SCRS/2016/016 Collect. Vol. Sci. Pap. ICCAT, 73(8): 2663-2678 (2017)

# PRELIMINARY ECOLOGICAL RISK ASSESSMENT OF SMALL TUNAS OF THE ATLANTIC OCEAN

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*SUMMARY*

*This paper assesses the vulnerability of the small tunas caught in the tuna longline fisheries of the Atlantic Ocean based on the Productivity and Susceptibility Analysis (PSA). We compiled data on nine life history traits for 18 stocks from South and North Atlantic. Life history traits of the small tuna species from South Atlantic is poorly documented; data on Amax, A50 and k were missing for more than half of the species. Most of the life history traits displayed a wide range of variation and were highly correlated. A wide range of productivity (1.24 - 2.53) and susceptibility (1.5 - 2.5) scores were computed.* Scomberomorus cavalla *(South Atlantic) were the less productive and* Auxis thasard *and* A. rochei *of the south and north Atlantic respectively are the most productive.* A. solandri *and* Euthynnus alleteratus *of the South Atlantic Ocean were the most susceptible. The top 4 species at risk were* A. solandri *(South Atlantic Ocean),* S. cavalla *of both hemispheres and* S. maculatus. *The quality of the data was considered moderate.*

*RÉSUMÉ*

*Le présent document évalue la vulnérabilité des thonidés mineurs capturés à la palangre dans l'océan Atlantique sur la base d'une analyse de sensibilité et de productivité (PSA). Des données relatives à neuf caractéristiques du cycle vital de 18 stocks de l'Atlantique Sud et Nord ont été collectées à cette fin. Les caractéristiques du cycle vital des espèces de thonidés mineurs de l'Atlantique Sud sont peu documentées. Les données sur $A_{max}$, $A_{50}$ et K manquaient pour plus de la moitié des espèces. La plupart des caractéristiques du cycle vital présentaient une large gamme de variations et étaient fortement corrélées. Une large gamme de valeurs de productivité (1,24 - 2,53) et de sensibilité (1,5 - 2,5) a été calculée.* Scomberomorus cavalla *(Atlantique Sud) était l'espèce la moins* productive *et* Auxis thazard *et* A. rochei*, de l'Atlantique Sud et de l'Atlantique Nord respectivement, les espèces les plus productives. A. solandri et* Euthynnus alleteratus *de l'océan Atlantique Sud étaient les plus sensibles. Les quatre principales espèces en péril étaient* A. solandri *(océan Atlantique Sud),* S. cavalla *des deux hémisphères et* S. maculatus. *On considère que la qualité des données était moyenne.*

*RESUMEN*

*Este documento evalúa la vulnerabilidad de los pequeños túnidos capturados en las pesquerías de palangre atuneras del Atlántico basándose en el Análisis de productividad y susceptibilidad (PSA). Se han compilado datos de nueve rasgos del ciclo vital para 18 stocks del Atlántico norte y sur. Los rasgos del ciclo vital de las especies de pequeños túnidos del Atlántico sur están poco documentados, faltaban datos sobre $A_{max}$, $A_{50}$ y k para más de la mitad de las especies. La mayor parte de los rasgos del ciclo vital mostraban una amplia gama de variación y estaban muy correlacionados. Se calculó una amplia gama de valores de productividad (1,24 - 2,53) y susceptibilidad (1,5 - 2,5).* Scomberomorus cavalla *(Atlántico sur) fue la especie menos productiva y* Auxis thasard *y* Auxis rochei *del Atlántico sur y norte, respectivamente, las más*

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*productivos.* A. solandri *y* Euthynnus alleteratus *del Atlántico sur fueron los más suscpetibles. Las cuatro especies principales en peligro fueron* A. solandri *(Atlántico sur),* S. cavalla *de ambos hemisferios y* S. maculatus*. La calidad de los datos se consideró moderada.*

*KEYWORDS*

*Vulnerability, Life history traits, Long lining, Fishery management*

## 1. Introduction

The tuna longline fishery is one of the main large-scale fishing activities in the world ocean, targeting large and medium-size pelagic species, mainly tuna and swordfish. By-catch is an increasingly important management issue for the longline fishing fleets and a growing concern for Regional Fisheries Management Organizations (RFMOs). In the Atlantic Ocean, most of the bycatch of teleost species in the tuna fisheries has never been studied, partly due to the limited data available since a large part of their catches are not recorded. This is the case of the Atlantic small tunas. Consequently, stock status and life history characteristics for the majority of these teleosts are largely unknown. Growing concerns over the impact of the tuna longline fishery on bycatch species (King and McFarlane, 2003) have therefore led RFMOs to develop holistic approaches to the assessment and management of all exploited species.

Current management practices mainly involve individual stock assessments based on detailed biological information and fishery statistics for targeted species only (King and McFarlane, 2003). However, the actual magnitude of bycatch is often poorly recorded and the population dynamics of most of these species has not been described. Knowledge of basic life history aspects, such as growth, maturity and fecundity, have proven to be very valuable for management in data poor situations (Cortés *et al.*, 2009; Kokkalis *et al.*, 2014). Several approaches have been developed with the aim to support the management of species with a lack of long term fisheries statistics: some are based on basic life history information, which have proved useful to rank species according to their intrinsic sensitivities to threats such as fishing (Jennings *et al.*, 1999; Dulvy *et al.*, 2004, Reynolds *et al.*, 2005).

This study aims to partially fill the gap in our knowledge of small tunas caught by the tuna longline fishery in the Atlantic Ocean. The main species caught were identified and their life history traits were then compiled from a review in peer reviewed and gray literature. A first approach of Productivity and Susceptibility Analysis (PSA) were also obtained. The information provided here will help further studies to be conducted, hopefully resulting in their inclusion in management measures adopted by tuna RFMOs, within an ecosystem approach.

## 2. Material and Methods

### *2.1 Life history traits*

The life history traits of small tunas caught by the tuna longline fishery was evaluated. For the South Atlantic *Acanthocybium solandri, Auxis rochei, A. thazard, Euthynnus alleteratus, Sarda sarda, Scomberomorus brasiliensis, Scomberomorus cavalla, Scomberomorus regalis and Thunnus atlanticus* were evaluated. For the North Atlantic, *A. solandri, A. rochei, A.thazard, E. alleteratus, S. sarda, S. cavalla, S. regalis, S. maculatus* and *T. atlanticus* were considered.

