Biological attributes and major threats as predictors of the vulnerability of species: a case study with Brazilian reef fishes

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Abstract Global biodiversity declines and increasing rates of extinction necessitate the assessment and prediction of the vulnerability of species to extinction. Here, we examine the relationships between conservation status and ecological traits of reef fish species of the Brazilian biogeographical province. We used binomial tests and a logistic regression to address two questions. Do biological attributes differ between threatened and non-threatened fishes? Which combination of traits and impacts exerts greater influence on species threat status? Of the 559 species, 36 are categorized as threatened (compiled from global, national and local Red Lists). Three species are categorized as Critically Endangered, seven as Endangered and 26 as Vulnerable. Our analyses revealed that Elasmobranchii, sex-changing bony fishes and endemic species are the most vulnerable reef fishes in Brazilian waters. Body size and trophic category were identified as good predictors of the vulnerability of a species to extinction. Small-bodied species that are exploited by the ornamental trade and have complex reproductive strategies are also of concern. Such combinations of attributes could be of value in predicting which reef fish species elsewhere have a high risk of extinction.

Keywords Extinction probability, fishing, impacts, logistic regression, Red List, South-west Atlantic

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Introduction

The ongoing threats to ecosystems are increasing contemporary extinction rates (Soulé, 1991; Purvis et al., 2000). In marine ecosystems anthropogenic pressure, predominantly overexploitation, has led to marked reductions in ranges and population sizes (Dulvy et al., 2003, 2004; Myers & Worm, 2005; Jackson 2008; Worm & Tittensor, 2011), and to the extinction of species (Casey & Myers, 1998; Roberts & Hawkins, 1999; Dulvy et al., 2003, 2004; del Monte-Luna et al., 2007). For reef ecosystems the key drivers of decline are pollution, disease and climate change (Bellwood et al., 2004; Jackson, 2008). Evaluation of the effect of multiple stressors on the risk of species extinction is essential for conservation planning and prioritization (Mace & Lande, 1991; IUCN, 2001). IUCN provides an objective evaluation system under which species must meet quantitative criteria to be assigned to Red List categories (IUCN, 2001). The IUCN Red List and the categories and criteria used to assess species have become an important tool for management, monitoring and decision making (Rodrigues et al., 2006). However, evaluations of extinction risk using such methods require population data, which are not available for the majority of species, including reef fishes.

The scarcity of population data combined with the threats to marine ecosystems highlight the urgent need to assess and predict the vulnerability of fishes to multiple stressors (Dulvy et al., 2003; Cheung et al., 2005; Graham et al., 2011). Attempts to predict vulnerability to extinction include factors such as species' geographical range, area occupancy and rarity (Hawkins et al., 2000), ecological specialization (Graham et al., 2011), and body size and other life-history traits (Cheung et al. 2005). For fish species biological attributes such as slow growth, late maturity and low reproductive output can be correlated to body size, which can thus be used as a predictor of the threat of extinction (Roberts & Hawkins, 1999; Dulvy et al., 2003; Reynolds et al., 2005; Olden et al., 2007). Biological traits can help determine the probabilities of local declines, and factors such as range size, occupancy and rarity can indicate declines that could potentially lead to global extinction (Graham et al., 2011). Therefore, identifying the attributes and the interactions between traits and extrinsic threats to species at risk can

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provide information on the vulnerability of species to extinction.

Studies of species decline are commonly used to identify which attributes predispose species to particular threats (Pimm, 1991; Purvis et al., 2000). Such studies can be used as a benchmark to identify vulnerability patterns that could exist among species not yet threatened (Gustafsson, 1994; Hero et al., 2005; Kotiaho et al., 2005). However, such an approach has not previously been used to assess the vulnerability of reef fishes to extinction.

Here we analyse quantitatively the species-specific biological traits and the main anthropogenic threats to threatened and non-threatened reef fishes in the Brazilian biogeographical province (sensu Floeter et al., 2008). We address two questions. Do biological attributes differ between threatened and non-threatened fishes? Which combination of traits and impacts exerts greater influence on species threat status?

