



HAL
open science

Vulnerability of teleosts caught by the pelagic tuna longline fleets in South Atlantic and Western Indian Oceans

Flávia Frédou, Laurie Kell, Thierry Frédou, Daniel Gaertner, Michel Potier, Pascal Bach, Paulo Travassos, Fábio Hazin, Frédéric Ménard

► **To cite this version:**

Flávia Frédou, Laurie Kell, Thierry Frédou, Daniel Gaertner, Michel Potier, et al.. Vulnerability of teleosts caught by the pelagic tuna longline fleets in South Atlantic and Western Indian Oceans. *Deep Sea Research Part II: Topical Studies in Oceanography*, 2017, 140, pp.230-241. <10.1016/j.dsr2.2016.10.008>. <ird-01528460>

HAL Id: ird-01528460

<https://ird.hal.science/ird-01528460v1>

Submitted on 29 May 2017

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



HAL Authorization



Contents lists available at ScienceDirect

Deep-Sea Research II

journal homepage: www.elsevier.com/locate/dsr2

Vulnerability of teleosts caught by the pelagic tuna longline fleets in South Atlantic and Western Indian Oceans



Flávia Lucena-Frédou^{a,b,*}, Laurie Kell^c, Thierry Frédou^{a,b}, Daniel Gaertner^b, Michel Potier^b, Pascal Bach^b, Paulo Travassos^a, Fábio Hazin^a, Frédéric Ménard^d

^a Universidade Federal Rural de Pernambuco (UFRPE), Departamento de Pesca e Aquicultura, Av. Dom Manuel s/n, Recife, Pernambuco 52171-900, Brazil

^b Institut de Recherche pour le Développement (IRD), UMR MARBEC (IRD, IFREMER, Univ. Montpellier, CNRS), CS 30171, 34203 Sète Cedex, France

^c International Commission for the Conservation of Atlantic Tunas (ICCAT), Corazón de María, 28002 Madrid, Spain

^d IRD, Mediterranean Institute of Oceanography (MIO), Aix-Marseille Université/CNRS/IRD/Université de Toulon, 13288 Marseille, France

ARTICLE INFO

Keywords:

Productivity and Susceptibility Analysis

Bycatch

Risk

Fishery management

ABSTRACT

Productivity and Susceptibility Analysis (PSA) is a methodology for evaluating the vulnerability of a stock based on its biological productivity and susceptibility to fishing. In this study, we evaluated the vulnerability of 60 stocks of tuna, billfishes and other teleosts caught by the tuna longline fleets operating in the South Atlantic and Indian Ocean using a semi-quantitative PSA. We (a) evaluated the vulnerability of the species in the study areas; (b) compared the vulnerability of target and non-target species and oceans; (c) analyzed the sensitivity of data entry; and (d) compared the results of the PSA to other fully quantitative assessment methods. Istiophoridae exhibited the highest scores for vulnerability. The top 10 species at risk were: Atlantic *Istiophorus albicans*; Indian Ocean *Istiompax indica*; Atlantic *Makaira nigricans* and *Thunnus alalunga*; Indian Ocean *Xiphias gladius*; Atlantic *T. albacares*, *Gempylus serpens*, *Ranzania laevis* and *X. gladius*; and Indian Ocean *T. alalunga*. All species considered at high risk were targeted or were commercialized bycatch, except for the Atlantic *G. serpens* and *R. laevis* which were discarded, and may be considered as a false positive. Those species and others at high risk should be prioritized for further assessment and/or data collection. Most species at moderate risk were bycatch species kept for sale. Conversely, species classified at low risk were mostly discarded. Overall, species at high risk were overfished and/or subjected to overfishing. Moreover, all species considered to be within extinction risk (Critically Endangered, Endangered and Vulnerable) were in the high-risk category. The good concordance between approaches corroborates the results of our analysis. PSA is not a replacement for traditional stock assessments, where a stock is assessed at regular intervals to provide management advice. It is of importance, however, where there is uncertainty about catches and life history parameters, since it can identify species at risk, and where management action and data collection is required, e.g. for many species at high and most at moderate risk in the South Atlantic and Indian oceans.

1. Introduction

Several frameworks and approaches have been developed to help manage the risks posed to species bycaught in a range of fisheries (Astles et al., 2006; Arrizabalaga et al., 2011; Brown et al., 2015). One

(Hobday et al., 2011; Cortés et al., 2015).

PSA is a semi-quantitative risk analysis which has been used by several management and advisory bodies for a range of taxa: e.g. the Australian Fisheries Management Authority (Hobday et al., 2007; Smith et al., 2007), the Lenfest Working Group (Rosenberg et al., 2007) and for assessing the vulnerability of USA fisheries (Dunbar

of Atlantic Tunas (ICCAT) has conducted a PSA for sharks, which subsequently resulted in the implementation of a range of management measures for their conservation (Cortés et al., 2015).

Tuna and tuna-like species are important social and economic resources worldwide, both for industrial fleets operating offshore in areas beyond national jurisdiction and for artisanal fleets operating in coastal waters (Arrizabalaga et al., 2011). The tuna longline fishery is one of the main large-scale fishing activities in the world. Due to their highly migratory nature and widespread distribution, five Regional Fisheries Management Organizations (RFMOs) are in charge of the management and conservation of tunas and billfishes: ICCAT (Atlantic Ocean), the Indian Ocean Tuna Commission (IOTC, Indian Ocean), the Inter-American Tropical Tuna Commission (IATTC, Eastern Pacific Ocean), the Western and Central Pacific Fisheries Commission (WCPFC, Western Pacific Ocean), and the Commission for the Conservation of Southern Bluefin Tuna (CCSBT, Southern Ocean).

There is a growing concern about the status of several pelagic fish stocks targeted or caught incidentally in the tuna longline fishery, especially for Scombrids and billfishes, which may be heavily overfished or are recovering from being overfished (Collette et al., 2011). The assessment and management of bycatch and byproduct caught by the tuna longline fisheries is hampered because species-specific catch and biological data are limited or are aggregated with other species, making it difficult to run conventional stock assessment models. Even for the main target tunas (e.g. *Thunnus thynnus*, *T. alalunga*, *T. obesus*, *T. albacares* and *T. maccoyii*) and swordfish (*Xiphias gladius*), where relatively good data exist, stock assessments rely on fisheries dependent data. The PSA approach therefore is useful as an exploratory or triage tool for fisheries managers helping to identify species, populations, stocks or regions where the risk of negative interaction with the fishery activity is greatest, being also used in determining priorities for data collection, stock assessment and management.

In the current study, the relative vulnerability of tuna, billfishes and other teleost species caught in pelagic longlines in the South Atlantic and Indian Oceans is assessed by applying a semi-quantitative PSA. Specifically, (a) the vulnerability of the species in the study areas was evaluated; (b) the vulnerability of target and non-target species by ocean was compared; (c) the sensitivity of the results to data quality was analyzed; and (d) the results of the PSA were compared to other more quantitative assessments methods.

2. Material and methods

2.1. Catch composition of the tuna longline fishery in South Atlantic and Indian Oceans

A list of species of the infraclass Teleostei caught by the tuna longline fishery in the South Atlantic and the Indian Ocean was compiled from a variety of sources. The initial list was based on official statistics from ICCAT and IOTC. The list was then updated using published documents (Marín et al., 1998; Bach et al., 2008, 2009; Hurrell et al., 2010; Pardo et al., 2011), the national Fisheries

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 indicates a relative low productivity and high risk and 3 indicates a relative high productivity and low risk. Conversely, for the susceptibility attributes, 3 indicates relatively high susceptibility and high risk and 1 relatively low susceptibility and low risk. Where attributes were missing, a score was not assigned and were not used in the computation of the final P or S scores. Each attribute score was then weighted and the overall species productivity and susceptibility scores were a weighted mean of the attribute scores.

The two-dimensional nature of the PSA leads directly to the calculation of an overall vulnerability score (v) for a stock, defined as the Euclidean distance from the origin of a PSA scatter plot:

$$v = \sqrt{(P - X_0)^2 + (S - Y_0)^2}$$

where X_0 and Y_0 are the (x, y) origin coordinates.

Stocks were then assigned to a risk category (high, moderate and low) by ranking the vulnerability scores using a quantile method. The scores can be depicted graphically in a scatter plot, with P on the x-axis and S on the y-axis. The x-axis is reversed (i.e. it starts at 3 and ends at 1) so that the region close to the origin (which was at 3, 1) corresponded to the less vulnerable stocks, i.e. those with high-productivity and low-susceptibility stocks, while the most vulnerable stocks are found furthest from the origin.

