and is characterized by the width of the continental shelf, reaching as far as 170 km at its southern limit, with a relatively uniform topography. The Southeast Continental Shelf, extends from Cabo de São Tomé (22°02'S and 041°03'W) to Cabo de Santa Marta Grande. Width of the continental shelf is quite variable, with narrowest stretches occurring near Cabo Frio (~50 km) and Cabo de Santa Marta Grande (~70 km), but reaching around 230 km at midpoint off the city of Santos. The whole region is seasonally influenced by the convergence between warm waters of the Brazil Current and cold nutrient-rich waters of the Malvinas Current, and regional upwelling events (Madureira *et al.* 2020). Three industrial pole and line live-bait fleets, based in the fishing ports of Rio Grande (RS), Itajai (SC) and Niterói (RJ), respectively, operate in the area.

Between January 2017 and August 2018, 66 random samples from commercial catch landings were taken at the ports of Rio Grande (southern sampling, S) and Niterói (southeastern sampling, SE), following a weekly, bi-weekly and/or monthly frequency for biological data collection. In each occasion, 100 to 300 individuals were randomly selected and sampled for fork-length (FL) measurement, following the ICCAT standards (ICCAT 2016).

For each sample, a subsample of 15 to 30 individuals was randomly drawn to obtain the following additional biological information: total weight (g), gutted weight (g), eviscerated weight (g), weight of gonads (g), weight of liver (g), sex (male, female and undetermined), identification of the gonadal maturity stage, removal of the first spine of the first dorsal fin and the *sagittae* otoliths.

Size data (FL) were separated by sampling region (S, SE) and by the austral seasons as follows: summer (January-March), autumn (April-June), winter (July-September) and spring (October-December). Fork length frequency distributions were arranged into one centimeter length classes to observe modal shifts.

The weight-fork length relationship was estimated separately for each region (S, SE) and for the grouped data (SWA), and expressed as $W = a.FL^b$, where: W is the weight, FL is the fork length, a and b correspond to parameters related to the type of fish growth. For each b, the Student's t-test was applied to test the hypothesis that the calculated value was equal to 3.0 (Zar 1984).

Fork length growth curves were estimated for the grouped data (both sexes) for each region, using monthly size frequency distributions grouped into two-cm classes. Sections of the hard spines of the 1st dorsal fin were observed under transmitted light and interpreted. Opaque zones (active growth) and translucent (slow growth) bands in 497 individuals from the southern region were counted from the spine center to the outer edge. The von Bertalanffy ($L_\infty$, k and $t_0$) were estimated using three approaches: a) Minimum residual variance method using the MINIVAR routine (Gonçalves and Fontoura 1999; Bervian and Fontoura 2007); b) applying routines available in the FISAT program (Gulland and Holt, Appeldorn and minimum variance routines) (Gayanilo Jr. 2005), using the identified FL size distributions patterns; c) using the ages determined in the spine readings to adjust the parameters of the growth model in such a way as to minimize the squares of the differences between the observed and estimated values (SOLVER routine of the Excel program).

Total mortality (Z) was estimated from the linearized catch curve, using the length structure from sampling sites transformed into an age structure. The survival rate (S) was calculated through $S = e^{-Z}$ or $S = 100*e^{-Z}$.

The reproductive cycle was described through the calculation of three condition indices to identify spawning patterns: a) gonadosomatic index: $GSI = (G_M/E_M)*100$; b) hepatosomatic index: $HSI = (L_M/E_M)*100$; c) Allometric condition factor K (LeCren 1951): $\Delta K = K-K'$ where $K=W/FL^{\boldsymbol{b}}$; $K'= E_M/FL^{\boldsymbol{b}}$; $\boldsymbol{b}=3$, and $G_M$, $L_M$, $E_M$, are the gonad, liver, and eviscerated weights, respectively. All of these indices were calculated for each individual, and then averaged per month and region (S, SE) with 95% confidence intervals estimated.

The length at first maturity ($L_{50}$) was estimated for grouped sexes through the curve relating the relative frequency of adults to the midpoint of the length classes, adjusted by equation: $Fr = 1 - (e^{-aFL^b})$, where (Fr) is the relative frequency of adult individuals, (e) is the base of the neperian logarithm, *a* and *b* are the coefficients estimated by the least squares method applied in the linear relationship obtained by the transformation of the variables involved and (FL) mean point of the fork length classes (Moresco and Bemvenuti 2006).

Stomach contents were removed and kept frozen or fixed in formalin (10%) until further processing in the laboratory (S: n = 391; SE: n = 340). Food items were sorted and identified to the lowest taxon possible. For each individual stomach, prey items from each category were weighed (g) and counted. The degrees of digestion were determined following Vaske *et al.* (2004). Bait species (i.e., *Sardinella brasiliensis*, *Engraulis anchoita*) classified in initial stages of digestion (i.e., non-digested, starting digestion) were removed from analysis, assuming they were ingested during fishing activities.

To evaluate the importance of prey items we used the Prey-Specific Index of Relative Importance (%PSIRI), calculated as:

$$\%PSIRI_i = \frac{\%FO_i \times (\%PN_i + \%PW_i)}{2}$$

Where: $\%FO_i$ is the frequency of occurrence of prey *i*, calculated as the number of stomachs containing prey *i* divided by the total number of stomachs; $\%PN_i$ and $\%PW_i$ are the prey-specific abundances, calculated as the sum of proportions by number and weight, of prey *i* divided by the number of stomachs in which prey *i* occurred (Brown *et al.* 2012).