Methods

Reef fish database

A list of 559 species (509 Teleostei, 50 Elasmobranchii) from the Brazilian province was compiled by A. Carvalho-Filho & S.R. Floeter (unpubl. data). Species distributions are based on Carvalho-Filho (1999) and Floeter et al. (2008). We define reef fishes as any shallow-living (< 100 m) tropical/subtropical benthic or benthopelagic fishes that constantly associate with hard substrates of coral, algal or rocky reefs, or that occupy adjacent sandy substrate (i.e. use reef structures or the surrounding area for reproduction, feeding and/or protection; Floeter et al., 2008). Species biological traits (maximum body size: < 10, 10–25, 25–50, > 50 cm; trophic category, after Ferreira et al., 2004: macrocarnivore, herbivore, planktivore, omnivore, mobile benthic invertivore/cleaner, coral/colonial sessile invertivore; reproductive traits: monogamy, nest guarding, mouth brooding, spawning aggregation, sex change; mutualisms) were determined from the available literature (Böhlke & Chaplin, 1993; Randall, 1996; Smith, 1997; Carvalho-Filho, 1999; Halpern & Floeter, 2008) and Fishbase (Froese & Pauly, 2009). If the maximum length of a species could not be found we assigned the mean value for the genus or family, as appropriate. Potential threats to species (artisanal fishing, game fishing, ornamental trade, bycatch, restricted range/endemism) were based on literature searches of peer-reviewed reports (Haimovici & Klippel, 1999; Gasparini et al., 2005; Floeter et al., 2006) and were assessed as: 0, no impact; 1, low impact; 2, high impact.

We compiled information on the conservation status of reef fish species from global (IUCN, 2008), national (MMA, 2004, 2005) and local (Brazilian state) Red List inventories. At the regional level we also included information from the 2008 IUCN Workshop for Brazilian Epinephelinae and Lutjanidae Assessment (Subirá et al., 2012). The local inventories (Espírito Santo, Paraná, Rio de Janeiro and Rio Grande do Sul states) are based on IUCN criteria and categories (IUCN, 2001). We considered species to be threatened if they are categorized as Critically Endangered, Endangered or Vulnerable, and non-threatened if categorized as Near Threatened, Least Concern or Data Deficient.

With the exception of endemic species, global conservation status is often not representative of conservation status at the regional scale (Rodríguez et al., 2000; Gärdenfors, 2001). The transfer of information from global to national assessments could decrease the credibility of national Red Lists and the efficiency of conservation at this level, where actions are most likely to have an impact (Rodríguez et al., 2000). However, we included data from the global IUCN Red List because only a small number of reef fishes have been evaluated and listed in the national inventory. As we want to provide insights into species that could become threatened, those Brazilian reef fishes that have not been assessed with the IUCN Red List criteria were termed non-threatened, and were compared with threatened species.

Statistical analysis

To identify which trophic groups and body size categories are disproportionately threatened we applied binomial tests ($P < 0.05$; Zar, 2008) to compare threatened and non-threatened species. We also explored the differences in the percentages of threatened and non-threatened Elasmobranchii and endemic species because of concern about the vulnerability of these groups. Sharks and rays appear to be particularly vulnerable to overexploitation because of life-history traits such as slow growth, late sexual maturity, long life spans and low fecundity (Stevens et al., 2000). The majority (74%) of the species endemic to the Brazilian Province are benthic demersal spawners, with a short planktonic stage and consequently restricted dispersal (Floeter & Gasparini, 2000). Restricted-range species are thought to face a greater risk of extinction than widespread species because local threats and impacts could cause the extinction of such restricted-range species at a global scale (Hawkins et al., 2000).

We assessed which factors have more influence on the threatened status of species (response variable: threatened, 1; non-threatened, 0) using a logistic regression, which is a special case of Generalized Linear Models (Nelder & Wedderburn, 1972). Explanatory variables were type (Teleostei, Elasmobranchii), size category (small, medium, large), trophic category (planktivore, herbivore, macrocarnivore, invertebrate feeder), game fishing, artisanal fishing, ornamental trade, bycatch, monogamy, nest guarding,