Vulnerability was assessed by ocean, family and considering the fate of the catch. The fate of the catch of each species was assigned into four categories (Bach et al., 2008; Lucena Frédou et al., 2016), namely: target species (T), bycatch species kept for consumption on board (BY/KA), bycatch species kept for sale (BY/KC), bycatch and discarded species (BY/D). The fate category was assigned based on literature, market data and expert advice.

2.2.1. Productivity attributes

Seven life-history traits were selected for productivity attributes (Table 1), as follows:

- (1) Maximum size (L_{max} , cm): maximum reported fork length obtained from the literature, the RFMOs (ICCAT, IOTC and CCSBT) and national Brazilian and French databases. When fork length was missing, conversion factors from the literature or national observer program databases were used.
- (2) Fecundity (Fec, in millions of oocytes): mid-point of the reported range of number of eggs per individual for a given spawning event or period. Data were obtained from literature.
- (3) r : the intrinsic rate of population growth or maximum population growth that would occur in the absence of fishing at a small size, calculated from life history parameters for each stock using the approach of Fortuna et al. (2014) (see details in SOM 1).

Data on the following attributes were obtained from the literature and, when values were given by sex, these were averaged.

Table 2
Susceptibility attributes and rankings used to determine the vulnerability of a stock caught by tuna longline fishery in South Atlantic and Indian Oceans.

| Attribute | 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 |
| Vertical overlap | < 25% of stock occurs in the depths fished | Between 25% and 50% of the stock occurs in the depths fished | > 50% of stock occurs in the depths fished |
| Mort | < 33 | 33–67% | > 67 |
| % > 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 | No regulation are in effect |
| Z/k | < 0.5 | 0.5–1.0 | > 1 |

- (4) von Bertalanffy growth coefficient (k , cm.k^{-1}): measures how rapidly a fish reaches its maximum size.
- (5) Size at first maturity (L_{50} , cm): length at which 50% of the individuals attain sexual maturity for the first time.
- (6) Maximum age (T_{max} , years): maximum reported age.
- (7) L_{50}/L_{max} : a ratio that describes the relative investment into somatic and reproductive growth.

Many studies have shown that life history parameters are correlated (e.g. Roff, 1984; Jensen, 1996; Reynolds et al., 2001). Therefore, when data were missing, we used empirical relationships between life history parameters to estimate biological attributes. For instance, missing L_{50} and k were estimated from linear regressions against maximum size (SOM 2).

The boundaries between the three risk categories (low, medium, high) were established using the quantiles of the distribution of the vulnerability scores for the 60 stocks (Table 1).

2.2.2. Susceptibility attributes

Six attributes for susceptibility were considered (Table 2):

- (1) Availability or horizontal overlap: greater overlap implies greater susceptibility, since 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 were obtained from the IUCN (*International Union for Conservation of Nature*) or FISHBASE (Froeser and Pauly, 2007). Effort distribution, from year 2000 to 2011, was obtained for the South Atlantic Ocean from ICCAT and, for the

Brazilian (2005 to 2011) and the French national databases (2001 to 2011). For the southern bluefin tuna (*T. maccoyii*), the CCSBT database was used (2000 to 2011). Z/k is a life history invariant and a natural parameter in yield-per-recruit analysis (Beverton and Holt, 1993, Gallucci et al., 1995). Z/k is associated with different patterns of survivorship, e.g. how the number of survivors decreases at size (and age), and a high value of Z/k for a stock indicates reduced survivorship and hence higher susceptibility. Species with a ratio larger than 1 are considered the most susceptible (Pauly, 1984).

- (4) Percentage of adults in catches ($\% > L_{50}$): the percentage of individuals larger than the length at first maturity (L_{50}), obtained from the length distributions. The score threshold of this attribute was defined using the quantiles of the distribution.
- (5) Post-capture mortality (Mort): obtained from the literature (Ward and Curran, 2004; Poisson et al., 2010; Pacheco et al., 2011). The thresholds of this attribute were based on Patrick et al. (2010).
- (6) Management strategy: the management measures for each species were obtained from the reports of SCRS (Standing Committee on Research and Statistics, ICCAT, 2015a), for the South Atlantic, from the IOTC Scientific Committee, for the Indian Ocean (IOTC, 2015) and from CCSBT, specifically for the Southern Bluefin Tuna (see SOM 3 for a list of regulations in operation). Stocks subjected to a number of conservation and management measures were assumed to be less susceptible to be overfished and/or subjected to overfishing, while stocks with no effective regulation were considered more susceptible.

2.3. Attributing weights

Weights were adjusted within a scale from 1 to 3 (default weight of 2). Lucena Frédou et al. (2016) showed that differences between species and oceans were mainly explained by L_{max} and k . These two attributes, plus r (a key to resilience; Musick et al., 2001) were thus given weight 3. A default weight of 2 was used for all other susceptibility attributes except for Management Strategy for which a weight of 1 was assigned, given that, although there are often a large amount of regulations in force (see SOM 3), it is difficult to guarantee compliance with these by each flag state.

2.4. Measuring uncertainties

Data-poor stocks may receive inflated vulnerability scores due to a lack of information (Fujita et al., 2014). Therefore, a data-quality index, to identify cases with limited data, was adapted from Patrick et al. (2010). This was obtained for the productivity and susceptibility scores as a weighted average (using the same weights as 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 a comparison of the estimated vulnerability with the best data (see

Table 3

Tiers of data quality used when evaluating the productivity and susceptibility of the teleosts caught by tuna long line fisheries in South Atlantic and Indian Oceans.

| 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 pseudocoort) |
| Acceptable data (3) | Parameters obtained by empirical relationships or on studies of the same species in adjacent area. | Parameters estimated from linear regressions 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 | |

2.5. Statistical test

The differences between productivity, susceptibility and vulnerability scores by ocean, families and fate of the catch were assessed using Kruskal-Wallis rank sum tests and post-hoc multiple comparison tests. These tests were also used to test for differences in the data quality index. Statistical analyses were performed using the R statistical software v.3.0.2 (R Development Core Team, 2014).

2.6. Integrating data analysis

To gain a good understanding of the relative risks faced by teleosts species caught by the tuna longline fisheries, the results of the PSA were compared with two others approaches: (a) IUCN Red List of Threatened Species, which determines the species’ relative risk of extinction and threat category using a detailed set of qualitative and quantitative criteria; and (b) stock assessment conducted by the RFMO’s (ICCAT, IOTC and CCSBT).

The IUCN Red List categories considered in this study comprised 6 levels of extinction risk: Critically Endangered (CR), Endangered (EN), Vulnerable (VU), Near Threatened (NT), Least Concern (LC) and Data Deficient (DD). The classification criteria, application guidelines and IUCN Red List methodology on how to apply the Criteria are detailed in IUCN (2014). For the South Atlantic Ocean, the categories were obtained from a regional assessment, coordinated by the Brazilian Ministry of Environment (MMA), through the Instituto Chico Mendes de Conservação da Biodiversidade (ICMBIO) (ICMBIO, 2016). No regional assessment was available for the Indian Ocean, and so the Global Assessment categories were adopted in that case. IUCN assessments were carried out from 2009 to 2014 (see SOM 4 for assessment

species were present in both oceans (Table 4).

A wide range of productivity (1.00–2.87) and susceptibility (1.40–3.00) scores were seen (Table 4, Fig. 1). There was a significant ($P < 0.05$) difference between productivity scores by family. The Istiophoridae family exhibited the lowest scores compared to species of the family Bramidae (Table 5a, Fig. 2). *Scomberomorus regalis* (Scombridae, Atlantic) were the most productive, and *Nesiarchus nasutus* (Gempylidae, Atlantic) the less susceptible (Table 4, Fig. 1). No significant differences in productivity and susceptibility scores were observed between oceans ($P < 0.05$) (Table 5b).

A large range in vulnerability scores was also seen, ranging from 2.64 (Atlantic Sailfish *Istiophorus albicans*) to 0.67 (*N. nasutus* from the South Atlantic Ocean) (Table 4, Fig. 1). Again, the differences in vulnerability scores between oceans were not significant, but those between families were. Species of the Istiophoridae showed the highest vulnerability scores when compared to species of the family Bramidae ($P < 0.05$) (Table 5a, Fig. 2).

Significant differences were observed for productivity and vulnerability scores between the catch fate categories ($P < 0.05$) (Table 5c). Target species (T) showed lower scores of productivity than all the other categories and were also more vulnerable than non-commercialized species (BY/D and BY/KA) ($P < 0.05$) (Fig. 3, Table 5c).

