Fisheries Research 275 (2024) 107029

Contents lists available at ScienceDirect

Fisheries Research

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

Short communication

Fishing shrinks the size structure of exploited coral reef fishes in Brazil

Madeline V. Wood [1], Felipe M. Carvalho [2,1,*], Leandro Castello

Department of Fish and Wildlife Conservation, Virginia Tech, Blacksburg, VA, United States

ARTICLE INFO

Keywords:
Endangered species
Marine protected area
Size spectra
Tropical regions

ABSTRACT

Coral reef fisheries are important as they support the economy, livelihoods, and food security of millions of people worldwide. However, reef fisheries are widely overfished, impacting the abundance and size structure of highly biodiverse fish assemblages. Here, we assessed the effects of fishing on the size structure of exploited coral reef fishes using size spectra analysis, a method that informs about fishing mortality and ecosystem productivity. We used data from over 500 landing site interviews with hook and line fishers in Northeastern Brazil. The data included 18 fishing grounds (i.e., fringing reefs), fishing effort (fishers/km^2) of a widely used gear (hooks and line), and 3690 measurements of exploited fish body size. We fitted linear regressions to body size estimates in the catch of each fishing ground to estimate the slopes of the size spectra and tested for a possible effect of fishing effort on those slopes. We found that fishing effort associated with hook and line negatively affected the slopes of size spectra ($p = 0.04$; $R^2 = 0.22$). This likely occurred because hook and line generally selects for the largest individuals in the assemblage, so that, as expected, higher levels of fishing effort were associated with smaller size of the exploited fishes. Given body size is usually proportional to trophic level in reef fishes, our finding suggests fishing may be disproportionately affecting predators in the study area. Our study provides the first documentation of fishing impacts on the size structure of coral reef fishes exploited by a predominant gear type in Northeastern Brazil, establishing a baseline for future monitoring of fishing impacts and contributing to the development of sustainable fisheries management strategies.

1. Introduction

Around the world, many coral reefs fisheries are overfished (Roberts et al., 2005; Abesamis et al., 2014). Prior studies have shown that fishing typically induces declines in the size structure of exploited fish assemblages (e.g., Graham et al., 2005; Wilson et al., 2010; MacNeil et al., 2015). This often occurs as overfished large-bodied species (i.e., K-strategists) whose populations typically have low tolerance to fishing mortality are replaced with smaller-bodied species, which are more productive (i.e., r-strategists) and generally can sustain higher levels of fishing mortality (Robinson et al., 2017). Such fishing-induced changes in the size structure of exploited fish assemblages can affect food and income security, and the structure and function of whole coral reef food webs (Graham et al., 2005; Zgliczynski and Sandin, 2017).

The need to understand the ecosystem effects of fishing spurred the development of new research methods (Graham et al., 2005; Petchey and Belgrano, 2010). A method of growing interest, called size spectra analysis, can assess the effects of fishing on the size structure of exploited fish assemblages, given that the body size of organisms affects many ecological processes, from the individual to the community level (Petchey and Belgrano, 2010). Size spectra analysis relies on the widely held notion that the biomass of individuals of all species decrease log-linearly with increasing body size (Petchey and Belgrano, 2010). Size spectra analysis involves fitting a linear regression to such data (i.e., body size on the independent axis and abundance or biomass data on the dependent axis). The slope of the fitted regression informs about the mortality rates of the organisms, and the intercept informs about rates of ecosystem productivity (Rice and Gislason, 1996; Daan et al., 2005; Mehner et al., 2018). Because the regression slope of size spectra analysis is believed to be proportional to mortality rates, it can be used to characterize the effects of fishing on the size structure of fish assemblages (Dulvy et al., 2004; Petchey and Belgrano, 2010; Hatton et al., 2021).