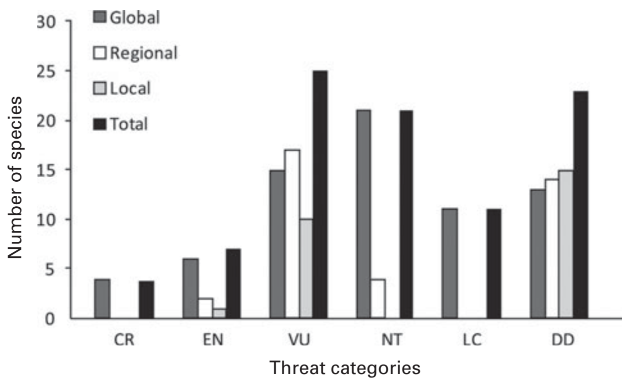

FIG. 1 Number of reef fishes of Brazilian waters in each Red List category on the global IUCN Red List (IUCN, 2008), regional MMA list (MMA 2004, 2005), local lists (Bender et al., 2012, and references therein) and the total number of species categorized as threatened (black). Note that the total number does not correspond to the sum of species within the global, regional and local lists because some species have been assessed for several lists. CR, Critically Endangered; EN, Endangered; VU, Vulnerable; NT, Near Threatened; LC, Least Concern; DD, Data Deficient.

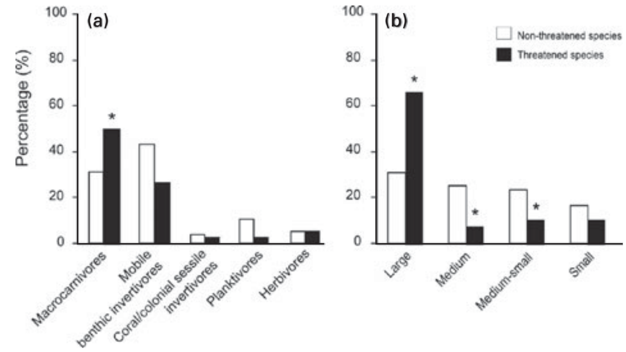

FIG. 2 Percentage of non-threatened and threatened reef fish species in Brazilian waters in (a) trophic categories and (b) maximum body-size class (large, > 50 cm; medium, 25–50 cm; small–medium, 10–25 cm; small, < 10 cm; *Significant difference at $P < 0.05$ with the Binomial test).

mouth brooding, spawning aggregation, sex change and endemism.

Variables were selected with forward and backward stepwise procedures, using both the Akaike information criterion (AIC; Akaike, 1974) and deviance (*D*) reduction. We used likelihood ratio tests to identify terms that would significantly reduce the deviance, and could be included in the model. We used a likelihood ratio χ^2 statistic as a goodness-of-fit measure. To check the model assumptions we analysed the normal probability plots and the Cook's distance of studentized residuals. The odds ratio (odds of a positive and a negative response) was applied to facilitate interpretation. The probability of Brazilian reef fish species being threatened with extinction were calculated based on predictions from the final model, which were obtained from the estimated parameters. More details can be found in Supplementary Information 1. Analyses were performed using *R v. 2.7.2* (R Development Core Team, 2008).

Results

Of the 559 species, 36 Brazilian reef fishes are at risk of extinction at the global, national or regional level (Supplementary Table S1, Fig. 1). From the six Red Lists compiled, four species are considered Critically Endangered, seven Endangered and 25 Vulnerable (Fig. 1). Extinction risk is not distributed evenly, or randomly, across Brazilian reef fish groups: 12 of 106 families contain > 25% of the species at risk of extinction (Supplementary Table S1). The families Epinephelidae and Lutjanidae have 27.7% of the threatened fishes (eight and three species, respectively). Of the threatened species 13 (36.1%) are sharks and rays (26% of the Brazilian Elasmobranchii reef fauna). The percentage of the Elasmobranchii ($n = 10$) threatened is significantly greater than that of the Teleostei ($n = 26$; binomial test: $p1 > p2$, $P < 0.0001$). Of 21 Near Threatened reef fishes, 16 are in the Elasmobranchii, of which eight are in the Carcharhinidae.

The macrocarnivores comprise the most threatened trophic group: 21 (58.3%) of the 36 threatened reef fishes (binomial test: $p1 > p2$, $P < 0.001$; Fig. 2a). In addition to top predators, 11 species of mobile invertebrate feeders (30.5%) are amongst the species at risk of extinction (Table 1). Reef fishes that attain large-body sizes are also disproportionately threatened in relation to other length categories (Fig. 2b). The binomial tests also indicated that the percentage of medium ($p1 < p2$, $P < 0.001$) and small–medium ($p1 < p2$, $P = 0.04$) threatened species is lower than expected.