The top 10 species at risk were Atlantic *Istiophorus albicans*; Indian Ocean *Istiompax indica*; Atlantic *Makaira nigricans* and *Thunnus alalunga*; Indian Ocean *X. gladius*; Atlantic *T. albacares*, *Gempylus serpens*, *Ranzania laevis* and *X. gladius* and Indian Ocean *T. alalunga*. Species considered at high risk (i.e. the 21 first ranked species) included all billfishes (Istiophoridae and Xiphidae - except for Atlantic *T. pfluegeri* and Indian Ocean *K. audax*, which had a moderate risk) and most targeted species (except Atlantic *T. obesus* and Indian Ocean *T. albacares*, which were at moderate risk). Bycatch Scombridae species, such as *S. brasiliensis*, Atlantic *Katsuwonus pelamis* and the Indian Ocean *Acanthocybium solandri*, were in the high-risk group. All species considered at high risk were target or commercialized bycatch (BY/KC), except Atlantic *G. serpens* and *R. laevis*, which are discarded (BY/D) (Table 4).

Species from 8 different families occurred in the moderate risk group (rank 22 to 40; vulnerability score from 1.89 to 1.51) (Table 4). Most species at moderate risk are commercialized bycatch (BY/KC). Most discarded species (BY/D) were classified as being at low risk. Species classified at low risk (vulnerability scores varying from 1.49 to 0.67) belonged to several families (Table 4, Fig. 3). No target species were assessed as being at low risk.

The most common species, in both oceans, were classified as being in the same risk category. However, the target species *T. albacares* was considered as being at high risk in the Atlantic whereas it was categorized at only moderate risk in the Indian Ocean. The opposite was observed for the targeted species *T. obesus*, which was at high risk in the Indian Ocean and at moderate risk in the Atlantic. *K. pelamis* and *R. laevis* were at high risk in the Atlantic and low risk in the Indian Ocean (Table 4).

Table 4

Productivity, susceptibility and vulnerability scores, rank and risk of the teleosts caught by tuna longline fisheries in South Atlantic and Indian Oceans. Data quality index for productivity, susceptibility and vulnerability scores. Data-quality scores: poor > 3.5; moderate 2.0–3.5 and good < 2.0. T - target species, BY/KA - bycatch species kept for consumption on board, BY/KC - bycatch species kept for sale, BY/D - bycatch and discarded species. Alepsauridae (ALÉ), Bramidae (BRA), Carangidae (CAR), Coryphaenidae (COR), Gempylidae (GEM), Isthophoridae (IST), Lampridae (LAM), Molidae (MOL), Scombridae (SCO), Sphyrænidae (SPH), Trachipteridae (TRA), Xiphidae (XIP). South Atlantic Ocean (ATL), Indian Ocean (IND). Critically Endangered (CR), Endangered (EN), Vulnerable (VU), Near Threatened (NT), Least Concern (LC), Data Deficient (DD). Stocks considered overfished (SByear/SB_{MSY} < 1) and subject to overfishing (Fyear/F_{MSY} > 1) – red; Stocks considered overfished (SByear/SB_{MSY} < 1) but not subject to overfishing (Fyear/F_{MSY} < 1) – yellow; Stocks not overfished (SByear/SB_{MSY} > 1) and subject to overfishing (Fyear/F_{MSY} > 1) - orange and Stocks not overfished (SByear/SB_{MSY} > 1) and not subject to overfishing (Fyear/F_{MSY} > 1); grey – see explanation on Section 3.3 of the results. ? – uncertainty in the determination of the status of the stock.