## 3. Results and Discussion

Between January 2017 and August 2018, 46 landings of SKJ were sampled for fork length and weight at Rio Grande (S), and 20 at Rio de Janeiro (SE), totaling 1,031 specimens (S = 465, SE = 566**)**. Fork length distribution for the entire period in the southern region showed individuals represented in FL size classes ranging from 37 to 70 cm, with a predominant mode in the 49 cm FL class and a secondary one at the 56 cm FL class. In the southeast, SKJ ranged in size between 38 and 83 cm FL with a polymodal frequency distribution for the entire period, with at least two well-defined modes occurring at the 42 cm and 48-49 cm size classes (**Figure 1, a and b**). Seasonally, the highest frequencies occurred in the summer for length classes between 46 and 52 cm FL in the southern region. The largest individuals occurred in the autumn and the smallest in the spring, suggesting a modal progression across the summer (**Figure 2.a**). In the southeastern region, polymodal distributions occurred in all seasons. Larger individuals were well represented in the autumn, but also occurred in summer and spring. Smallest size classes (<41 cm FL) did not occur in winter (**Figure 2.b**).Winter landings were not monitored in the southern, and occurred sporadically in the southeastern regions, with very few individuals measured. Both fleets usually stop in the period, due to the closure of the Brazilian sardine (*Sardinella brasiliensis*) fishery, which is the predominant bait used by the pole and line.

The following weight-length relationships were determined for SKJ. SWA: $W = 0.004FL^{3.4217}$, $R^2 = 0.9461$. S: $W = 0.0128FL^{3.1363}$, $R^2 = 0.9039$. SE: $W = 0.0028FL^{3.5075}$, $R^2 = 0.9642$ (**Figure 3**). These relationships suggest that the SKJ gains more weight in relation to its growth in length. Such a pattern has been observed over the past three decades in this area of the Southwest Atlantic.

Best statistical results (minimal residual variation) for growth estimates were obtained from the age “seed” values of the individuals in the first sample/cohort, i.e., based on the average fork lengths of individuals caught in the summer (S and SE: 2.34 years; SWA: 2.42 years) (**Table 1**). This parameter works as a “biological anchor”, whose hypothetical starting date is the time interval between the known reproductive peak (summer/autumn) (Soares *et al.* 2019) and the first sample. Thus, growth curve parameters were estimated from the modal progression of the first age group identified in the summer samples and followed for an entire year.

The growth curves with minimal residual variation are expressed in the following mathematical terms: S: $FL = 75.6*(1^{-e-0.37(t)})$; SE: $FL = 87.5*(1^{-e-0.29(t)})$ and SWA: $FL = 91.8*(1^{-e-0.24(t)})$ (**Figure 4**). The catch curves for S, SE and SWA were represented based on the age compositions in the corresponding catches (**Figure 5**). Mortality rates (Z, M and F), catch (E) and estimated survival rate (S) were: a) southern: Z = 1.62, M = 0.58, F = 1.04, E = 0.64 and S = 19.8%; b) southeastern: Z = 0.96; M = 0.45; F = 0.51; E = 0.53 and S = 38.3%; c) Southwest Atlantic: Z = 1.17; M = 0.37, F = 0.80; E = 0.68 and S = 31.0%.

The skipjack is an opportunistic spawner, allowing for a given year class the presence of several size cohorts which influence vB parameter estimations. At the same time, prevailing oceanographic conditions in each year may influence feeding and growth. As shown in **Table 1**, there is a considerable variation in the estimates of the vB growth parameters. Direct estimates derived from hard part readings (growth rings from spines of the first dorsal fin) obtained during this study and presented in a separate contribution, derived additional values of SKJ growth in the southeastern range of the project, where most of the size classes were represented (see **Figure 1**). While indirect stock assessment tools are an established and straight forward method for tropical and sub-tropical stocks (Panhwar and Liu 2013), parameter estimates based on size structure may be influenced by the presence (or absence) of larger individuals in the samples. Under these circumstances, it is important to incorporate an uncertainty component into growth models, since they describe the average growth trajectory, which may be affected by growth variability among individuals, and biased sampling.

Comparing the estimated values for M and F of both regions, it is possible to conclude that fishing was the most important mortality factor (F > M) for the Southwest Atlantic stock. All estimated catch rates (E) were compared with the reference value of 0.5, remembering that E > 0.5 may indicate overexploitation. For the southeastern region, E is close to the sustainable limit, showing different capture strategies between the regions that make up the Southwest Atlantic. Additionally, the survival rate is higher rate in the SE region (38.3%) relative to the S region (19.8%). If only natural mortality were to work in these regions, the southern survival rate would be 56.0% and in the southeastern 63.8%. Even so, we observe a reduction in the survival rate due to fishing in the southern when compared with the southeastern regions. Furthermore, the assessment for the Southwest Atlantic also corroborates an inverse relationship between capture and survival rates.

Skipjack tuna is an opportunistic spawner, presenting a synchronized spawning behavior when in schools. The small variation of GSI observed in the southern region throughout the year (n = 394; average = 0.6 ± 0.5) contrasts with the large variations recorded in the southeast (n = 424; average = 1.0 ± 1.1; between 0.95 and 0.04), suggesting the formation of reproductive aggregations off this region during the summer, as previously noted by Soares *et al.* (2019). Previous studies on the reproduction of SKJ off the south-southeastern Brazilian coast (Cayré and Farrugio 1986; Goldberg and Au 1986), also indicated a reproductive period from December to March, with a spawning peak between January and February. The highest condition factor (ΔK) values in the southern region (**Figure 6**), across all seasons, suggests that the southern area is used for feeding and growth area, where maturing females gain body mass before the northward migration to the spawning grounds. Monthly differences in the Hepatosomatic Index (HSI), on average almost three times higher in the southeast, corroborates a temporal pattern of feeding area in the southern area, and a reproductive area in the southeastern region (**Figure 6**). SKJ eggs and larvae analysis show greater densities near the Abrolhos archipelago (Matsuura 1986; Katsuragawa *et al.* 2020). On the other hand, the limited occurrence of larvae and juveniles in the southern-southeastern regions, agree with the northward reproductive migration hypothesis (Jablonski *et al.* 1984).