Of the potential threats the ornamental trade and endemism seem to have the greatest influence on threatened status. The residual deviance ($D = 77.82$, $df = 134$) of the logistic regression indicated that the model properly fitted the data ($P \sim 0.99$; Table 1). Residual analysis for the final model showed no evidence of any failures in the assumptions. Parameter estimates and odds ratios are given in Supplementary Table S2.

Of the biological traits, type, ability to change sex and body length significantly affected the probability of a species being threatened (Table 1). The model predicted that species most likely to face threats are sharks and rays, sex-changing bony fishes and endemic species (90, 20 and > 6,000 times greater, respectively; Supplementary Table S2). Six reef fish species endemic to the Brazilian Province are at risk of extinction (Supplementary Table S1).

Variable interactions that exert influence on the probability of a species being threatened are the following pairs: sex change–game fishing; type Elasmobranchii/Teleostei–artisanal fishing; and nest guarding–ornamental trade (Table 1). According to the model predictions reef

Table 1 Deviance analysis of the logistic regression model.

Variable/interaction	df	Deviance	Residual df	Residual deviance	P[1]
Null			154	272.22	
Type	1	44.151	153	228.06	0.0000***
Size	2	10.459	151	217.61	0.0054**
Sex change	1	50.529	150	167.08	0.0000***
Artisanal fishing	1	2.342	149	164.73	0.1259
Ornamental trade	1	16.146	148	148.59	0.0001***
Trophic category	3	2.632	145	145.96	0.4520
Mouth brooding	1	8.335	144	137.62	0.0039**
Monogamy	1	3.430	143	134.19	0.0640
Game fishing	1	0.001	142	134.19	0.9734
Endemic	1	12.093	141	122.1	0.0005***
Nest guarding	1	7.714	140	114.38	0.0055**
Size : Endemic	2	12.080	138	102.3	0.0024**
Type : Artisanal fishing	1	6.584	137	95.72	0.0103*
Ornamental trade : Nest guarding	1	5.868	136	89.85	0.0154*
Trophic category : Monogamy	1	7.529	135	82.32	0.0061**
Sex change : Game fishing	1	4.499	134	77.82	0.0339*

[1]Likelihood ratio χ^2 test applied to the initial model and this model plus each following candidate interaction. Variable interaction that significantly reduces the deviance has $P < 0.05$.
***$P < 0.001$; **$P < 0.01$; *$P < 0.05$

fish species with the highest probabilities of being threatened have the trait combination of invertebrate feeder trophic category, small body size and endemism. Species with lower probabilities of extinction risk are medium-sized planktivores. However, there are several trait combinations that can generate similar threat probabilities for different species (Supplementary Table S3). For example, the Brazilian endemic ray *Dasyatis marianae* (a medium-sized, invertebrate feeder) and the grouper *Dermatolepis inermis* (a large-bodied macrocarnivore and sex-changing species) both have c. 75% probability of being threatened).

Discussion

The risk of extinction for the reef fishes of Brazilian waters is a result of a combination of fishing pressure and species' traits that enhance their vulnerability to harvesting and habitat loss. Our analysis reveals that biological attributes capable of predicting species susceptibilities are consistent with previous studies (Jennings et al., 1999; Musick, 1999; Roberts & Hawkins, 1999; Reynolds et al., 2005; Pinsky et al., 2011). Despite the small number of threatened species identified in our database these species share many attributes with the non-threatened species, making the former suitable for predicting extinction risks for those not yet threatened (Supplementary Table S3). Species' biological attributes and their interaction with fishing pressure are discussed separately below.

Biological attributes

Of the traits believed to enhance vulnerability to extinction the most widely cited is body size (Jennings et al., 1999). This biological feature has been examined in a variety of mammals, birds and fishes, and large-bodied species are consistently more prone to declines or extinctions (Bennet & Owens, 1997; Jennings et al., 1999; Reed & Shine, 2002; Cardillo et al., 2006). Large-bodied Brazilian reef fishes are disproportionately threatened in relation to other body size categories. Larger fishes are heavily targeted in fisheries and tend to suffer greater declines than smaller fishes (Jennings et al., 1999; Dulvy et al., 2000; Stevens et al., 2000) given the correlated life-history traits that render populations less resilient to exploitation (Coleman et al., 2000; Reynolds et al., 2001). However, small-bodied, low trophic level fish species are highly vulnerable to overexploitation (Pinsky et al., 2011) and climate change disturbances (Graham et al., 2011).