| Ocean | Species | Code | Family | Productivity | Susceptibility | Vulnerability | | | | Data Quality | | | | IUCN | Stock Asses. |
|-------|----------------------------|------|--------|--------------|----------------|---------------|------|-------------------|----------|--------------|---------|-----------|------------|------|--------------|
| | | | | | | Score | Rank | Fate of the catch | Risk | QualProd | QualSus | Mean Qual | Data Qual. | | |
| ATL | Istiophorus albigens | SAI | IST | 1.000 | 2.727 | 2.643 | 1 | BY/KC | High | 1.35 | 1.00 | 1.18 | Good | LC | ? |
| IND | Istiompax indica | BLM | IST | 1.000 | 2.545 | 2.528 | 2 | BY/KC | High | 1.82 | 1.00 | 1.41 | Good | DD | |
| ATL | Makaira nigricans | BUM | IST | 1.235 | 2.636 | 2.407 | 3 | BY/KC | High | 1.71 | 1.00 | 1.35 | Good | EN | |
| ATL | Thunnus alalunga | ALB | SCO | 1.294 | 2.636 | 2.364 | 4 | T | High | 1.35 | 1.00 | 1.18 | Good | LC | |
| IND | Xiphias gladius | SWO | XIP | 1.353 | 2.636 | 2.322 | 5 | T | High | 1.59 | 1.00 | 1.29 | Good | LC | |
| ATL | Thunnus albacares | YFT | SCO | 1.412 | 2.636 | 2.280 | 6 | T | High | 1.35 | 1.00 | 1.18 | Good | LC | |
| ATL | Gempylus serpens | GES | GEM | 1.667 | 2.714 | 2.172 | 7 | BY/D | High | 2.65 | 3.00 | 2.82 | Moderate | LC | |
| ATL | Ranzania laevis | RZV | MOL | 2.154 | 3.000 | 2.172 | 8 | BY/D | High | 3.12 | 3.18 | 3.15 | Moderate | LC | |
| ATL | Xiphias gladius | SWO | XIP | 1.588 | 2.636 | 2.161 | 9 | T | High | 1.35 | 1.00 | 1.18 | Good | NT | ? |
| IND | Thunnus alalunga | ALB | SCO | 1.647 | 2.636 | 2.123 | 10 | T | High | 1.35 | 1.00 | 1.18 | Good | NT | |
| IND | Istiophorus platypterus | SFA | IST | 1.588 | 2.545 | 2.093 | 11 | BY/KC | High | 2.41 | 1.00 | 1.71 | Good | LC | ? |
| IND | Thunnus maccoyii | SBF | SCO | 1.235 | 2.091 | 2.075 | 12 | T | High | 1.35 | 1.00 | 1.18 | Good | CR | |
| IND | Thunnus obesus | BET | SCO | 1.529 | 2.455 | 2.068 | 13 | T | High | 1.35 | 1.00 | 1.18 | Good | VU | |
| ATL | Coryphaena equiselis | CFW | COR | 2.533 | 3.000 | 2.054 | 14 | BY/KC | High | 2.88 | 3.18 | 3.03 | Moderate | LC | |
| IND | Makaira nigricans | BUM | IST | 1.471 | 2.364 | 2.049 | 15 | BY/KC | High | 2.41 | 1.00 | 1.71 | Good | VU | |
| ATL | Tetrapturus georgii | SPG | IST | 1.769 | 2.636 | 2.048 | 16 | BY/KC | High | 3.12 | 1.00 | 2.06 | Moderate | DD | |
| ATL | Katsuwonus pelamis | SKJ | SCO | 1.706 | 2.571 | 2.036 | 17 | BY/KC | High | 1.35 | 2.45 | 1.90 | Good | LC | |
| ATL | Kajikia albidus | WHM | IST | 1.824 | 2.636 | 2.015 | 18 | BY/KC | High | 1.35 | 1.00 | 1.18 | Good | VU | ? |
| ATL | Scomberomorus brasiliensis | BRS | SCO | 1.824 | 2.600 | 1.986 | 19 | BY/KC | High | 1.35 | 3.18 | 2.27 | Moderate | LC | |
| IND | Tetrapturus angustirostris | SSP | IST | 1.769 | 2.556 | 1.984 | 20 | BY/KC | High | 2.88 | 2.09 | 2.49 | Moderate | DD | |
| IND | Acanthocybium solandri | WAH | SCO | 2.059 | 2.714 | 1.956 | 21 | BY/KC | High | 2.06 | 2.45 | 2.26 | Moderate | LC | |
| ATL | Scomberomorus cavalla | KGM | SCO | 1.529 | 2.200 | 1.898 | 22 | BY/KC | Moderate | 1.35 | 3.18 | 2.27 | Moderate | LC | |
| IND | Kajikia audax | MLS | IST | 1.941 | 2.545 | 1.873 | 23 | BY/KC | Moderate | 2.41 | 1.00 | 1.71 | Good | NT | |
| ATL | Acanthocybium solandri | WAH | SCO | 2.118 | 2.636 | 1.859 | 24 | BY/KC | Moderate | 1.94 | 1.00 | 1.47 | Good | LC | |
| IND | Sphyræna barracuda | GBA | SPH | 1.706 | 2.333 | 1.858 | 25 | BY/KC | Moderate | 2.06 | 2.64 | 2.35 | Moderate | - | |
| ATL | Mola mola | MOX | MOL | 1.538 | 2.143 | 1.855 | 26 | BY/D | Moderate | 3.47 | 3.00 | 3.24 | Moderate | LC | |
| IND | Trachipterus ishikawae | TRI | TRA | 1.538 | 2.143 | 1.855 | 26 | BY/D | Moderate | 3.12 | 3.00 | 3.06 | Moderate | - | |
| ATL | Thunnus obesus | BET | SCO | 1.706 | 2.273 | 1.815 | 28 | T | Moderate | 1.35 | 1.00 | 1.18 | Good | NT | |
| ATL | Tetrapturus pfluegeri | SPF | IST | 2.067 | 2.556 | 1.814 | 29 | BY/KC | Moderate | 1.82 | 1.73 | 1.78 | Good | LC | |
| IND | Thunnus albacares | YFT | SCO | 1.941 | 2.455 | 1.799 | 30 | T | Moderate | 1.35 | 1.00 | 1.18 | Good | LC | |
| IND | Lampris guttatus | LAG | LAM | 2.133 | 2.556 | 1.781 | 31 | BY/KC | Moderate | 3.00 | 2.64 | 2.82 | Moderate | LC | |
| ATL | Sphyræna barracuda | GBA | SPH | 2.000 | 2.429 | 1.744 | 32 | BY/KA | Moderate | 2.88 | 3.00 | 2.94 | Moderate | LC | |
| ATL | Euthynnus alletteratus | LTA | SCO | 2.412 | 2.600 | 1.705 | 33 | BY/KC | Moderate | 2.41 | 3.18 | 2.80 | Moderate | LC | |
| IND | Gempylus serpens | GES | GEM | 1.867 | 2.273 | 1.704 | 34 | BY/D | Moderate | 3.00 | 1.91 | 2.45 | Moderate | - | |
| ATL | Auxis rochei | BLT | SCO | 2.471 | 2.600 | 1.685 | 35 | BY/KC | Moderate | 3.00 | 3.18 | 3.09 | Moderate | DD | |
| ATL | Auxis thazard | FRI | SCO | 2.533 | 2.600 | 1.667 | 36 | BY/KC | Moderate | 3.24 | 3.18 | 3.21 | Moderate | LC | |
| IND | Ruvettus pretiosus | OIL | GEM | 1.800 | 2.091 | 1.622 | 37 | BY/KC | Moderate | 3.00 | 1.36 | 2.18 | Moderate | LC | |
| IND | Alepisaurus ferax | ALX | ALE | 2.154 | 2.273 | 1.528 | 38 | BY/D | Moderate | 2.65 | 1.00 | 1.82 | Good | LC | |
| ATL | Alepisaurus ferax | ALX | ALE | 2.000 | 2.143 | 1.519 | 39 | BY/D | Moderate | 3.12 | 2.82 | 2.97 | Moderate | LC | |
| IND | Gasterochisma melampus | BUK | SCO | 2.000 | 2.143 | 1.519 | 39 | BY/D | Moderate | 3.12 | 3.00 | 3.06 | Moderate | LC | |
| ATL | Ruvettus pretiosus | OIL | GEM | 1.800 | 1.889 | 1.493 | 41 | BY/D | Low | 1.35 | 2.27 | 1.81 | Good | LC | |
| IND | Elagatis bipinnulata | RRU | CAR | 2.692 | 2.429 | 1.461 | 42 | BY/KC | Low | 3.12 | 3.00 | 3.06 | Moderate | LC | |
| IND | Brama brama | POA | BRA | 2.692 | 2.429 | 1.461 | 42 | BY/KA | Low | 3.12 | 2.82 | 2.97 | Moderate | LC | |
| IND | Ranzania laevis | RZV | MOL | 2.692 | 2.429 | 1.461 | 42 | BY/D | Low | 3.12 | 2.82 | 2.97 | Moderate | LC | |
| ATL | Elagatis bipinnulata | RRU | CAR | 2.267 | 2.200 | 1.406 | 45 | BY/KA | Low | 2.18 | 3.18 | 2.68 | Moderate | LC | |
| ATL | Sarda sarda | BOM | SCO | 2.294 | 2.200 | 1.392 | 46 | BY/KC | Low | 1.82 | 3.18 | 2.50 | Moderate | LC | |
| IND | Thyrsites atun | SNK | GEM | 2.333 | 2.143 | 1.323 | 47 | BY/D | Low | 1.82 | 2.45 | 2.14 | Moderate | - | |
| IND | Katsuwonus pelamis | SKJ | SCO | 2.471 | 2.143 | 1.260 | 48 | BY/KA | Low | 1.35 | 2.45 | 1.90 | Good | LC | |
| ATL | Lepidocybium flavobrunneum | LEC | GEM | 2.538 | 2.143 | 1.233 | 49 | BY/KC | Low | 2.88 | 3.00 | 2.94 | Moderate | LC | |
| ATL | Lampris guttatus | LAG | LAM | 2.133 | 1.857 | 1.219 | 50 | BY/KC | Low | 2.88 | 2.82 | 2.85 | Moderate | LC | |
| ATL | Coryphaena hippurus | DOL | COR | 2.471 | 2.091 | 1.213 | 51 | BY/KC | Low | 1.59 | 1.00 | 1.29 | Good | LC | |
| ATL | Scomberomorus regalis | CER | SCO | 2.867 | 2.200 | 1.207 | 52 | BY/KC | Low | 2.88 | 3.18 | 3.03 | Moderate | LC | |
| ATL | Thunnus atlanticus | BLF | SCO | 2.529 | 2.111 | 1.207 | 53 | BY/KC | Low | 1.47 | 1.73 | 1.60 | Good | LC | |
| ATL | Alepisaurus brevirostris | ALO | ALE | 2.846 | 2.143 | 1.153 | 54 | BY/D | Low | 3.12 | 2.82 | 2.97 | Moderate | LC | |
| IND | Coryphaena hippurus | DOL | COR | 2.706 | 2.091 | 1.130 | 55 | BY/KC | Low | 1.71 | 1.55 | 1.63 | Good | LC | |

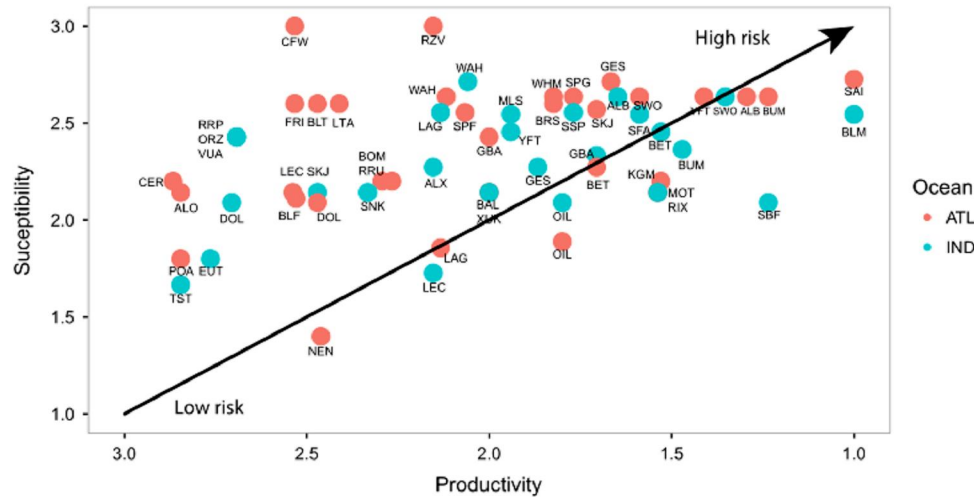


Fig. 1. Overall distribution of productivity and susceptibility plot for the teleosts caught by tuna longline fisheries in South Atlantic and Indian Oceans. Codes are in Table 4.

