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

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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 well-accepted framework is Productivity and Susceptibility Analysis (PSA; Hobday et al., 2007, 2011). PSA is a methodology for estimating the vulnerability of a stock based on its biological productivity and susceptibility to fishing. The approach relies on the relationship between the life history characteristics of a stock and its productivity, and its susceptibility to being caught in a fishery. PSA is considered a first step in data-poor situations to identify the main species at risk (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 US fish stocks (Patrick et al., 2010). The approach is included in the Marine Stewardship Council Fisheries Assessment Methodology (2011) and, Expert Groups of the International Council for the Exploration of the Sea (ICES) have explored a range of data deficient assessment methods to support development of management advice including PSA (ICES, 2012a, 2012b). Finally, the International Commission for the Conservation

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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; Huang and Liu, 2010; Pacheco et al., 2011), the national Brazilian on-board Observer Program database (South Atlantic Ocean), and the national database for observer data on-board pelagic longliners based in La Reunion (Indian Ocean), hosted by IRD (Institut de Recherche pour le Développement) (Bach et al., 2008, 2013).

2.2. Determining the vulnerability of the stocks

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, which are combined to produce a single score that quantifies the risk to a stock. Stocks that received a low productivity score and a high susceptibility score were considered to be the most vulnerable to fishing, 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 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 accessed 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 1
Productivity attributes and rankings used to determine the vulnerability of a stock caught by tuna longline fishery in South Atlantic and Indian Oceans.

Atribute	Ranking		
	High (3)	Moderate (2)	Low (1)
Maximum Size (L_{max})	< 110 cm	110–200	> 200 cm
von Bertalanffy growth coefficient (k)	> 0.36	0.27–0.36	< 0.27
Size at first maturity (L_{50})	< 54	54–105	> 105
Maximum age (T_{max})	< 8	8–14	> 14
L_{50}/L_{max}	< 0.51	0.51–0.55	> 0.55
Fecundity (Fec)	> 2.88	1.03–2.88	< 1.03
r	> 0.48	0.26–0.38	< 0.38