Nine life history traits were selected for each species and stock (South and North Atlantic) (**Table 1**). Values available by sex (e.g. the growth coefficient k, the size at first maturity $L_{50}$ and the age at first maturity $A_{50}$, see **Table 1** for definition of the life history traits) were averaged. Missing data ($L\infty$, k and $L_{50}$) were estimated with empirical equations, and $A_{50}$ was computed using the von Bertalanffy inverse equation, given the value of $L_{50}$.

The Spearman's rank correlation was used to test the relationships between observed life history traits. Bivariate plots were then used to display variables. Statistical analyses were performed using the R statistical software v.3.0.2 (R Development Core Team, 2014).

*2.2 Productivity and Susceptibility Analysis (PSA)*

Vulnerability (v) is a measure of the extent to which fishing mortality on a species exceeds its biological ability to renew itself (Stobutzki *et al.*, 2002). It is a function of productivity and susceptibility attributes for a given species, which are combined to produce a single score that quantifies the risk of overexploitation. Stocks that received a low productivity score and a high susceptibility score were considered to be the most vulnerable to overfishing, while stocks with a high productivity score and low susceptibility score were considered to be the least vulnerable. Each attribute of P (productivity) and S (susceptibility) was scored on a three-point scale, indicating low (1), medium (2), and high (3) values. For productivity, 1 indicated relative low productivity and anticipated high risk and 3 indicated relative high productivity and anticipated low risk. Conversely, for the susceptibility attributes, 3 indicated relative high susceptibility and anticipated high risk and 1 indicated relative low susceptibility and anticipated low risk. Missing attributes ($T_{max}$ and Fecundity) which were not estimated, were not given a score and were not used in the computation of the final P and/or S scores. Each attribute score was then weighted (see section 2.3) and the overall species productivity and susceptibility scores were a weighted mean of the ad hoc attribute scores.

The two-dimensional nature of the Productivity and Susceptibility Analysis (PSA), a semi-quantitative analysis, leads directly to the calculation of an overall vulnerability score (v) of a species, as the Euclidean distance from the origin of a PSA scatter plot:

$$v = \sqrt{(P - X_{0)}{}^2 + \ (S - Y_{0)}{}^2}$$

where X0 and Y0 are the (x, y) origin coordinates, respectively.

Risk categories (high, moderate and low) were defined by ranking the vulnerability scores in three classes, by using a quantile method. The scores were depicted graphically in a scatter plot, with P on the x-axis and S on the y-axis. The x-axis was reversed (i.e. it starts at 3 and ends at 1), so that the area of the plot close to the origin (which was at 3, 1) corresponded to high-productivity, low-susceptibility stocks, hence less vulnerable stocks. The most vulnerable stocks are those placed further from the origin.

From the life history traits described in section 2.1., six life-history traits were selected as productivity attributes (**Table 1**), as follows: $L_{max}$, Fecundity, k, $L_{50}$, $T_{max}$, $L_{50}/L_{max..}$ The intrinsic rate of population growth or maximum population growth that would occur in the absence of fishing at the lowest population size (r) were also included as a productivity attribute. This parameter was calculated for each stock using the approach of Lucena Frédou *et al.* (2016a). The thresholds of productivity scores that defined the three ordered categories were established using the quantiles of the distribution for the species (**Table 2**).

A total of 4 attributes for susceptibility were considered (**Table 3**).

Availability or horizontal overlap - Greater overlap implies greater susceptibility, because some degree of geographical overlap is necessary for a fishery to impact a stock (Patrick *et al.*, 2010). Availability was evaluated qualitatively as the proportion of the spatial distribution of a given stock that overlaps with the fishery. Species distribution was obtained from the IUCN (International Union for Conservation of Nature) or FISHBASE (Froeser and Pauly, 2007). Effort distribution was obtained from ICCAT. Effort distribution was considered from year 2000. The score thresholds of this attribute were based on Patrick et al. (2010). See **appendix 1** for Availability maps.

Z/k – the ratio of total mortality Z over the growth rate k was estimated using the Powell–Wetherall plot (Wetherall *et al.*, 1987). This method assumes that the right hand tail of a length-frequency distribution is determined by the asymptotic length L∞, k and Z. Length-frequency distributions were obtained from the ICCAT database and, in the case of South Atlantic, also from the Brazilian National Observer Program for foreign vessels operating in the northeastern Brazil. Z/k ratio (from less than or around 1) is expected to increase along the intensification of the exploitation rate (Pauly, 1984). Hence species with a ratio larger than 1 were considered most susceptible.

Percentage of adults in catches (% > L50) - Sum of the percentage of the individuals larger than the length at first maturity ($L_{50}$). Length distribution was obtained as described above and $L_{50}$ was the productivity attribute. The score thresholds of this attributes was defined using a quantile method.

Management strategy - The management measures by each species was revised by literature - reports of SCRS (Standing Committee on Research and Statistics, ICCAT, 2014). National regulations of coastal countries were also considered. We assumed that stocks subjected to a number of conservation and management measures were considered to be less susceptible to overfishing or becoming overfished, while stocks with no effective regulation were considered more susceptible.

It was given a score of 1–3 for each attribute, where 3 indicated relative low productivity and anticipated high risk and 1 indicated relative high productivity and anticipated low risk. Conversely, for the susceptibility attributes, 3 indicated relative high susceptibility and anticipated high risk and 1 indicated relative low susceptibility and anticipated low risk. Missing attributes were not given a score.

### *2.3 Attributing weights*

Attribute weights were adjusted within a scale from 0 to 3. In this study, higher weights were assigned to three productivity attributes as they were of greater relevance for describing productivity. Lucena-Frédou *et al.* (2016b) carried out a PCA analysis on these data, and showed that differences between species were mainly explained by $L_{max}$ and k. These two attributes plus r (a key factor to resilience since it incorporates others life history components, Musick *et al.*, 2001), were given weight 3. We used a default weight of 2 for the other productivity and all the susceptibility attributes.