Table 5

Nonparametric post-hoc multiple comparison tests of the productivity, susceptibility and vulnerability scores of teleosts caught by tuna longline fisheries in South Atlantic and Indian Oceans by family (a); Ocean (b); and Fate of the catch (c). T=target species. BY/KA=bycatch species kept for consumption on board. BY/KC=bycatch species kept for sale. BY/D=bycatch and discarded species. Different letters indicate significant differences.

| (a) | | | |
|-------------------|---------------------|-------------------|---------------------|
| Familly | Productivity | Susceptibility | Vulnerability |
| Alepsauridae | 2.33 ^{a,c} | 2.18 ^a | 1.40 ^{a,c} |
| Bramidae | 2.79 ^{b,c} | 1.96 ^a | 0.98 ^{b,c} |
| Carangidae | 2.47 ^{a,c} | 2.31 ^a | 1.43 ^{a,c} |
| Coryphaenidae | 2.56 ^{a,c} | 2.39 ^a | 1.46 ^{a,c} |
| Gempylidae | 2.08 ^{a,c} | 2.04 ^a | 1.41 ^{a,c} |
| Isthiophoridae | 1.56 ^a | 2.57 ^a | 2.14 ^a |
| Lampridae | 2.13 ^{a,c} | 2.20 ^a | 1.49 ^{a,c} |
| Molidae | 2.05 ^{a,c} | 2.52 ^a | 1.82 ^{a,c} |
| Scombridae | 2.01 ^{a,c} | 2.39 ^a | 1.74 ^{a,c} |
| Sphyraenidae | 1.85 ^{a,c} | 2.38 ^a | 1.80 ^{a,c} |
| Trachipteridae | 1.53 ^{a,c} | 2.14 ^a | 1.85 ^{a,c} |
| Xiphiidae | 1.47 ^{a,c} | 2.63 ^a | 2.24 ^{a,c} |
| Mean | 2.05 | 2.26 | 1.60 |
| (b) | | | |
| Ocean | Productivity | Susceptibility | Vulnerability |
| S. Atlantic | 2.04 ^a | 2.38 ^a | 1.72 ^a |
| Indian | 2.00 ^a | 2.30 ^a | 1.68 ^a |
| (c) | | | |
| Fate of the catch | Productivity | Susceptibility | Vulnerability |
| BY/D | 2.12 ^b | 2.14 ^a | 1.48 ^b |
| BY/KA | 2.51 ^b | 2.13 ^a | 1.25 ^b |
| BY/KC | 2.02 ^b | 2.44 ^a | 1.78 ^{a,b} |
| T | 1.52 ^a | 2.49 ^a | 2.11 ^a |

4. Discussion

Ecosystem-based management (EBM) is widely considered to be a strategy for achieving sustainable delivery of marine ecosystem services (Francis et al., 2011). The application of the EBM framework to fisheries management, i.e. taking an Ecosystem Approach to Fisheries (EAF), is mandated in several nations around the world (Micheli et al., 2014). Ecological Risk Assessment (ERA), a hierarchical risk assessment framework, has been adopted by the Marine Stewardship Council and is one of the tools found in the FAO-EAF toolbox (Dunstan et al., 2016).

PSA, a semi-quantitative risk analysis procedure, has the ability to provide broad scientific advice to policy makers and stakeholders (Kwon et al., 2009). Even though this approach does not result in traditional fishery management reference points (Fujita et al., 2014), it does allow for the prioritization of monitoring, assessment and management for stocks and species that are at the greatest risk from fishing (Hobday et al., 2011). Under the Precautionary Approach (PA), undesirable outcomes should be anticipated and measures taken to reduce the probability of them occurring (Garcia, 1995). PSA is particularly useful in data poor situations, when catch or biological data are not comprehensive, often aggregated across species or are insufficient to run a quantitative stock assessment. The latter is the case for the tuna longline fishery in the South Atlantic and Indian Ocean.

A total of 33 and 27 species were recorded as the main teleost species caught by the tuna longline fisheries in the South Atlantic and Indian Ocean, respectively, although only four and five species respectively were considered as targets (T). 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.

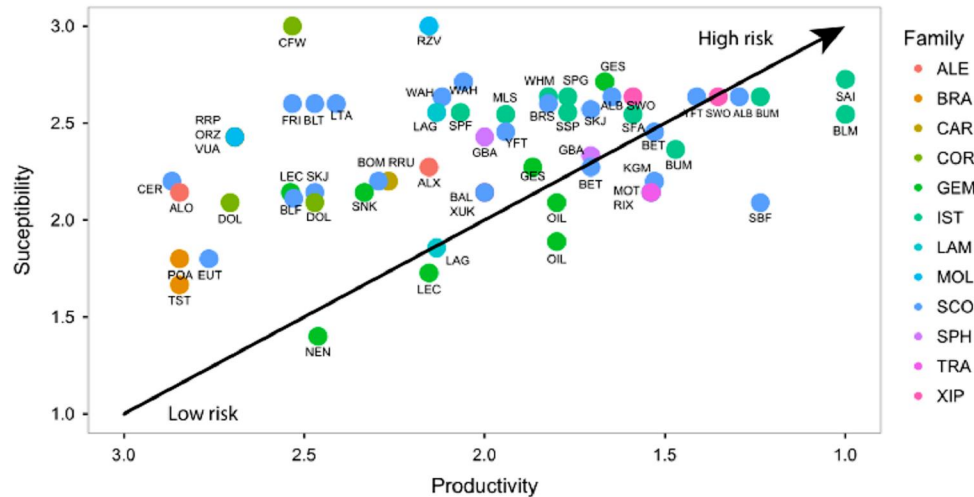


Fig. 2. Overall distribution of productivity and susceptibility plot by family of teleosts caught by tuna longline fisheries in South Atlantic and Indian Oceans. Codes are in Table 4.

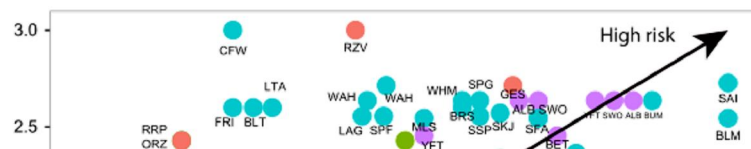
These species have moderate to low productivity and high susceptibility, and so are vulnerable to potential negative impacts. For target species, this is perhaps not surprising as the objective of longline fisheries are to catch them, and hence encounterability and availability are high. Even if these species are well managed, they are likely to exhibit high rates of mortality, particularly for juveniles (see SOM 5). Those two latter attributes could be considered in future management scenarios, by using PSAs to re-score stocks under alternative management options (Phillips et al., 2015). This would help to identify the effects of alternatives strategies for reducing risk. For the North Atlantic Ocean, among the 10 species with the highest risk scores were coastal and pelagic sharks, non-ICCAT teleosts and two ICCAT species, *T. alalunga* and *T. obesus* (Arrizabalaga et al., 2011), species that were at high and moderate risk in our study, respectively. For the Pacific Ocean, *T. alalunga*, *T. obesus*, *T. albacares*, *K. pelamis*, and billfishes were considered at medium risk, while sharks were considered at high risk (Kwon et al., 2009).

Istiophoridae are inherently vulnerable due to their biological characteristics, coupled with moderate to high market values (Marín et al., 1998). They are also highly vulnerable in relation to encounterability and availability; being exposed to considerable mortality rates with important catches of juveniles. For Istiophoridae in the South Atlantic, mitigation measures are in place for *Makaira nigricans* and *Kajikia albidus* (see SOM 3). However, for the Indian Ocean, no species-specific conservation and management measures are currently

adopted for any of the billfishes.

Some stocks at high risk, such as the south Atlantic *Scomberomorus brasiliensis* and the Indian *Acanthocybium solandri*, and most species at moderate risk, were not assessed in recent years and there is an overall lack of regulation. The South Atlantic *S. brasiliensis* and *S. cavalla* stocks (high and moderate risk, respectively) were considered fully exploited using length-based methods with data collected up to 2000 (Lucena Frédou and Asano Filho, 2006; Lessa et al., 2009a, 2009b; Nóbrega and Lessa 2009). *A. solandri* was also considered at high risk in the Western and Central Pacific (Kwon et al., 2009). Coastal scombrids are important source of wealth and food security to local fishing communities, especially in the South Atlantic (Lessa et al., 2009a, 2009b; Nóbrega and Lessa, 2009; Isaac et al., 2012; Mourão et al., 2014). The small tunas group of ICCAT has therefore encouraged future studies and application of this approach for those species, and is considering an extension of this analysis to the North Atlantic (ICCAT, 2015b). Managers must also remain vigilant to species and stocks in the more intermediate rankings (Phillips et al., 2015), especially with regard to data requirements for future assessments. Most species at moderate risk are commercialized bycatch (BY/KC). Given its secondary nature from an economic point of view, these bycatch species are often ignored when management regulations are adopted (Lucena Frédou et al., 2016).