Trophic category is another biological attribute that could predict those species with greater vulnerabilities. For mammalian carnivores and birds large-bodied species with sizeable home ranges, low densities and of high trophic level are the most prone to extinction (Gaston & Blackburn, 1995; Cardillo et al., 2006). This also seems to be the case for many marine fishes (Morris et al., 2000; Myers et al., 2007; Baum & Worm, 2009), including Brazilian macrocarnivores, which is the most threatened trophic group, many of them being large bodied (Supplementary Table S1). Other high trophic level fishes of Brazilian waters are on the path to extinction risk: 38% of Near Threatened fishes are species of

Carcharhinidae. These top predators exert a fundamental influence on marine communities (Heithaus et al., 2008), and changes in abundance modify ecosystem structure, functioning and resilience (Duffy, 2002; Jackson, 2010).

It has been proposed that sex-changing species are more vulnerable to overexploitation because selective fishing pressure affects sex ratios (Hawkins & Roberts, 2003). We found that 33.3% of threatened species were sex changing (of the 12 sex-changing species, eight are groupers) and this trait was identified as an important driver of threat in reef fishes. Many grouper species exhibit protogynous hermaphrodite life histories (Shapiro, 1987). Additionally, several groupers spawn in aggregations, and this reproductive strategy is known to increase the vulnerability of a species to overfishing (Cheung et al., 2005). However, spawning aggregation was not significant in our model results but this could be because only a small number of species in our study exhibit this behaviour.

Potential threats and their interactions with biological attributes

Our results suggest that species exhibiting nest-guarding behaviour and that are harvested for the ornamental trade are highly vulnerable. Aquarium fisheries have a significant impact on reef fisheries elsewhere (Wood, 2001; Sadovy & Vincent, 2002), and are active along the Brazilian coast (Gasparini et al., 2005). Furthermore, many traded species exhibit complex reproductive strategies (Gasparini et al., 2005), which are usually associated with their low recruitment rates, possibly leading to population declines.

The size of the geographic range of a species also influences vulnerability and threat status (Purvis et al., 2000), and may be a useful tool in predicting which species are likely to have a higher risk of extinction elsewhere (Hero et al., 2005). Hawkins et al. (2000) investigated restricted-range coral reef fishes and found that $> 50\%$ of species qualified as threatened. Even though a small range does not necessarily predispose a species to being rare (Hawkins et al., 2000; 25.1% of the total abundance of South-western Atlantic reef fishes are endemic species) many endemics are highly threatened (Gasparini et al., 2005; Floeter et al., 2006). This is the case for large parrot-fishes endemic to Brazil, such as *Scarus trispinosus*, which is heavily targeted by fisheries (Ferreira & Gonçalves, 2006; Francini-Filho et al., 2008). We found that endemic species have a high probability of being threatened, especially if this attribute is combined with others such as small body size.

The reef fishes of Brazilian waters are as threatened as fishes elsewhere (Floeter et al., 2006), and this is a consequence of similar sources of threat. In addition, the biological attributes that are predictive of the vulnerability of a species to extinction are in accordance with those previously identified for marine fishes (Jennings et al., 1999; Musick, 1999; Roberts & Hawkins, 1999; Reynolds et al., 2005). These results strengthen the importance of including species' biological traits into conservation planning analyses, as has been done for Neotropical anurans and mammals (Loyola et al., 2008a, b).

Making predictions, and thus informing conservation priorities, is one of the goals of trait-based analyses (Fisher & Owens, 2004; Vila-Nova et al., 2011). Our results suggest that body size, trophic category, ability to change sex and taxonomic group are good predictors of species vulnerabilities. Special attention needs to be given to small-bodied (Pinsky et al., 2011), restricted-range species, which have a high probability of being threatened. Such traits can be used as guidelines for global inferences of the extinction risk of fish species.

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