### *2.4 Data quality index*

Data-poor stocks might receive inflated vulnerability scores due to the lack of information (Fujita *et al.*, 2014). Therefore, a data-quality index, derived for inflated scores due to limited data, was adapted from Patrick *et al.* (2010). This was obtained for productivity and susceptibility scores as a weighted average (with the same weights applied to the productivity and susceptibility scores) allowing a mean risk score for vulnerability to be obtained (Ormseth and Spencer, 2011). The index was based on five tiers, ranging from best data (or high belief in the score) to no data (or little belief in the score) (modified from Patrick *et al.* (2010) (**Table 4**). Like Hobday *et al.* (2007), the data-quality scores were divided into three categories: poor >3.5; moderate 2.0–3.5; and good <2.0.

## 3. Results

### *3.1 Life history traits*

Life history traits of the species small tunas from South Atlantic is poorly documented. For example, data on $A_{max}$, $A_{50}$ and k were missing for more than half of the species (**Table 5**).

Most of the life history traits displayed a wide range of variation (**Table 5**). Maximum observed length ($L_{max}$) varied from 65 (*Auxis rochei*) to 200 cm FL (*Acanthocybium solandri* North Atlantic). Growth coefficient (k) varied from 0.12 (*Scomberomorus cavalla*, South Atlantic Ocean) to 0.7 $year^{-1}$ (*Thunnus atlanticus*, North Atlantic Ocean). Both short ($A_{max}$= 4, *Euthynnus alleteratus, A. thasard*) and long lived ($A_{max}$= 26 and 15, North and South *S.cavalla* respectively) species occurred in the longline catches (**Table 5**). Life history traits were highly correlated (**Table 6**). $L_{max}$ was positively correlated with $L_{\infty}$, $A_{max}$, $L_{50}$ and fecundity (**Table 6, Figure 1**). $A_{max}$ is positively correlated to $L_{max}$ and $L\infty$ and negatively correlated to k. The growth coefficient k was negatively correlated to $A_{max}$ (**Table 6, Figure 1**), i.e. long-lived species have lower growth rate. Fecundity was positively correlated to $L_{max}$, $A_{max}$ and $L\infty$ as long lived, large-sized species are most fecund (**Table 6, Figure 1**).

### *3.2. Productivity and Susceptibility Analysis (PSA) and data quality index*

A wide range of productivity (1.24 - 2.53) and susceptibility (1.5 - 2.5) scores were computed (**Table 7, Figure 2**). *Scomberomorus cavalla* (South Atlantic) were the less productive and *Auxis thasard* and *A. rochei* of the south and north Atlantic respectively are the most productive. *A. solandri* and *Euthynnus alleteratus* of the South Atlantic Ocean were the most susceptible. No differences were observed for the productivity, susceptibility and vulnerability scores between South and North Atlantic. The top 7 species at risk were *S. cavalla* (South Atlantic Ocean), *A. solandri* (South Atlantic Ocean), *S. cavalla* (North Atlantic Ocean), *S. maculatus, Euthynnus alleteratus* (South Atlantic) and *Thunnus atlanticus* (both oceans) (**Table 7, Figure 2**).

The quality of the data was considered moderate (average vulnerability quality scores of 2.05) **(Table 7)**. Differences in overall data quality between South and North Atlantic were not significant ($p > 0.05$). The top 4 species at risk had either good or moderate quality data (**Table 4; Figure 3**).

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**Table 1**. Life history trait attributes of species caught by the tuna longline fishery in the Atlantic Ocean.

| Attribute | Code | Definition |
|---|---|---|
| Asymptotic Length | $L_\infty$ (cm) | Asymptotic fork length reported |
| Maximum size | $L_{max}$ (cm) | Maximum fork length reported |
| Maximum age | $A_{max}$ (years) | Maximum observed age reported |
| von Bertalanffy growth coefficient | k (cm.year$^{-1}$) | A measure of how rapidly a fish reaches its maximum size |
| Size at first maturity | $L_{50}$(cm) | Length at which 50% of the individuals attain gonadal maturity for the first time |
| Age at first maturity | $A_{50}$ (years) | Age at which 50% of the individuals attain gonadal maturity for the first time |
| Ratio of size at first maturity to maximum size | $L_{50}/L_{max}$ | Describes somatic and reproductive investment |
| Ratio of size at first maturity to Asymptotic length | $L_{50}/L_\infty$ | Describes somatic and reproductive investment |
| Fecundity | Fec (millions of oocyts) | Mid-point of the reported range of number of oocyts per individual for a given spawning event or period |

**Table 2.** Productivity attributes and rankings used to determine the vulnerability of the small tunas stocks caught by tuna longline fishery in the Atlantic Ocean.

| | ***Ranking*** | | |
|---|---|---|---|
| ***Atribute*** | ***High (3)*** | ***Moderate (2)*** | ***Low (1)*** |
| Maximum Size ($L_{max}$) | < 80 cm | 80 - 98 | > 98 cm |
| von Bertalanffy growth coefficient (k) | > 0.36 | 0.21 - 0.36 | < 0.21 |
| Size at first maturity ($L_{50}$) | < 37 cm | 37-42 cm | > 42 cm |
| Maximum age ($T_{max}$) | < 5 years | 5-9 years | > 9 years |
| $L_{50}/L_{max}$ | < 0.53 | 0.43 - 0.53 | > 0.53 |
| Fecundity (in millions of oocyts); | > 1.14 | 0.72 - 1.14 | < 1.14 |
| R | > 0.54 | 0.45-0.54 | < 0.45 |

**Table 3.** Susceptibility attributes and rankings used to determine the vulnerability of the small tunas stocks caught by tuna longline fishery in the Atlantic Ocean.

| Atribute | Ranking | | |
|---|---|---|---|
| | Low (1) | Moderate (2) | High (3) |
| Availability | < 25% of stock occurs in the area fished | Between 25% and 50% of the stock occurs in the area fished | > 50% of stock occurs in the area fished |
| % > $L_{50}$ (Adults) | >95% | 50-95% | <50% |
| Management strategy | Currently subject to a number of conservation and management measures | No specific regulation are in effect, but some indirect measures are in course and/or some countries have established domestic regulations | No regulation are in effect |
| Z/k | <0.5 | 0.5 - 1.0 | >1 |