Different authors have adopted alternative definitions of productivity and or susceptibility, depending on the species characteristics and



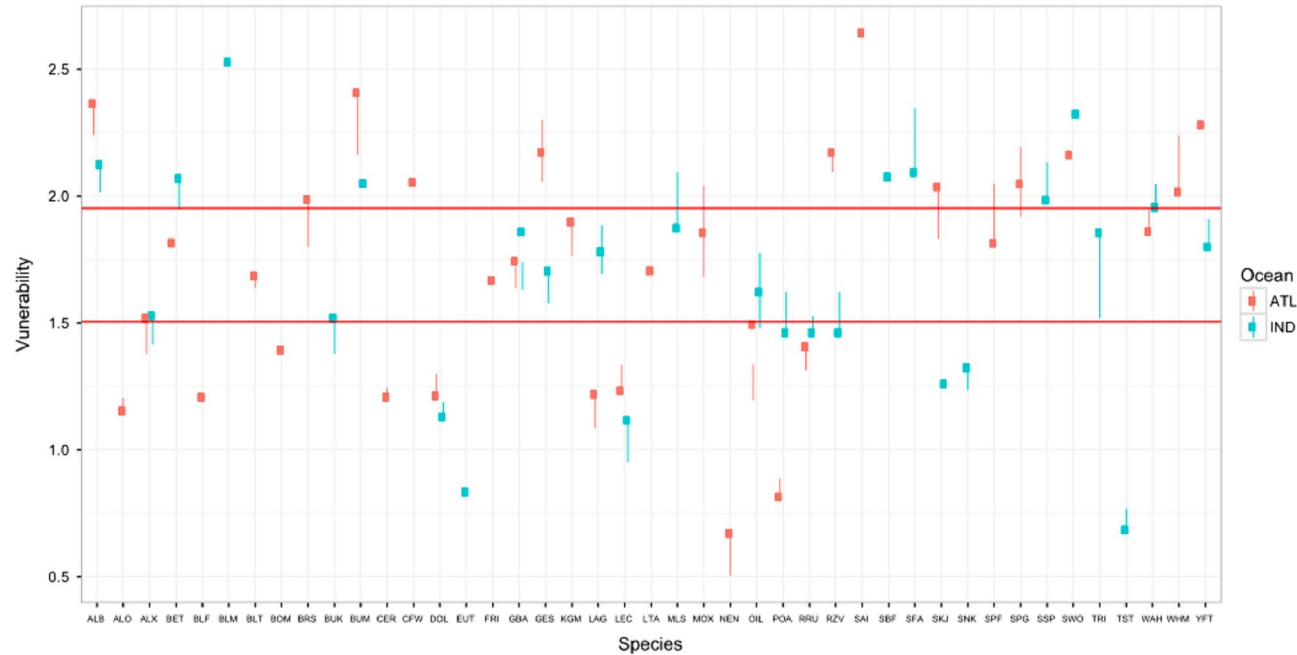
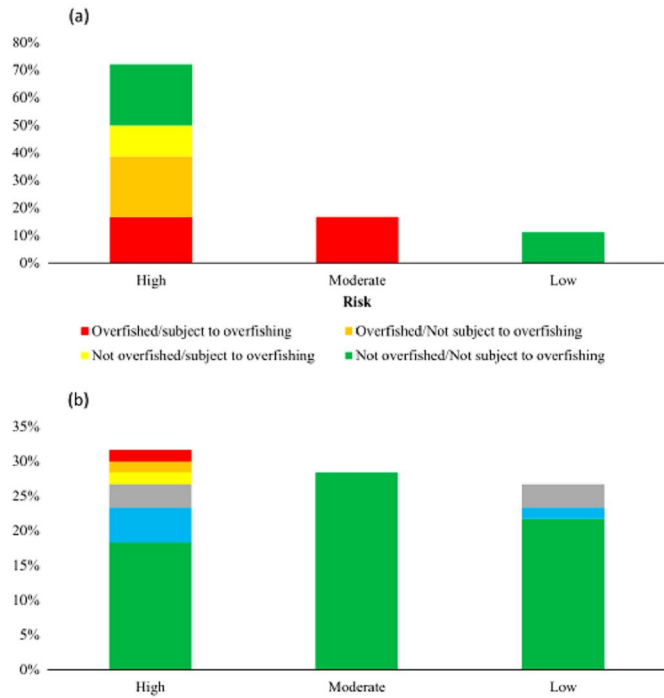


Fig. 5. Overall distribution of vulnerability scores with error bars corresponding to the scores when the lower and upper confidence limits of r is used for the calculation of Productivity score. Lines corresponds to the limits of Low to Moderate and Moderate to High Risks. Codes are in Table 4.



and (b) by evaluating the impact of the uncertainty of the estimated r (using the 2.5th and 97.5th percentiles) in rank and risk of the species. The uncertainty of the estimated intrinsic rate of population growth (r) altered the minority of the species. Data-poor stocks might receive inflated vulnerability scores due to lack of information (Fujita et al., 2014). In our study, data quality scores relied mainly within the moderate quality category although most species at high risk had good quality data. The conservative scoring approach classifies many stocks at high and major risk because of a lack of knowledge rather than true vulnerability, since PSA tends to over-classify species vulnerability (Osio et al., 2015). This occurs when a species is missing information on its productivity and susceptibility attributes and the risk score defaults to high risk.

There is a great scarcity of biological information for by-catch species caught by the tuna longline fishery (Lucena Frédou et al., 2016). This is the case of *Gempylus serpens* and *Ranzania laevis* (rank 7 and 8 respectively), classified as being at high risk. For those species, and also for *Coryphaena equiselis* (rank 14) (SOM 5) and *Katsuwonus pelamis* (rank 17), many susceptibility attributes are missing, and they are also within the high risk classification. According to Hobday et al. (2011), in general, this approach results in more false positives than false negatives (units scored at a lower risk than would occur when assessed at a higher level with more data). False positive results can be screened out at higher levels in the Ecological Risk Assessment hierarchy, while false negatives result in improper elimination of a

It appeared that vulnerability assessments were comparable. Overall, species at high risk were overfished and/or subjected to overfishing. Moreover, all species considered to be within extinction risk (CR, EN and VU) were in the high-risk category. These approaches have different level of complexities. Although some of the data used by IUCN, stock assessment methods and the PSA are similar, the criteria used to derive the risk, stock status and vulnerability are not and, converging conclusions are indeed a good indication of the health of these stocks and the robustness of PSA, even considering the limitations of the method. *Dulvy et al. (2005)* compared predictions of extinction risk for exploited marine fish and invertebrates (IUCN categories) with those of stock status reported in stock assessments, and found the results from the two approaches to be consistent. *Davies and Baum (2012)* also reported that IUCN categories and fisheries status (measured by whether the stock was above or below reference points) agreed well in assessing the status of marine fish, although they warned about equating falling below a fishery reference point with a Red List threatened status. *Osio et al. (2015)* compared vulnerability scores with IUCN extinction risk categories and found that species with higher vulnerability are, with few exceptions, ranked as most threatened by the IUCN.

Most species considered in our study are also caught by other gears, such as purse seine and pole and line. PSA, however, does not account for the relative cumulative risk to species from multiple activities. The method could be extended to assess individual and cumulative risk associated with different gears (see *Micheli et al., 2014*). The extension of PSA may provide a tool for evaluating risk posed by overlapping fisheries within an ecosystem-based management framework that accounts for the full suite of extractive activities and their possible interactions (*Micheli et al., 2014*). Also, for high-risk stocks, for which data quality is good, a move to quantitative ERA can be made.

Climate change and decadal variability are impacting marine fish and invertebrate species worldwide (*Hare et al., 2015*). The PSA approach could also take into account additional possible stressors due climate change in the future, particularly where changes are mainly related to life history and marine species distribution (*Perry et al., 2005; Petitgas et al., 2012; Lehodey et al., 2013*), which may negatively affect the populations by a decrease in productivity (*Hare et al., 2015*). When species distribution is changed, the distribution and magnitude of fishing effort (*Gamito et al., 2015; Pinsky and Fogarty, 2012*) may be affected and therefore the effectiveness of conservation and management measures (*Mackenzie et al., 2007*). Specifically for tuna populations, even if they have developed elaborated thermoregulation mechanisms (*Brill, 1994*), they are strongly influenced by the temperature and by other variables like dissolved oxygen, currents and prey concentration (*Lehodey et al., 2013*). The range of a stock is largely determined by environmental factors (*Arrizabalaga et al., 2015*), for example, the effect of climate change on Pacific skipjack is predicted to be an expansion of its range (*Lehodey et al., 2013*). Stocks may contract as a result of overfishing, which will affect fishing effort distribution and the PSA "horizontal overlap" attribute (*Sibert et al., 2006*). Such

contracting could limit the PSA assessment to the level of effort, management, data collection and research. In this regard, special attention should be given to Isthiophoridae, which has the highest vulnerability and stock status in largely unknown. Scombrids, particularly small tunas, given their economic importance for local fishing communities, should also be prioritized.