The average fork length at first maturity ($L_{50}$) for males and females (grouped sexes) was estimated at 45.5 cm (confidence interval of 44.8 and 45.9 cm) (**Figure 7**). There were no significant differences between sexes (45.4 for males and 45.5 for females) and regions (S, SE). These values are below the values estimated in the 1980s by Vilela and Castello (1993), and close to those estimated by Soares *et al.* (2019) for the southeastern region in previous years (2014 to 2016).

Prey identified from SKJ stomach contents were separated into three taxonomic groups: Crustacea, Mollusca, and Teleostei (**Table 2**). A graphical analysis from skipjack diet, by region, off the southwestern Atlantic is shown in **Figure 8**. In the southeastern region, Unidentified fish was the most important prey type (%FO = 32; %PSIRI = 26), followed by *Sardinella brasiliensis* (%FO = 20; %PSIRI = 16), and Clupeidae (%FO = 18; %PSIRI = 14). In the southern region, *Euphausia similis* was the main prey found in skipjack stomachs (%FO = 42; %PSIRI = 40). Within Teleostei group, Unidentified fish was the most important category (%FO = 27; %PSIRI = 17), followed by *Engraulis anchoita* (%FO = 15; %PSIRI = 8), and lanternfish (*Maurolicus stehmanni*) (%FO = 5; %PSIRI = 2).

Continuous and systematic fisheries monitoring programs allow the scientific community to estimate life history parameters that may be used by managers for stock assessment of fishery resources. This contribution represents an effort to provide up to date estimates of SKJ life history parameters captured by the pole and line fleet in the SWA, including size structure, growth, reproductive dynamics and feeding ecology.

A unimodal pattern of recurrent size since the 1980s still persists along the Southwest Atlantic, with individuals between 50 and 56 cm FL. Sizes frequencies were similar between regions, but decreasing trend towards the southern region was noted, which may indicate the arrival of recruits to the stock. These fish are pre-adults under the size of first maturity ($L_{50}$ = 45.4 cm). Although there are records of individuals with sizes smaller than $L_{50}$ in the southern region, metabolic (HSI) and physiological ($\Delta K$) evidences suggest that the southern region is used as nursing ground in which fish feed and accumulate energy from dense patches of krill and forage fish during austral summer.

Growth parameters are strongly influenced by the environmental characteristics. SKJ gains more body weight in the southern region. As they move northward to the southeastern region, they continue to gain weight, following productive patches and gyres along the shelf break and slope, culminating in the summer reproductive period with a January peak. As for the growth parameters arising from the integrated analysis of each individual, different behaviors were observed between the regions. This is naturally expected due to the environmental characteristics of each region. It should also be noted that the development of marked thermal fronts in the Brazilian Current reaching its southernmost limit may trigger vital stimuli for the northward reproductive migration, maintaining the stock susceptible to commercial exploitation. Evidences from reproductive indexes, size and weight of individuals, corroborated these reproductive patterns. In fact, most individuals captured in the southeastern region, were in reproductive conditions, indicating that the reproductions occurs in the lower latitudes of the SWA, where SKJ eggs and larvae were recorded in higher densities (Katsuragawa *et al.* 2020). The relationship between the seasonality of the movements of the Brazilian Current and the migration patterns of the species shows the use of the area in order to maintain the stock over time. Another aspect that corroborates this hypothesis is the integration of the condition factor and hepatosomatic indexes that indicated high levels of individual well-being, as well as the transfer of reserve energy (liver) shortly before and/or concurrently with reproductive activities, in order to guarantee this vital process.

The population growth parameters obtained ($k_{vB}$, $L_\infty$ and longevity) from the captured individuals follow a pattern of values similar to those of the last decades for the Southwest Atlantic, with latitudinal distinctions determined by natural conditions (temperate, intertropical and tropical zones), as well as through fishing. Estimates on the population status of the stock available for fishing generated from these parameters (mortality, survival and capture rates) are primary information for supporting stock management strategies. Our results indicate that fishing is more intense in the southern, compared to the southeastern ranges. However, the stock still seems to be in an exploration phase below the limit of 50% of maximum sustainable catches. These estimates also bring the scientific community attention to the need for continuous and systematic programs for monitoring fish landings/catches, in order to develop a fully sustainable production chain on this fishing resource.

There is only a single stock unit that uses three geographic regions of the Brazilian coast (S, SE and NE). In this area of the SWA, patterns of habitat use (regions) associated with environmental conditions can be observed, such as the Brazilian Current and the primary productivity vortices that are formed in different seasons of the year, at specific latitudes of the coast (Madureira *et al*. 2020). Therefore, this unique stock unit in the SWA has bioecological peculiarities that corroborate behavioral patterns described in the literature for the region, but share similarities with studies from other oceanic areas, influenced by different environmental conditions and fishing effort.

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**Table 1**. Growth parameters estimated by different methods. $L_\infty$ = asymptotic fork length; CV = coefficient of variation; k = instantaneous growth rate; $R^2$ = coefficient of determination; Rn = adjustment index; MQ = least squares method and Vm = minimum residual variance. S = Southern; SE = Southeastern, SWA = Southwestern Atlantic Ocean.

| Routines | Method | $L_\infty$ | CV-$L_\infty$ | $K_{vB}$ | CV-$K_{vB}$ | $t_0$ | $R^2$/Rn/MQ/Vm | Phi |
|---|---|---|---|---|---|---|---|---|
| FISAT (FL pattern analysis)* | Gulland and Holt | 90.00 | | 0.32 | | | | 3.42 |
| | Appeldorn | 106.72 | 0.32 | 0.19 | 0.64 | | 0.86 | 3.34 |
| | Automatic Search 1 | 86.35 | | 0.30 | | | 0.18 | 3.35 |
| | Automatic Search 2** | 87.15 | | 0.20 | | | 0.10 | 3.18 |
| SOLVER (Spines) * | n = 497 | 106.49 | | 0.09 | | -5.10 | 24062 | 3.01 |
| MINIVAR | S | 75.60 | | 0.37 | | -0.34 | 0.09 | 3.33 |
| | SE | 87.50 | | 0.28 | | -0.46 | 0.67 | 3.33 |
| | SWA | 91.80 | | 0.24 | | -0.54 | 0.67 | 3.31 |

* Estimates calculated from data obtained in the southern sampling.