**Table 4.** Tiers of data quality used when evaluating the productivity and susceptibility of the small tunas stocks caught by tuna longline fishery in the Atlantic Ocean. Modified from Patrick *et al*. (2010).

| Data quality tier | Description | Example |
|---|---|---|
| Best Data (1) | Data collected from the study stock and area, recent literature and appropriate stock assessment methods | Information used by RFMOs for systematic stock assessment |
| Good/adequate data (2) | Data collected from the study stock and area. Relatively old information, reasonably appropriate stock assessment | Short time series and/or more "robust" stock assessment (ex: using equilibrium methods and /or psedocohort) |
| Acceptable data (3) | Parameters obtained by empirical relationships or on studies of the same species/adjacent area. | Parameters estimated from empirical formulae or North Atlantic Ocean parameter considered for a South Atlantic species |
| Limited data (4) | Expert opinion or data of no adjacent area | General data not referenced |
| No data (5) | The person should give a score 5 and do not provide a score of productivity and susceptibility | |

**Table 5.** Life history traits for all small tunas caught by the tuna longline fishery in both South and North Atlantic Ocean. Units: $L_{max}$ (cm), $L_{\infty}$ (cm), k (cm.year-1), $A_{50}$ (years), $A_{max}$ (years), $L_{50}$ (cm), Fec (millions of oocyts). Values in blue are estimated. Value in orange – value converted to year$^{-1}$ .* female only. Red cell – Estimates of North Atlantic Ocean. Yellow cell – Estimate from South Atlantic Ocean.

| Species | CODE | Lmax | Fonte | Linf | Fonte | to | Fonte | k | Fonte | A50 | Fonte | Amax | Fonte | L50 | Fonte | Fecund | Fonte |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Acanthocybium solandri* | WAH | 197 | Viana et al. (2013) | 170.1 | Bride et al. (2008) | -1.63 | Bride et al. (2008) | 0.38 | Bride et al. (2008) | 2.0 | Brown-Petersen et al. (2000) | 9 | Bride et al. (2008) | 110 | Viana et al. (2013) | 1.32 | Viana et al. (2013) |
| *Auxis rochei* | BLT | 66 | Uchida (1981) | 45.26 | Bök and Oray (2001) | -1.6 | Bök and Oray (2001) | 0.39 | Bök and Oray (2001) | 2.0 | Bök and Oray (2001) | 5 | Rodriguez Roda (1983) | 34.4 | Bök and Oray (2001) | 0.23 | Macias et al (2005a) |
| *Auxis thazard* | FRI | 65 | Cayre (1993) | 51.47 | Grudtsev and Korolevich (1986) | -0.83 | Grudtsev and Korolevich (1986) | 0.32 | Grudtsev and Korolevich (1986) | 2.7 | Estimated | 4 | Grudtsev and Korolevich (1986) | 34.7 | Estimated | | |
| *Euthynnus alleteratus* | LTA | 81 | Menezes (1977) | 115 | Rodriguez-Roda (1979) | -1.71 | Rodriguez-Roda (1979) | 0.19 | Rodriguez-Roda (1979) | 0.2 | Estimated | 8 | Collette and Nauen (1983) | 35 | Collette and Nauen (1983) | 1.14 | Diouf (1980) |
| *Sarda sarda* | BOM | 77 | Castello (1969) | 74.61 | Hansen (1989) | -2.74 | Hansen, 1989 | 0.22 | Hansen (1989) | 0.5 | | 7 | Zaboukas and Megalofonou (2007) | 38 | Postel (1955) | 0.73 | Macias et al. (2005b) |
| *Scomberomorus brasiliensis* | BRS | 80 | Chellappa et al. (2010) | 109.18 | Nóbrega and Lessa (2009b) | -0.414 | Nóbrega and Lessa (2009b) | 0.114* | Nóbrega and Lessa (2009b) | 3.8 | Nóbrega and Lessa (2009b) | 8 | Nóbrega and Lessa (2009b) | 42 | Nóbrega and Lessa (2009c) | 0.87 | Lima et al. (2007) |
| *Scomberomorus cavalla* | KGM | 114.8 | Nóbrega and Lessa (2009a) | 132.7 | Nóbrega and Lessa (2009a) | 0.387 | Nóbrega and Lessa (2009a) | 0.159* | Nóbrega and Lessa (2009a) | 5.0 | | 15 | Nóbrega and Lessa (2009a) | 70 | Lessa et al. (2009) | 6.14 | Finicane et al. (1986) |
| *Scomberomorus regalis* | CER | 93.98 | IGFA (2011) | 96.77 | estimated | | | 0.26 | Estimated | 2.0 | Estimated | | | 38.6 | Figuerola-Fernandez et al. (2007) | 1.20 | Finucane and Collins (1984). |
| *Thunnus atlanticus* | BLF | 90 | Frota (2004) | 91 | Freire (2009) | -0.22 | Freire (2009) | 0.62 | Freire (2009) | 1.1 | Estimated | 5 | García-Coll (1988) | 51 | Freire (2009) | 0.71 | Bezerra et al. (2013) |