Size spectra is increasingly used in fisheries assessments in marine

* Corresponding author.
E-mail address: fmc@vt.edu (F.M. Carvalho).
[1] Madeline Wood and Felipe Carvalho have contributed equally to this work.
[2] Present address: 220 Ag-Quad Ln, Suite 441, Blacksburg, VA, 24061

https://doi.org/10.1016/j.fishres.2024.107029
Received 24 April 2023; Received in revised form 4 April 2024; Accepted 11 April 2024
Available online 27 April 2024

and freshwater ecosystems (Graham et al., 2005; Petchey and Belgrano, 2010; Wilson et al., 2010). However, no size spectra analysis has been used to characterize the effects of coral reef fisheries in the Atlantic. Furthermore, no size spectra analysis in coral reefs has used fisheries-dependent data, as most have used underwater visual census data (Graham et al., 2005; Stuart-Smith et al., 2008; Robinson et al., 2017). While underwater visual census data can be used to reliably assess most of the fish assemblage, visual census data is rarely available particularly in developing nations, which typically have ill-equipped institutions to collect field data (Edgar et al., 2004). Fisheries-dependent data offers an alternative and potentially useful source of information that is more often available than visual census data and that has been successfully applied in size spectra analysis in other ecosystems (Fabré et al., 2017; Leitão, 2019).

Here we used fisheries-dependent data and size spectra analysis to assess the effects of fishing on the size structure of exploited coral reef fishes in Brazil, in the southwest Atlantic Ocean. We predicted that the size structure of exploited coral reef fishes, as denoted by harvested specimens, would decrease with increasing fishing effort. Our analysis is timely as coral reef fisheries in Brazil remain poorly studied (Costa et al., 2002; Pinheiro et al., 2018; de Araújo et al., 2020), have a long history of exploration, and are lacking conservation action (Carvalho et al., 2021).

2. Methods

2.1. Study area

We studied fishing effects on the exploited portion of the coral reef fish assemblage within the Environmental Protected Area “Costa dos Corais” (Coast of Corals, EPACC), which covers 406,085 ha and includes three coral reef lines parallel to shore, encompassing 12 municipalities (Rudorff and Gherardi, 2008; Benevides et al., 2017; Fig. 1). The inner reef line is composed of beach rock, the second line contains calcareous algae, and the outer line is made primarily of zoanthids (Rudorff and Gherardi, 2008). These reefs harbor at least 185 known fish species, of which about 100 are caught by local fishers (Ferreira and Cava, 2001). Fishing is allowed in most of the reserve. With few fishing regulations and deficient rule enforcement, there is a growing concern for the sustainability of fishing. Some 8400 fishers live in 12 municipalities adjoining the reserve, and for them fishing represents a key source of income and animal protein (Floeter et al., 2006; Araújo and Bernard, 2016). The primary fishing gears used are hook and line, corrals, speargun, hook for octopus, seine net, beach seine, cast net and gillnets in general including a type of gillnet designed to select for lobsters (Ferreira and Cava, 2001).

2.2. Data collection

We collected data from 18 distinct fringing reefs, which we here refer to as ’fishing grounds’ (Fig. 1). Trained field assistants visited each fishing ground between four and six times a month, collecting 396 landing site interviews with the fishers from August 2018 to September 2019. The data captured weekly and seasonal variations in catch, effort, and fish size because of lunar, tidal, and seasonal cycles. Interviews were done when fishers were exiting the water, at which time the assistants explained the nature of the research and asked for the consent to interview them. Consenting fishers were asked about the species they caught and Total Length (TL) measurements were taken of their catch. In total, 3690 fish specimens were measured to the nearest mm. To measure fishing effort, field assistants used binoculars to identify the gear