** In this automatic calculation routine, $L_\infty$ was initially estimated as a "seed" based on the Taylor relationship (Taylor 1958), where $L_\infty = FL_{max}/0.95$.

**Table 2**. Diet composition of SKJ by percent frequency of occurrence (%FO), percent prey-specific weight (%PW), percent prey-specific number (%PN) and prey specific index of relative importance (%PSIRI)

| *Group* | *Order* | *Family* | *Species* | *Southeastern* | | | | *Southern* | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | *%FO* | *%PNi* | *%PWi* | *%PSIRI* | *%FO* | *%PNi* | *PWi* | *%PSIRI* |
| Crustacea | | | | 7 | 80 | 62 | 5 | 43 | 98 | 89 | 40 |
| | Decapoda | | Unidentified | 3 | 68 | 35 | 2 | 1 | 34 | 8 | 0 |
| | | | Unidentified Crab | 2 | 73 | 35 | 1 | 0 | 0 | 0 | 0 |
| | | | Dendrobranchiata Unid. | 1 | 43 | 26 | 0 | 0 | 0 | 0 | 0 |
| | | | Decapoda NI | 0 | 0 | 0 | 0 | 1 | 34 | 8 | 0 |
| | Euphausiacea | Euphausiidae | *Euphausia similis* | 3 | 100 | 100 | 3 | 42 | 99 | 90 | 40 |
| | Isopoda | | Isopoda Unid. | 1 | 100 | 100 | 1 | 0 | 0 | 0 | 0 |
| | | | Crustacea Unid. | 0 | 25 | 2 | 0 | 0 | 0 | 0 | 0 |
| Mollusca | | | | 10 | 73 | 40 | 6 | 5 | 34 | 37 | 2 |
| | Octopoda | | | 1 | 100 | 100 | 1 | 2 | 0 | 17 | 0 |
| | | Argonautidae | *Argonauta nodosa* | 1 | 100 | 100 | 1 | 1 | 0 | 20 | 0 |
| | | | Octopoda Unid. | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 |
| | Oegopsida | | | 3 | 67 | 57 | 2 | 3 | 53 | 53 | 2 |
| | | Ommastrephidae | | 3 | 67 | 57 | 2 | 3 | 53 | 53 | 2 |
| | | | *Illex argentinus* | 0 | 0 | 0 | 0 | 1 | 33 | 28 | 0 |
| | | | *Ornithoteuthis antillarum* | 0 | 0 | 0 | 0 | 1 | 68 | 85 | 1 |
| | | | Ommastrephidae Unid. | 3 | 67 | 57 | 2 | 2 | 52 | 46 | 1 |
| | Thecosomata | | | 6 | 69 | 27 | 3 | 0 | 0 | 0 | 0 |
| | | Cavoliniidae | | 6 | 69 | 27 | 3 | 0 | 0 | 2 | 0 |
| | | | *Diacavolinia atlantica* | 0 | 27 | 11 | 0 | 0 | 0 | 0 | 0 |
| | | | *Diacavolinia bicornis* | 0 | 3 | 3 | 0 | 0 | 0 | 0 | 0 |
| | | | *Diacavolinia elegans* | 0 | 43 | 17 | 0 | 0 | 0 | 0 | 0 |
| | | | Diacavolinia sp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | | *Cavolinia uncinata* | 0 | 3 | 3 | 0 | 0 | 0 | 0 | 0 |
| | | | Cavoliniidae Unid. | 6 | 64 | 26 | 3 | 0 | 0 | 2 | 0 |
| | | | Gastropoda | 0 | 14 | 2 | 0 | 0 | 0 | 0 | 0 |

**Table 2** (continued).

| *Group* | *Order* | *Family* | *Species* | *Southeastern* | | | | *Southern* | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | *%FO* | *%PNi* | *%PWi* | *%PSIRI* | *%FO* | *%PNi* | *PWi* | *%PSIRI* |
| Teleostei | | | | 65 | 92 | 98 | 62 | 45 | 60 | 67 | 29 |
| | Clupeiformes | | | 36 | 83 | 92 | 31 | 17 | 52 | 60 | 9 |
| | | Clupeidae | | 35 | 80 | 91 | 30 | 3 | 40 | 53 | 1 |
| | | | Clupeidae Unid. | 18 | 69 | 82 | 14 | 0 | 0 | 0 | 0 |
| | | | *Harengula clupeola* | 1 | 48 | 57 | 0 | 0 | 0 | 0 | 0 |
| | | | *Sardinella brasiliensis* | 20 | 75 | 81 | 16 | 3 | 40 | 53 | 1 |
| | | Engraulidae | | 3 | 67 | 51 | 2 | 15 | 52 | 59 | 8 |
| | | | Engraulidae Unid. | 1 | 61 | 39 | 1 | 0 | 0 | 0 | 0 |
| | | | *Engraulis anchoita* | 1 | 72 | 63 | 1 | 15 | 52 | 59 | 8 |
| | Perciformes | | | 3 | 22 | 46 | 1 | 0 | 4 | 4 | 0 |
| | | Carangidae | | 3 | 22 | 46 | 1 | 0 | 4 | 4 | 0 |
| | | | Carangidae Unid. | 1 | 28 | 60 | 1 | 0 | 0 | 0 | 0 |
| | | | *Selar crumenophthalmus* | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | | *Trachurus lathami* | 0 | 0 | 0 | 0 | 0 | 4 | 4 | 0 |
| | Scorpaeniformes | Dactylopteridae | *Dactylopterus volitans* | 4 | 70 | 52 | 2 | 1 | 46 | 50 | 0 |
| | Stomiiformes | Sternoptychidae | *Maurolicus stehmanni* | 1 | 52 | 49 | 0 | 5 | 47 | 54 | 2 |
| | Tetraodontiformes | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | | Fish larvae | 1 | 20 | 14 | 0 | 0 | 0 | 0 | 0 |
| | | | Unidentified fish | 32 | 80 | 83 | 26 | 27 | 60 | 65 | 17 |