**North Atlantic**

| Species | CODE | Lmax (FL) | Fonte | Linf | Fonte | to | Fonte | k | Fonte | A50 | Fonte | Amax | Fonte | L50 | Fonte | Fecund | Fonte |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Acanthocybium solandri* | WAH | 200.22 | Hogarth (1976) | 170.1 | Bride et al. (2008) | -1.63 | Bride et al. (2008) | 0.38 | Bride et al. (2008) | 0.6 | Bök and Oray (2001) | 9 | Bride et al. (2008) | 92.5 | Jenkins and McBride (2009) | 1.06 | Jenkins and McBride (2009) |
| *Auxis rochei* | BLT | 66 | Uchida (1981) | 45.26 | Bök and Oray (2001) | -1.6 | Bök and Oray (2001) | 0.39 | Bök and Oray (2001) | 2.0 | Bök and Oray (2001) | 5 | Rodriguez Roda (1983) | 34.4 | Bök and Oray (2001) | 0.23 | Macias et al (2006) |
| *Auxis thazard* | FRI | 65 | Cayre (1993) | 51.47 | Grudtsev and Korolevich (1986) | -0.83 | Grudtsev and Korolevich (1986) | 0.32 | Grudtsev and Korolevich (1986) | 2.7 | Estimated | 4 | Grudtsev and Korolevich (1986) | 34.7 | Estimated | | |
| *Euthynnus alleteratus* | LTA | 106.68 | IGFA (2011) | 115 | Rodriguez-Roda (1979) | -1.71 | Rodriguez-Roda (1979) | 0.19 | Rodriguez-Roda (1979) | 0.8 | Estimated | 9 | Kahraman and Oray (2001) | 43.8 | Hajjej et al. (2010) | 1.14 | Diouf (1980) |
| *Sarda sarda* | BOM | 97 | Di-Natale et al. (2005) | 80.6 | Santamaría et al. (1998) | -1.37 | Santamaría et al. (1998) | 0.36 | Santamaría et al., 1998 | 0.4 | Estimated | 5 | Di-Natale et al. (2005) | 38.5 | Rey et al (1984) | 0.73 | Macias et al. (200b5) |
| *Scomberomorus cavalla* | KGM | 158 | Devries and Grimes (1997) | 147.4 | Manooch et al (1987) | | | 0.12 | Manooch et al (1987) | 1.5 | Sturm and Salter (1990) | 26 | Devries and Grimes (1997) | 87.5 | Finucane et al. (1986) | 1.59 | Fitzhugh e et al. (2009) |
| *Scomberomorus regalis* | CER | 93.98 | IGFA (2011) | 96.77 | estimated | | | 0.26 | Estimated | 2.0 | Estimated | | | 38.6 | Figuerola-Fernandez et al. (2007) | 1.20 | Finucane and Collins (1984) |
| Scomberomorus maculatus | SSM | 80.2 | Fable et al. (1987) | 76 | Schmidt et al. (1993) | -2.44 | Schmidt et al. (1993) | 0.18 | Schmidt et al. (1993) | 2.5 | Sturm (1978) | 11 | Schmidt et al. (1993) | 35.8 | Schmidt et al. (1993) | | |
| *Thunnus atlanticus* | BLF | 104.14 | IGFA (2011) | 71.4 | Doray et al (2004) | -0.219 | Doray et al (2004) | 0.7 | Doray et al (2004) | 0.9 | Estimated | 5 | García-Coll (1988) | 39 | Valle-Gomez (1992) | 0.71 | Bezerra et al. (2013) |

**Table 6.** Spearman's correlation matrix. * (P < 0.05) ** (P< 0.01). NS: not significant.

| | $L_{max}$ | $L_\infty$ | k | $A_{50}$ | $A_{max}$ | $L_{50}$ | Fecund | $L_{50}/L_{max}$ | $L_{50}/L_\infty$ |
|---|---|---|---|---|---|---|---|---|---|
| $L_{max}$ | - | 0.00** | NS | NS | 0.00** | 0.00** | 0.00** | NS | NS |
| $L_\infty$ | 0.00** | - | NS | NS | 0.00** | 0.00** | 0.00** | NS | NS |
| k | NS | NS | - | NS | 0.015* | NS | 0.00** | NS | NS |
| $A_{50}$ | NS | NS | NS | - | NS | NS | NS | NS | NS |
| $A_{max}$ | 0.00** | 0.00** | 0.015* | NS | - | 0.00** | 0.00** | NS | NS |
| $L_{50}$ | 0.00** | 0.00** | NS | NS | 0.00** | - | 0.019* | NS | |
| Fecund | 0.00** | 0.00** | 0.00** | NS | 0.00** | 0.019* | - | NS | NS |
| $L_{50}/L_{max}$ | NS | NS | NS | 0.00** | NS | NS | NS | - | 0.012* |
| $L_{50}/L_\infty$ | NS | NS | 0.01** | NS | NS | NS | NS | 0.012* | - |

**Table 7**. Productivity, susceptibility and vulnerability scoring, rank and risk of the Small tunas caught by tuna longline fisheries in the Atlantic Ocean. Data quality index for productivity, susceptibility and vulnerability scores. Data-quality scores: poor >3.5 (red); moderate 2.0–3.5 (orange) and good <2.0 (blue)

| | | | | Productivity | | Susceptibility | | Vulnerability | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Stock Name | Species | Code | Ocean | Score | Data Quality | Score | Data Quality | Score | Rank | Risk | Data Quality |
| KGMsa | Scomberomorus cavalla | KGM | S. Atlantic | 1.24 | 1.59 | 2 | 3.00 | 2.03 | 1 | High | 2.29 |
| WAHsa | Acanthocybium solandri | WAH | S. Atlantic | 1.71 | 1.94 | 2.5 | 1.00 | 1.98 | 2 | High | 1.47 |
| KGMna | Scomberomorus cavalla | KGM | N.Atlantic | 1.41 | 1.35 | 2 | 2.50 | 1.88 | 3 | High | 1.93 |
| SSMna | Scomberomorus maculatus | SSM | N.Atlantic | 1.60 | 1.82 | 2 | 3.00 | 1.72 | 4 | High | 2.41 |
| LTAsa | Euthynnus alleteratus | LTA | S. Atlantic | 2.24 | 2.65 | 2.5 | 3.00 | 1.68 | 5 | High | 2.82 |
| BLFsa | Thunnus atlanticus | BLF | S. Atlantic | 1.65 | 1.59 | 2 | 1.00 | 1.68 | 6 | High | 1.29 |
| BLFna | Thunnus atlanticus | BLF | N.Atlantic | 2.00 | 1.59 | 2.3 | 2.00 | 1.67 | 7 | High | 1.79 |
| LTAna | Euthynnus alleteratus | LTA | N.Atlantic | 1.47 | 1.35 | 1.5 | 1.00 | 1.61 | 8 | Moderate | 1.18 |
| BRSsa | Scomberomorus brasiliensis | BRS | S. Atlantic | 2.00 | 1.35 | 2 | 3.00 | 1.41 | 9 | Moderate | 2.18 |
| CERsa | Scomberomorus regalis | CER | S. Atlantic | 2.07 | 2.07 | 2 | 2.00 | 1.37 | 10 | Moderate | 2.03 |
| FRIna | Auxis thazard | FRI | N.Atlantic | 2.13 | 2.29 | 2 | 2.00 | 1.32 | 11 | Moderate | 2.15 |
| BLTsa | Auxis rochei | BLT | S. Atlantic | 2.18 | 3.00 | 2 | 4.00 | 1.30 | 12 | Moderate | 3.50 |
| CERna | Scomberomorus regalis | CER | N.Atlantic | 2.27 | 2.18 | 2 | 3.00 | 1.24 | 13 | Low | 2.59 |
| BOMna | Sarda sarda | BOM | N.Atlantic | 2.29 | 1.35 | 2 | 1.00 | 1.22 | 14 | Low | 1.18 |
| BOMsa | Sarda sarda | BOM | S. Atlantic | 2.35 | 2.29 | 2 | 3.00 | 1.19 | 15 | Low | 2.65 |
| BLTna | Auxis rochei | BLT | N.Atlantic | 2.53 | 1.35 | 2 | 1.00 | 1.11 | 16 | Low | 1.18 |
| FRIsa | Auxis thazard | FRI | S. Atlantic | 2.53 | 3.24 | 2 | 3.00 | 1.10 | 17 | Low | 3.12 |
| WAHna | Acanthocybium solandri | WAH | N.Atlantic | 2.06 | 1.35 | 1.5 | 1.00 | 1.07 | 18 | Low | 1.18 |