Acknowledgements

The authors would like to acknowledge the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) for providing a senior post-doc fellowship to F. Lucena Frédou and T. Frédou (Grants BEX 2407/13-2 and BEX 2702/13-4) and to the Ministry of Fisheries and Aquaculture of Brazil, through the onboard observer program (regulated by SEAP/MMA, IN Nº1, 29/09/2006). The collection of data of French commercial and observer fisheries data was supported by the European Union Data Collection Framework (DCF), regulated by Commission Regulation (EC) 665/2008 of 14 July 2008 and Commission technical decision 2010/93/UE of 18 December 2009. The data processing from the collection on field and at port to archive in dedicated database was supervised by the staff of the Tuna Observatory of the Institut de Recherche pour le Développement (IRD). We also thank two anonymous reviewers for their constructive comments on an earlier version of the manuscript.

Appendix A. Supplementary material

Supplementary data associated with this article can be found in the online version at <http://dx.doi.org/10.1016/j.dsr2.2016.10.008>.

References

- Arrizabalaga, H., Bruyn, P., Diaz, G.A., Murua, H., Chavance, P., Molina, A.D., Gaertner, D., Ariz, J., Ruiz, J., Kell, L.T., 2011. Productivity and susceptibility analysis for species caught in Atlantic tuna fisheries. *Aquat. Living Resour.* 24, 1–12.
- Arrizabalaga, H., Dufour, F., Kell, L., Merino, G., Ibaibarriaga, L., Chust, G., Irigoien, X., Santiago, J., Murua, H., Fraile, I., Chifflet, M., 2015. Global habitat preferences of commercially valuable tuna. *Deep-Sea Res. Part II* 113, 102–112.
- Astles, K.L., Holloway, M.G., Steffe, A.S., Green, M., Ganassin, C., Gibbs, P.J., 2006. An ecological method for qualitative risk assessment and its use in the management of fisheries in New South Wales, Australia. *Fish. Res.* 82, 290–303.
- Bach, P., Rabearisoa, N., Filippi, T., Hubas, S., 2008. The First Year of SEALOR: Database of SEA-going Observer Surveys Monitoring the Local Pelagic Longline Fishery Based in La Réunion. IOTC – 2008 – WPEB – 13.
- Bach, P., Rabearisoa, N., Filippi, T., Romanov, E.V., Pianet, R., 2009. Digest of Major Information Collected from May 2008 to August 2009 in the Frame of the Longline Observer Program Based in La Réunion. IOTC – 2009 – WPEB – 10.
- Bach, P., Sabarros, P., Le Foulgoc, L., Richard, E., Lamoureaux, E., Romanov, E., 2013. Self-reporting Data Collection Project for the Pelagic Longline Fishery Based in La Réunion. IOTC–2013–WPEB09–42.
- Beverton, R., Holt, S., 1993. *On the Dynamics of Exploited Fish Populations*. Ed. Springer, New York.
- Brill, R.W., 1994. A review of temperature and O₂ tolerance studies of tunas pertinent to fisheries oceanography, movement models and stock assessments. *Fish. Oceanogr.* 3, 204–216.
- Brown, S.L., Reid, D., Rogan, E., 2013. A risk-based approach to rapidly screen of cetaceans to impacts from fisheries bycatch. *Biol. Cons.* 168, 78–87.
- Brown, S.L., Reid, D., Rogan, E., 2015. Spatial and temporal assessment of potential risk to cetaceans from static fishing gear. *Mar. Pol.* 51, 267–280.