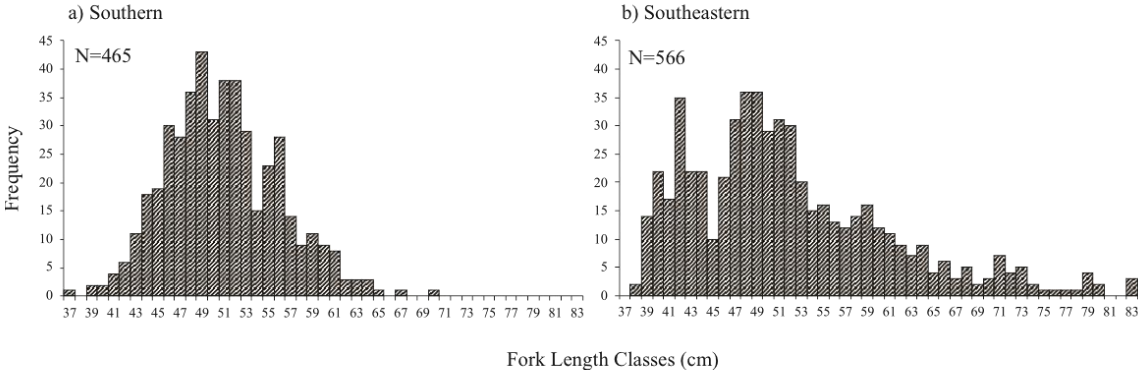

**Figure 1**. Fork length frequency distributions (FL, cm) of SKJ between January 2017 and August 2018, by geographical region.

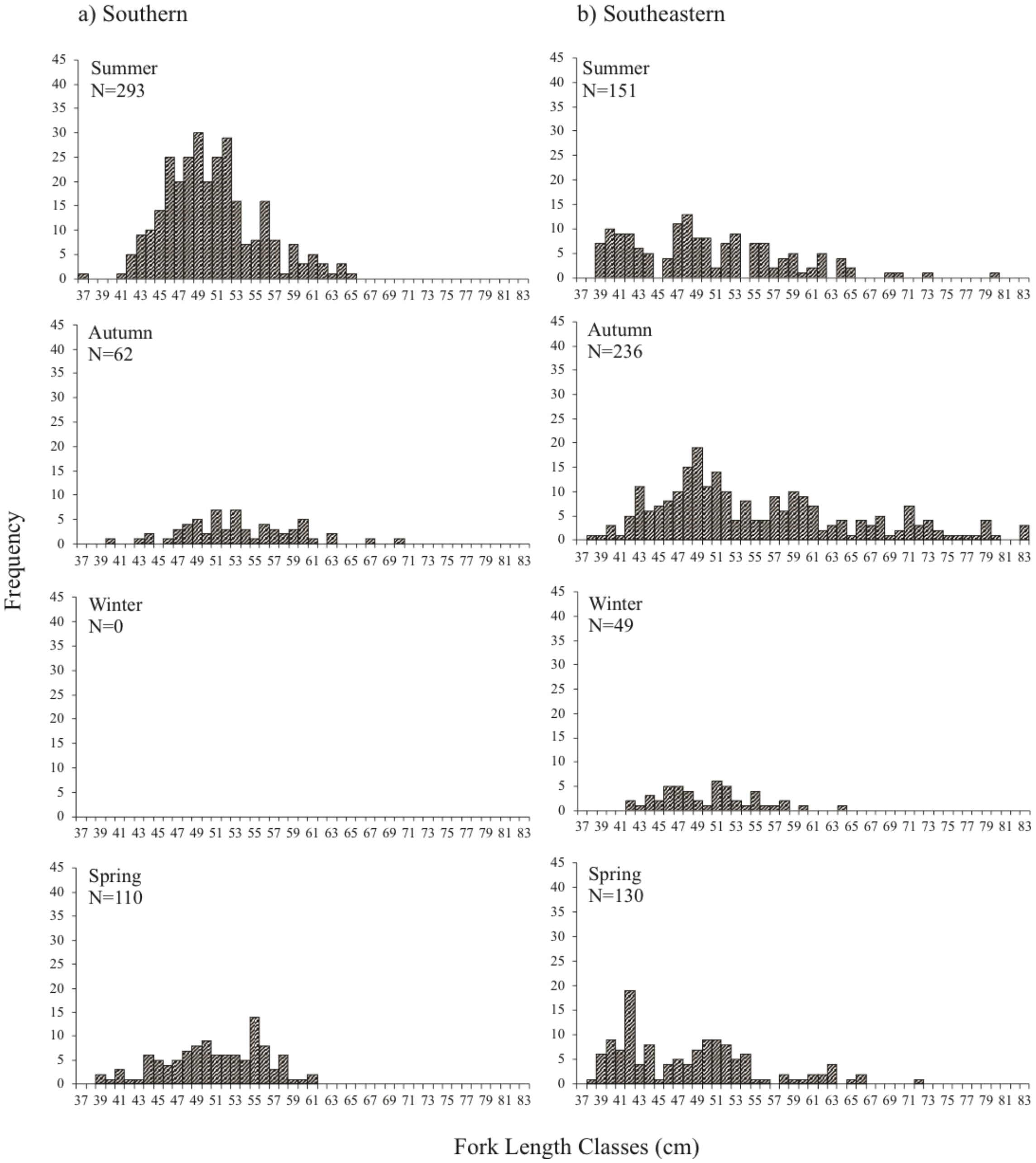

**Figure 2**. Seasonal fork-length frequency distributions (FL, cm) of SKJ between January 2017 and August 2018, by geographical region.