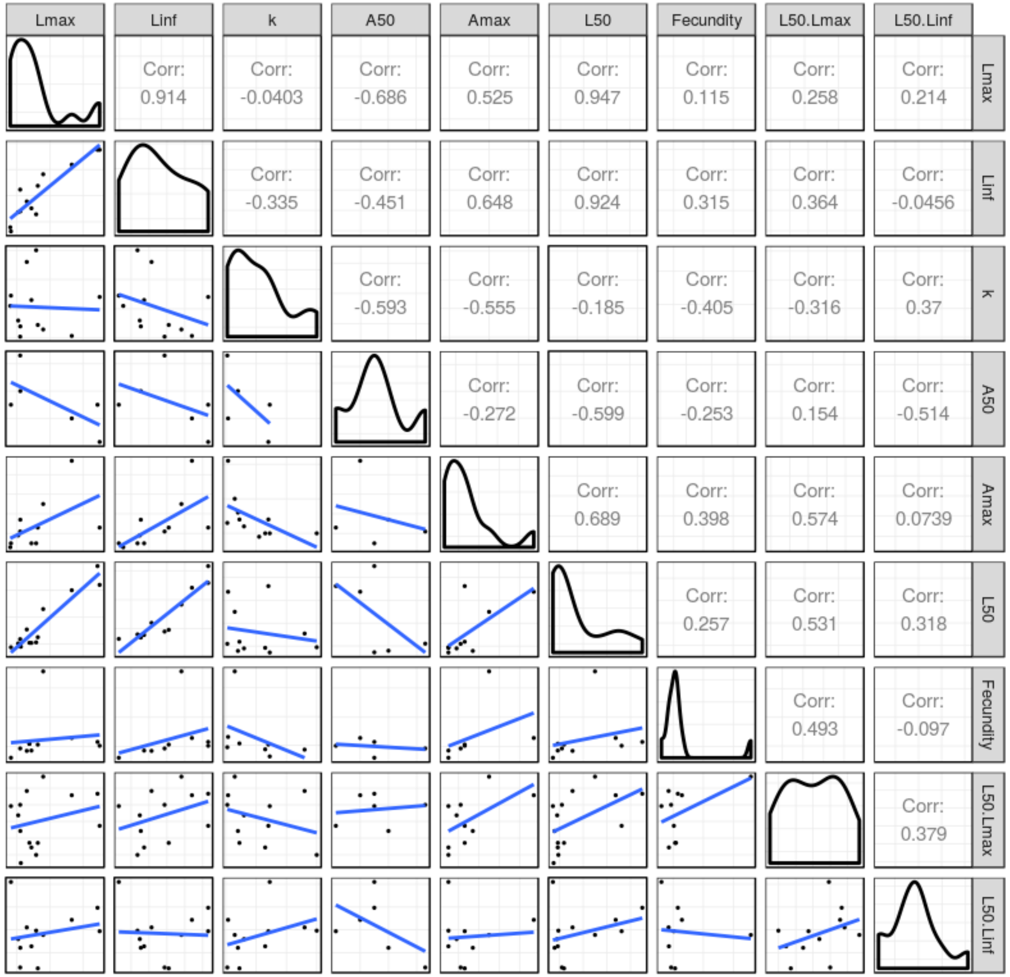



**Figure 1.** Bivariate relationships between pairs of life history traits. Units: Lmax (cm). L∞ (cm). k (cm.year-1). $A_{50}$ (years).$A_{max}$ (years). $L_{50}$ (cm). Fec (millions of oocyts). $L_{50}/L_{max}$ (no unit). $L\infty/L_{max}$ (no unit)