- Devine, J.A., Watling, L., Cailliet, G., Drazen, J., Durán Muñoz, P., Orlov, A.M., Bezaury, J., 2012. Evaluation of Potential Sustainability of Deep Sea Fisheries for Grenadiers (Macrouridae). *J. Ichthyol.* 52, 709–721.
- Dulvy, N.K., Jennings, S., Goodwin, N.B., Grant, A., Reynolds, J.D., 2005. Comparison of threat and exploitation status in Northeast Atlantic marine populations. *J. Appl. Ecol.* 42, 883–891.
- Dunstan, P.K., Bax, N.J., Dambacher, J.M., Hayes, K.R., Hedge, P.T., Smith, D.C., Smith, A.D.M., 2016. Using ecologically or biologically significant marine areas (EBSAs) to implement marine spatial planning. *Ocean. Coast. Manag.* 121, 116e127.
- Fortuna, C.M., Kell, L., Holec, D., Canese, S., Filidei, E., Jr, Mackelworth, P., Donovan, G., 2014. Summer distribution and abundance of the giant devil ray (*Mobula mobular*) in the Adriatic Sea: baseline data for an iterative management framework. *Sci. Mar.* 78, 227–237.
- Francis, T.B., Levin, P.S., Harvey, C.J., 2011. The perils and promise of futures analysis in marine ecosystem-based management. *Mar. Pol.* 35, 675–681.
- Fujita, R., Thornhill, D.J., Karr, K., Cooper, C.H., Dee, L.E., 2014. Assessing and managing data-limited ornamental fisheries in coral reefs. *Fish Fish* 15, 661–675.
- Froeser, R., Pauly, D., 2007. *Fishbase: World Wide Web Electronic Publication*. <http://www.fishbase.org> (accessed 02.01.16).
- Garcia, S.M., 1995. The precautionary approach to fisheries and its implications for fishery research, technology and management: an updated review. *FAO Tech. Pap.* 35, 1–76.
- Gallucci, V.F., Saila, S.B., Gustafson, D.J., Rothschild, B.J., 1995. *Stock Assessment: Quantitative Methods and Applications for Small Scale Fisheries* Ed.. CRC, Florida.
- Gamito, R., Teixeira, C.M., Costa, M.J., Cabral, H.N., 2015. Are regional fisheries' catches changing with climate? *Fish. Res.* 161, 207–216.
- Hare, J.A., Morrison, W.E., Nelson, M.W., Stachura, M.M., Teeters, E.J., Griffis, R.B., Alexander, M.A., Scott, J.D., Alade, L., Bell, R.J., Chute, A.S., Curti, K.L., Curtis, T.H., Kircheis, D., Kocik, J.F., Lucey, S.M., McCandless, C.T., Milke, L.M., Richardson, D.E., Robillard, E., Walsh, H.J., McManus, M.C., Marancik, K.E., Griswold, C.A., 2015. A vulnerability assessment of fish and invertebrates to climate change on the Northeast U.S. Continental shelf. *PLoS One* 11 (2), e0146756.
- Hewitt, D.A., Hoenig, J.M., 2005. Comparison of two approaches for estimating natural mortality based on longevity. *Fish. Bull.* 103, 433–437.
- Hobday, A.J., Smith, A.D.M., Webb, H., Daley, R., Wayte, S., Bulman, C., Dowdney, J., Williams, A., Sporeic, M., Dambacher, J., Fuller, M., Walker, T., 2007. *Ecological Risk Assessment for the Effects of Fishing: Methodology*. Australian Fisheries Management Authority, Canberra, (Report R04/1072).
- Hobday, A.J., Smith, A.D.M., Stobutzki, L.C., Bulman, C., Daley, R., Dambacher, J.M., Deng, R.A., Dowdney, J., Fuller, M., Furlani, D., Griffiths, S.P., Johnson, D., Kenyon, R., Knuckey, I.A., Ling, S.D., Pitcher, R., Sainsbury, K.J., Sporeic, M., Smith, T., Turnbull, C., Walker, T.L., Wayte, S.E., Webb, H., Williams, A., Wise, B.S., Zhou, S., 2011. Ecological risk assessment for the effects of fishing. *Fish. Res.* 108, 372–384.
- Huang, H., Liu, K., 2010. Bycatch and discards by Taiwanese large-scale tuna longline fleets in the Indian Ocean. *Fish. Res.* 106, 261–270.
- ICCAT, 2015a. *SCRS. Report of the Standing Committee on Research and Statistics (SCRS)*. https://www.iccat.int/Documents/Meetings/SCRS2015/SCRS_PROV_ENG.pdf (accessed 25.04.16)
- ICCAT, 2015b. *2015 Small Tunas Species Group Intersessional Meeting*. https://www.iccat.int/Documents/Meetings/Docs/2015_SMT_DATA_PREP_REP_ENG.pdf (accessed 25.04.16)
- ICES, 2012a. *Report of the Workshop on the Development of Assessments based on LIFE history traits and exploitation characteristics (WKLIFE)*. ICES CM 2012/ACOM:36.
- ICES, 2012b. *ICES Implementation of Advice for Data-limited Stocks in 2012 in its 2012 Advice*. ICES CM 2012/ACOM 68.
- ICMBIO, 2016. *Instituto Chico Mendes de Conservação da Biodiversidade*. <http://www.icmbio.gov.br/portal/faunabrasileira> (accessed 15.01.16).
- IOTC, 2015. *Report of the 18th Session of the IOTC Scientific Committee*. <http://www.iotc.org/documents/report-18th-session-iotc-scientific-committee-scl18>
- IUCN, 2014. *Guidelines for Using the IUCN Red List Categories and Criteria. Version 11*. <http://www.iucnredlist.org/documents/RedListGuidelines.pdf> (accessed 15.01.16).
- Isaac, V., Santo, R.E., Bentes, B., Mourão, K.R.M., Lucena Frédou, F., 2012. The *Scomberomorus brasiliensis* gill-net production system in Northern Brazil: an Invisible and Mismanaged Small-scale Fishery. In: Moksness, E., Dahl, E., Stottrup, J. (Eds.), *Global Challenges in Integrated Coastal Zone Management*. John Wiley & Sons, Oxford, 49–60.
- Jensen, A.L., 1996. *Report on Helt life history parameters result from optimal trade off & Cordeiro LTDA, Fortaleza, 35–48.*
- Lucena Frédou, F., Asano Filho, M., 2006. Recursos pesqueiros da região norte. In: Jablonski, S., Rossi-Wongtschowski, C.L.D.B., Haimovici, M., Lessa, R.P., Martins, A., Ávila, R., Lucena Frédou, F. (Eds.), *Programa REVIZEE – Relatório Executivo*. Ministério do Meio Ambiente, Brasília, 121–152.
- Lucena Frédou, F., Frédou, T., Gaertner, D., Kell, L., Potier, M., Bach, P., Travassos, P., Hazin, F., Ménard, F., 2016. Life history traits and fishery patterns of teleosts caught by the tuna longline fishery in the South Atlantic and Indian Oceans. *Fish. Res.* 179, 308–321.
- Mackenzie, B.R., Gislason, H., Christian Möllmann, C., Köster, F.W., 2007. Impact of 21st century climate change on the Baltic Sea fish community and fisheries. *Glob. Chang. Biol.* 13, 1348–1367.
- Marín, Y., Brum, F., Barea, L., Chocca, J., 1998. Incidental catch associated with swordfish longline fisheries in the southwest. *Atl. Ocean. Mar. Fresh. Res* 49, 633–639.
- Marine Stewardship Council, 2011. Fisheries Assessment Methodology: Productivity Susceptibility Analysis Workbook**. <http://www.msc.org/documents/scheme-documents/forms-andtemplates/msc-productivity-susceptibility-analysis-worksheet-for-rbf/view> (accessed in 15.02.2016).
- Micheli, F., De Leo, G., Butner, C., Martone, R.G., Shester, G., 2014. A risk-based framework for assessing the cumulative impact of multiple fisheries. *Biol. Conserv.* 176, 224–235.
- Mourão, K.R.M., Santos, R.E., Silva, B.B., Almeida, M., Isaac, V., Frédou, T., Lucena Frédou, F., 2014. A pesca da serra *Scomberomorus brasiliensis* e alternativas para o seu manejo no litoral nordeste do Pará, Brasil. In: Haimovici, M., Andriquetto Filho, J.M., Sunye, P.S. (Eds.), *A Pesca Marinha e Estuarina no Brasil: Estudos de Caso Multidisciplinares*. Editora de Furg, Rio Grande, 171–180.
- Musick, J.A., Harbin, M.M., Berkeley, S.A., Burgess, G.I., Eklund, A.M., Findley, L., Gilmore, R.G., Golden, J.T., Ha, D.S., Huntsman, G.R., McGovern, J.C., Parker, S.J., Poss, S.G., Sala, E., Schmidt, T.W., Sedberry, T.W.G.R., Weeks, H., Wright, S.G., 2001. Marine, estuarine, and diadromous fish stocks at risk of extinction in North America (Exclusive of Pacific Salmonids). *Fisheries* 25, 6–30.
- Nóbrega, M.F., Lessa, R.P., 2009. Espécies Pelágicas, *Scomberomorus brasiliensis*. In: Lessa, R., Nóbrega, M.F., Bezerra, J.L.Jr (Eds.), *Dinâmica de Populações e Avaliação dos Estoques dos Recursos Pesqueiros do Nordeste*. Martins & Cordeiro LTDA, Fortaleza, 64–75.
- Ormseth, O.A., Spencer, P.D., 2011. An assessment of vulnerability in Alaska groundfish. *Fish. Res.* 112, 127–133.
- Osio, G.C., Orio, A., Millar, C.P., 2015. *Assessing the vulnerability of Mediterranean demersal stocks and predicting exploitation status of un-assessed stocks*. *Fish. Res.* 171. <http://dx.doi.org/10.1016/j.fishres.2015.02.005>.
- Pacheco, J.C., Kerstetter, D.K., Hazin, F.H.V., Hazin, H., Graves, J., Carvalho, F.C., Travassos, P.E., 2011. A comparison of circle hook and J hook performance in a western equatorial Atlantic Ocean pelagic longline fishery. *Fish. Res.* 3038, 1–7.
- Patrick, W.S., Spencer, P., Link, J., Cope, J., Field, J., Kobayashi, D., Lawson, P., Gedamke, T., Cortés, E., Ormseth, O., Bigelow, K., Overholtz, W., 2010. Using productivity and susceptibility indices to assess the vulnerability of United States fish stocks to overfishing. *Fish. Bull.* 108, 305–322.
- Pauly, D., 1984. *Fish population dynamics in tropical waters: a manual for use with programmable calculators*. ICLARM. Stud. Rev. 8.
- Perry, A.L., Low, P.J., Ellis, J.R., Reynolds, J.D., 2005. Climate change and distribution shifts in marine fishes. *Science* 308, 1912–1915.
- Petitgas, P., Alheit, J., Peck, M.A., Raab, K., Irigoien, X., Huret, M., van der Kooij, J., Pohlmann, T., Wagner, C., Zarraonaindia, I., Dickey-Collas, M., 2012. Anchovy population expansion in the North Sea. *Mar. Ecol. Prog. Ser.* 444, 1–13.
- Phillips, S.R.M., Scott, F., Ellis, J.R., 2015. Having confidence in productivity susceptibility analyses: a method for underpinning scientific advice on skate stocks? *Fish. Res.* 171. <http://dx.doi.org/10.1016/j.fishres.2015.01.005>.
- Pinsky, M.L., Fogarty, M., 2012. Lagged social-ecological responses to climate and range shifts in fisheries. *Clim. Chang.* 115, 883–891.
- Poisson, F., Gaertner, J.C., Taquet, M., Durbec, J.P., Bigelow, K., 2010. Effects of lunar cycle and fishing operations on longline-caught pelagic fish: fishing performance, capture time, and survival of fish. *Fish. Bull.* 108, 268–281.
- R Development Core Team, 2014. R: A Language and Environment for Statistical Computing**.
- Reynolds, J.D., Jennings, S., Dulvy, N.K., 2001. Life histories of fishes and population responses to exploitation. In: Reynolds, J.D., Mace, G.M., Redford, K.H., Robinson, J.G. (Eds.), *Conservation of exploited species*. Cambridge University Press,

- Tuck, G.N., Phillips, R.A., Small, C., Thomson, R.B., Klaer, N., Taylor, F., Wanless, R.M., Arrizabalaga, H., 2011. An assessment of seabird-fishery interactions in the Atlantic Ocean. *ICES J. Mar. Sci.* 68, 1628–1637.
- Ward, P., Curran, D., 2004. Scientific Monitoring of Longline Fishing off Western Australia. Australian Fishery Management Authority, Australia, (accessed 13.02.16) http://www.afma.gov.au/wp-content/uploads/2010/06/scientific_monitoring_longline_wa.pdf
- Waugh, S., Filippi, D.P., Kirby, D.S., Abraham, E., Walker, K., 2012. Ecological Risk Assessment for seabird interactions in the Western and Central Pacific longline fisheries. *Mar. Pol.* 36, 933–946.
- Wetherall, J.A., Polovina, J.J., Ralston, S., 1987. Estimating growth and mortality in steady-state fish stocks from length-frequency data. In: Pauly, D., Morgan, G.R. (Eds.), *Length-based Methods in Fisheries Research*. ICLARM Conference Proceedings 13, International Center for Living Aquatic Resources Management, Manila, Philippines, and Kuwait Institute for Scientific Research, Safat, Kuwait, pp. 53–74.
- Zhou, S., Griffiths, S.P., 2008. Sustainability Assessment for Fishing Effects (SAFE): a new quantitative ecological risk assessment method and its application to elasmobranch bycatch in an Australian trawl fishery. *Fish. Res.* 91, 56–68.