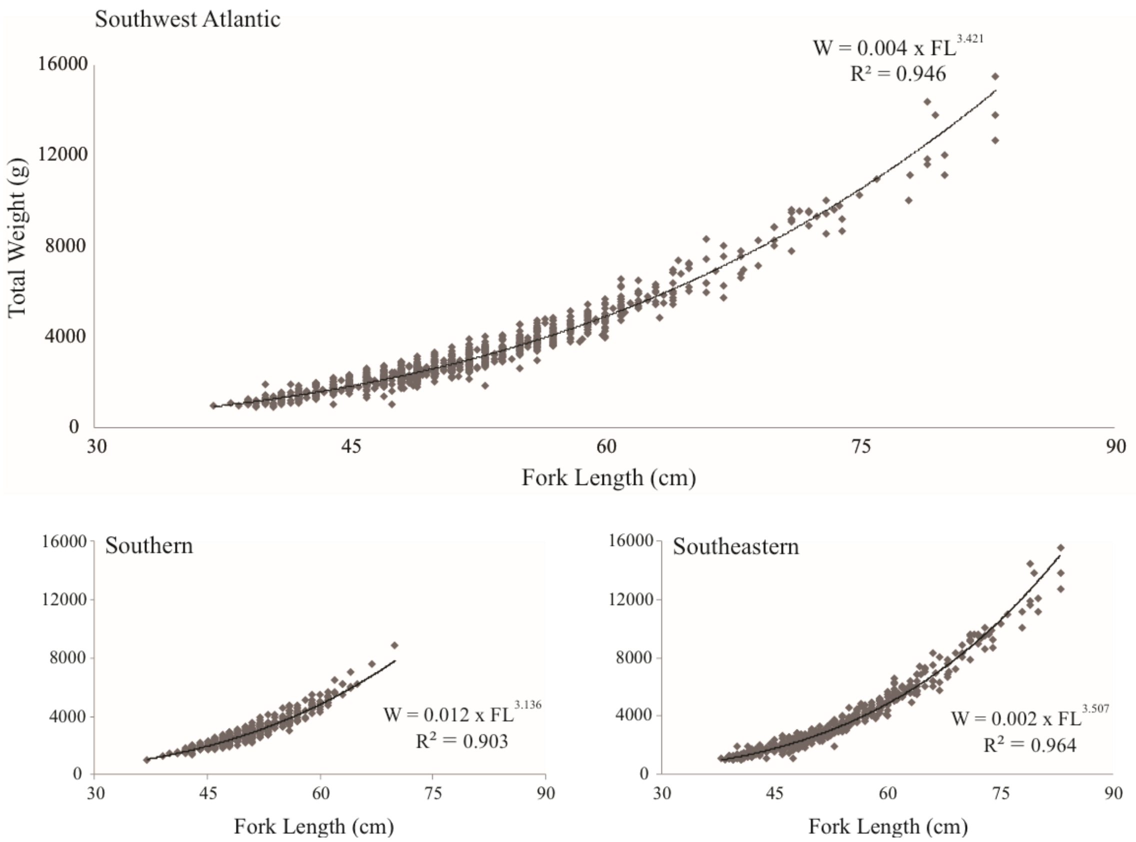

**Figure 3**. Weight-Fork Length relationship of SKJ in the Southwest Atlantic, southern and southeastern regions, between January 2017 and August 2018.