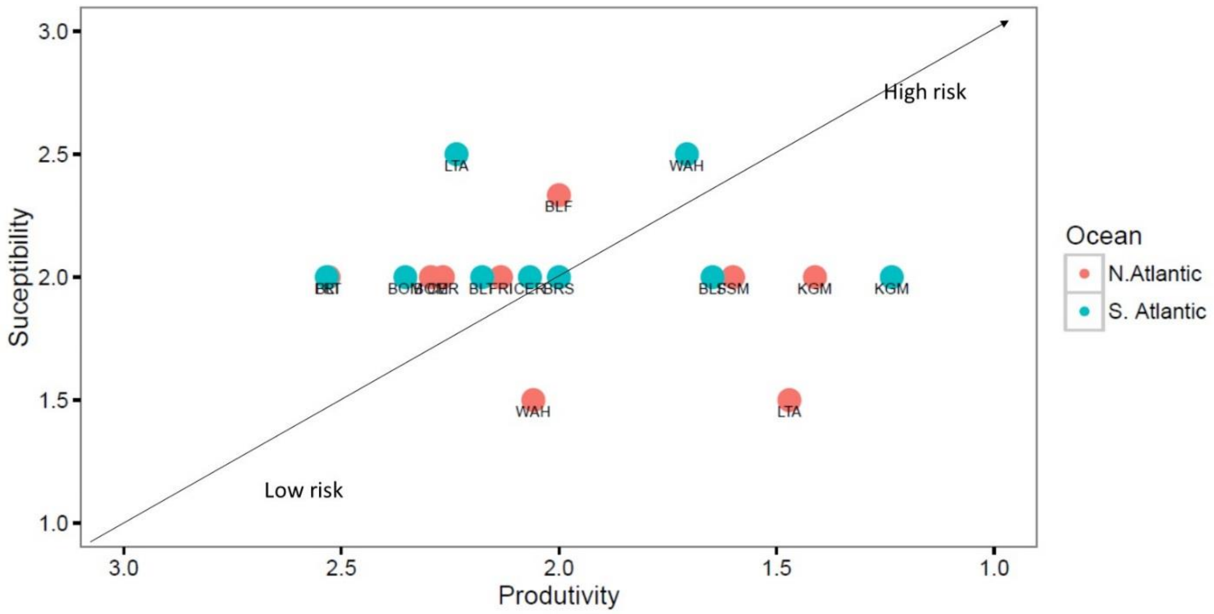



**Figure 2**. x-y plot of the productivity and susceptibility scores for the small tunas caught by tuna longline fisheries in South and North Atlantic. Codes are in **Table 7**.

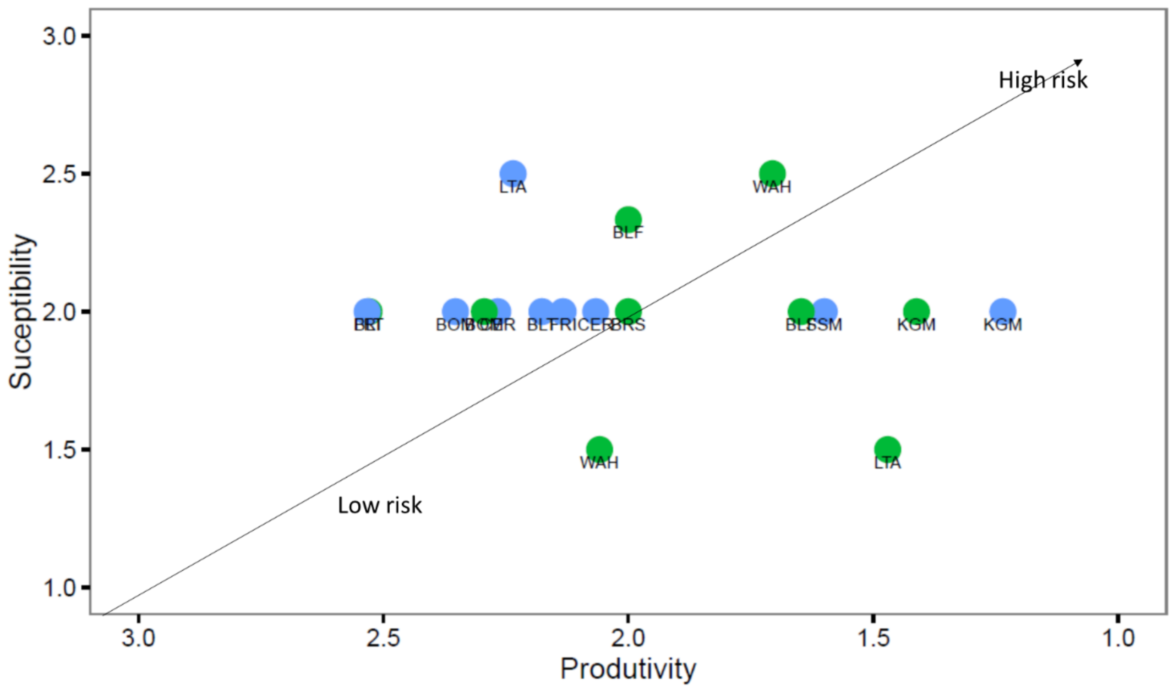
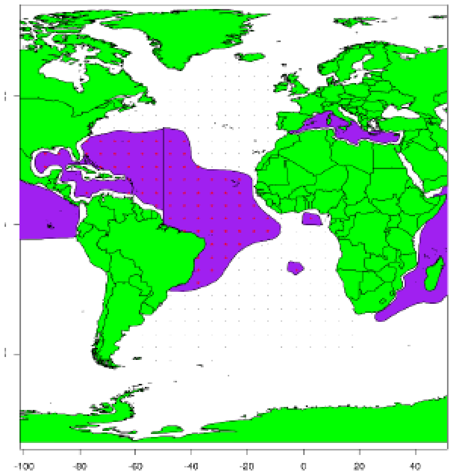


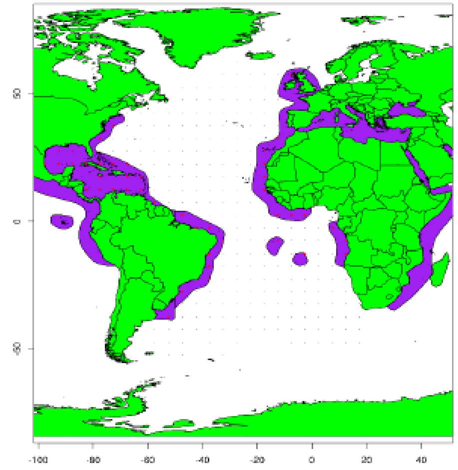

**Figure 3.** x-y plot of the productivity and susceptibility scores with indication of data quality for the small tunas caught by tuna longline fisheries in South and North Atlantic. Green – good quality data; blue – moderate quality data. Codes are in **Table 7**.