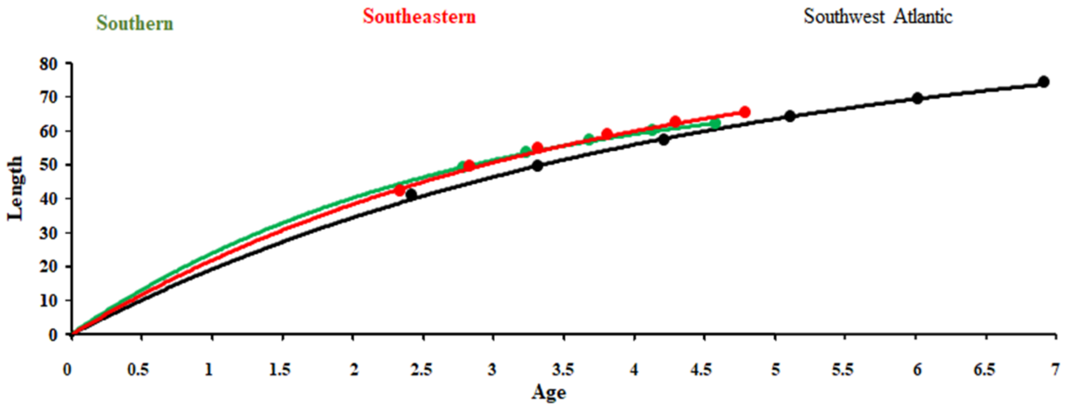

**Figure 4**. Growth curves in FL (cm) of SKJ captured in the Southwest Atlantic, between January 2017 and August 2018.

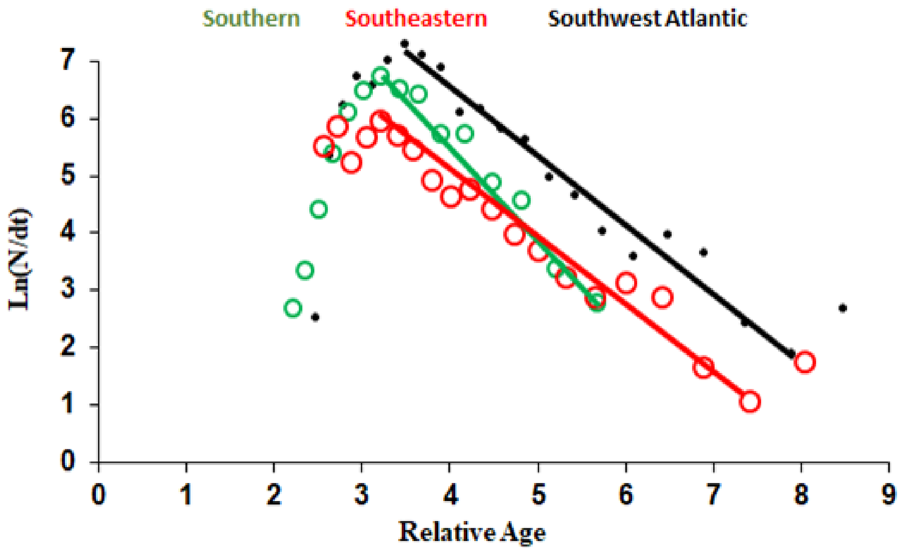

**Figure 5**. Linearized catch curves for SKJ in the southern and southeastern regions and the Southwest Atlantic.

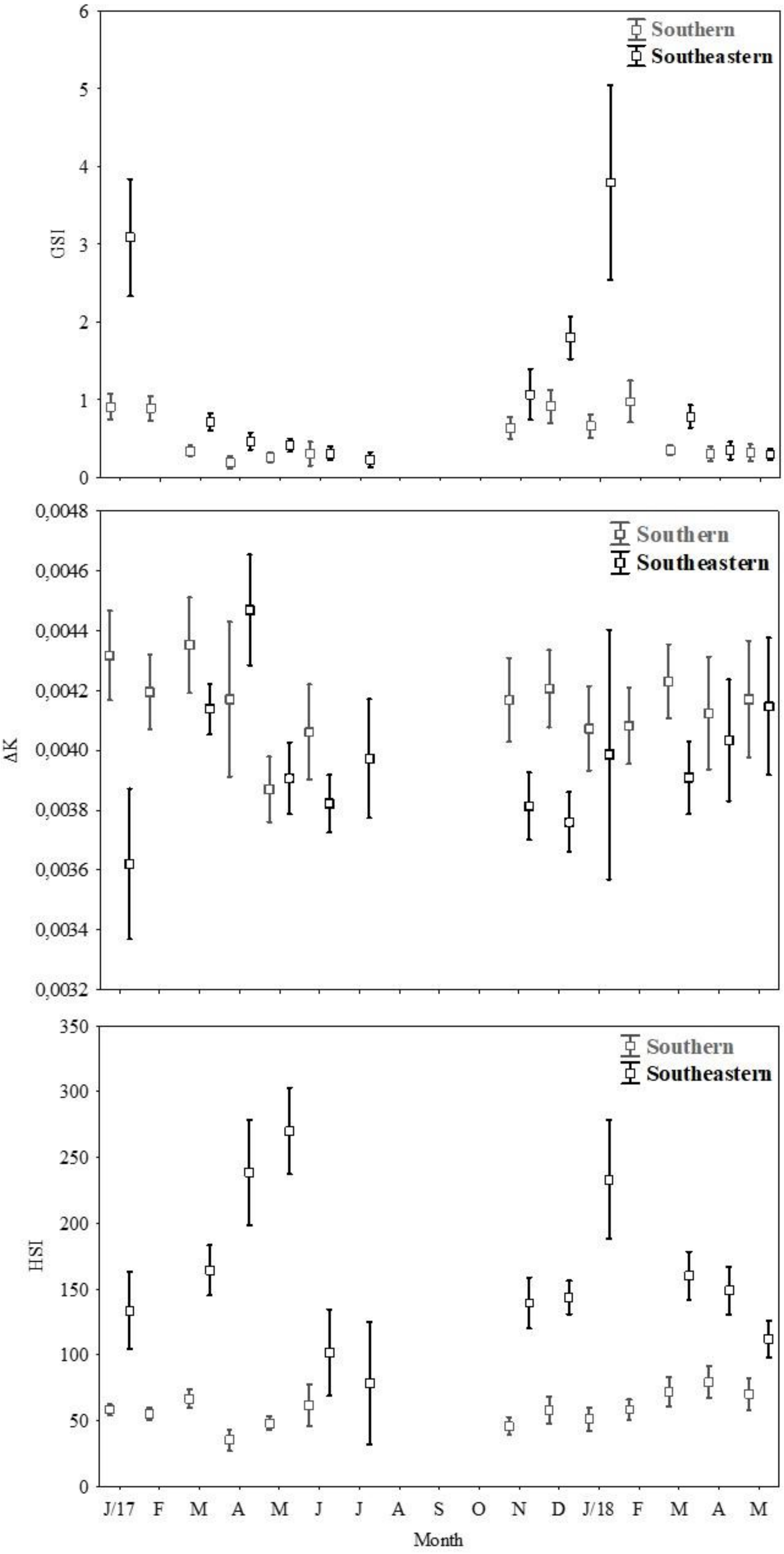

**Figure 6**. Monthly variation (average and 95% confidence intervals) of the Gonadosomatic Index (GSI), Condition Factor (ΔK) and Hepatosomatic Index (HSI) of SKJ from the southern and southeastern regions in the Southwest Atlantic.

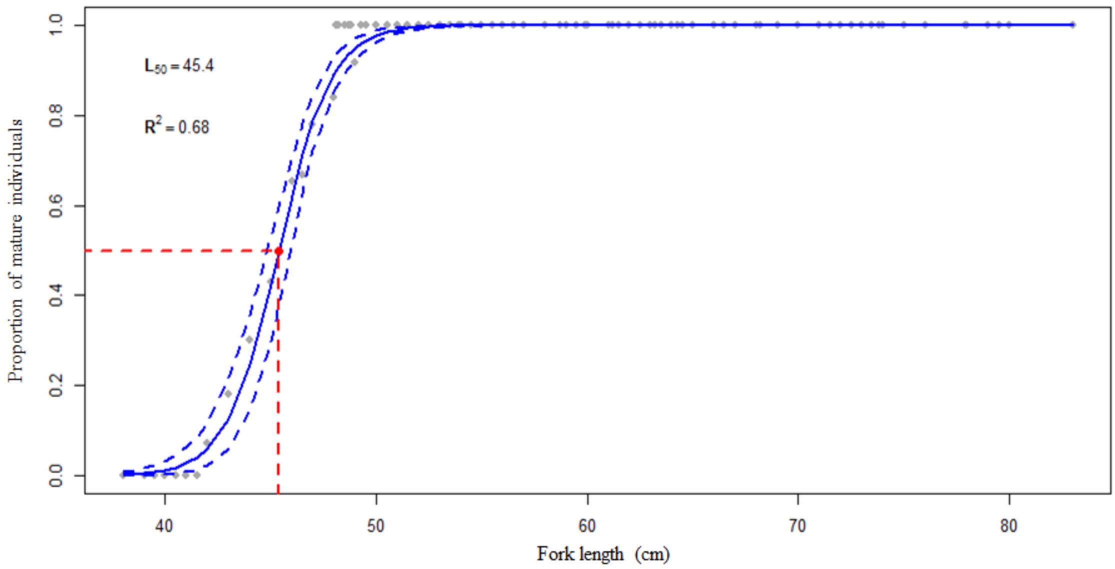

**Figure 7**. Relationship between the proportion of mature individuals and the fork length of SKJ in the Southwest Atlantic.

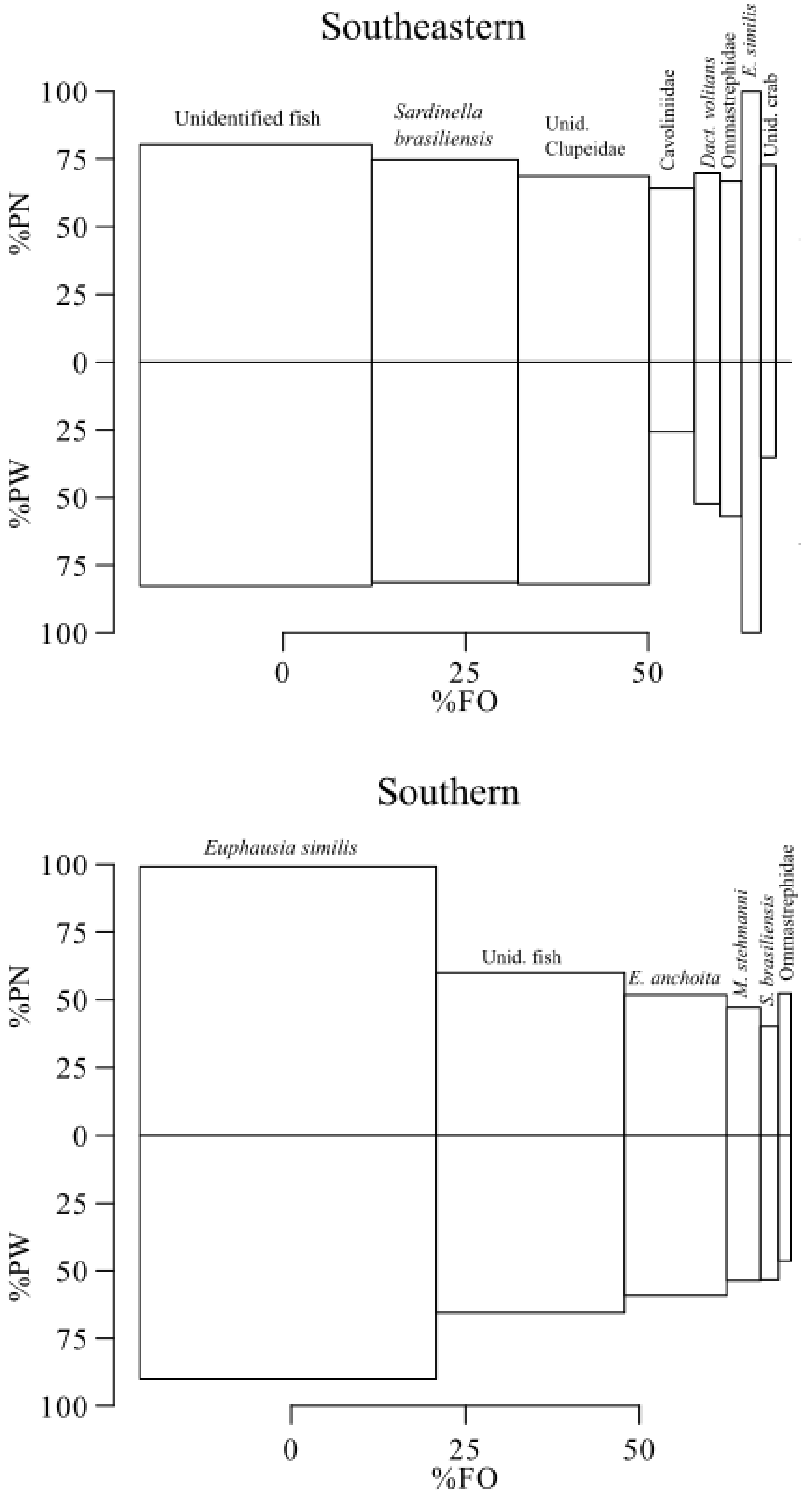

**Figure 8**. Graphical depiction of the diet composition for SKJ off the southeastern (upper) and southern (lower) regions of Brazilian coast. Prey types with %FO<2, were omitted for clarity. See **Table 2** for further details on prey indexes.