**Appendix 1** – Maps of species availability for Atlantic Small Tunas

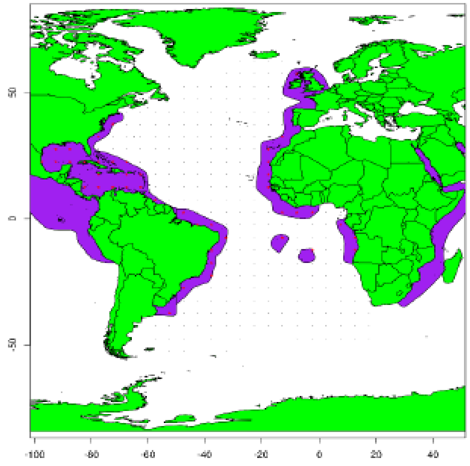
Acanthocybium solandri [out= 1461232572 in= 1045997272 ]



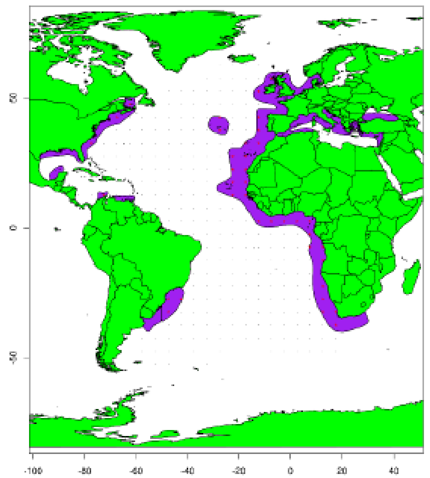
Auxis rochei [out= 2095487780 in= 411742064 ]



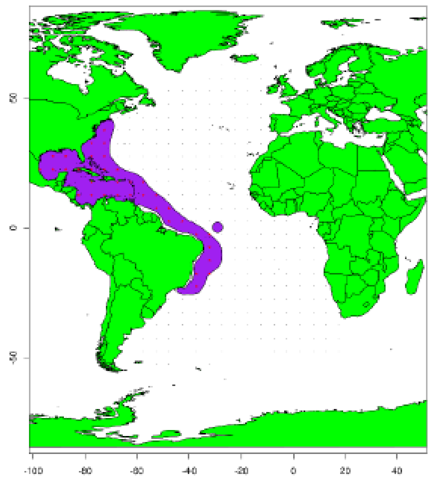
Auxis thazard [out= 2095487780 in = 411742064 ]

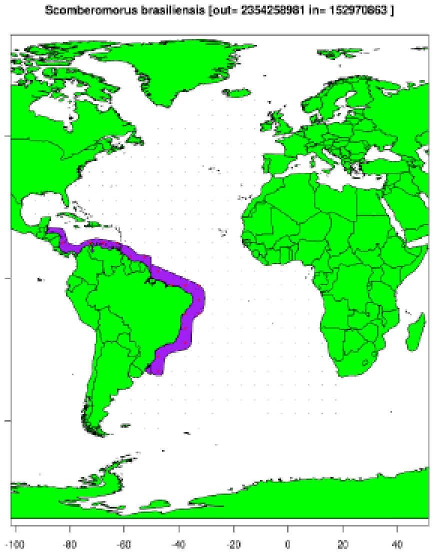


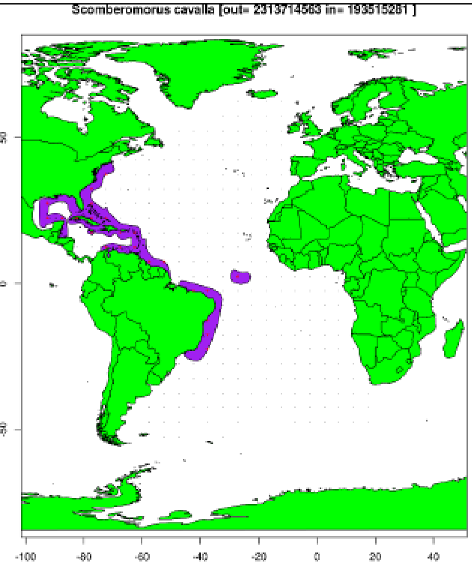
Sarda sarda [out= 2127210521 in= 380019322 ]

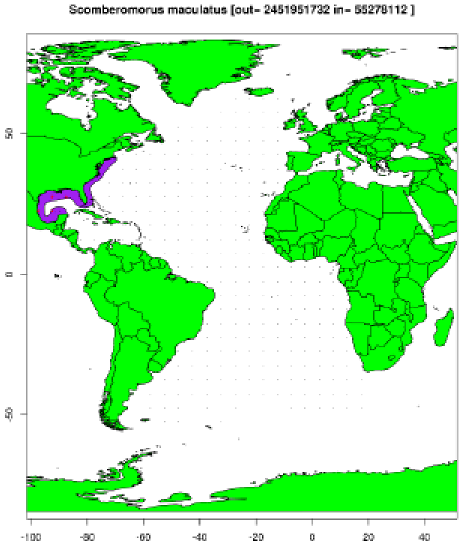


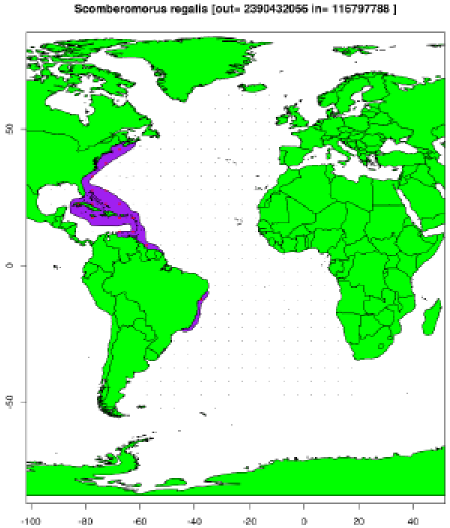
Thunnus atlanticus [out= 2202367206 in= 304862637 ]




Scomberomorus brasiliensis [out= 2354258981 in= 152970863 ]


Scomberomorus cavalla [out= 2313714563 in= 193515281 ]


Scomberomorus maculatus [out= 2451951732 in= 55278112 ]


Scomberomorus regalis [out= 2390432056 in= 116797788 ]