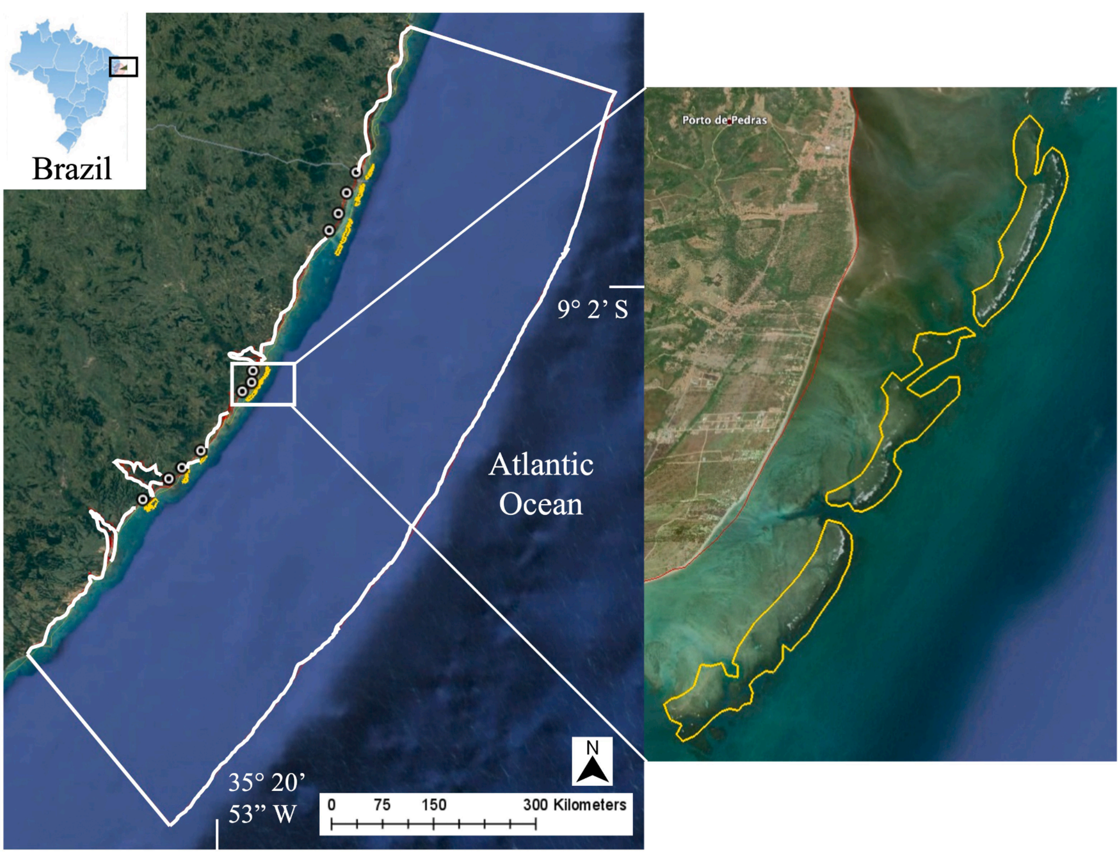

Fig. 1. The study area within the largest Environmental Protected Area “Costa dos Corais” (Coast of Corals) in Brazil, encompassing about 406,085 ha, as indicated by the outlined area within the left map. Within the Coast of Corals, there are 12 municipalities. Each smaller outlined area within the larger outlined area, represents one of the 18 fishing grounds in our study located along the northeastern coast of Brazil in the Atlantic Ocean. The right map panel shows a detailed and zoomed in area of three of the fishing grounds (top to bottom: Quintas, Araca and Carapitanga) with the circular dot markings denoting landing sites within the fishing grounds.

type and count the number of fishers in each fishing ground. To estimate fishing effort, we also measured reef area using satellite imaging from Google Earth Pro. Our analysis focused on shallow reef areas closer to the shore, which are predominantly exploited by local fishers. Landing site interview form used is presented in the Supplementary Material.

To minimize variability in the data, we considered data stemming only from hook and line, which was the most used gear type and was consistently used across all 18 fishing grounds. Hook and line caught 56 species but was highly selective towards four species (*Sparisoma axillare, Holocentrus adscensionis, Epinephelus adscensionis* and *Haemulon aurolineatum*), which comprised >70% of all specimens. Our choice to focus on this gear was also due to most species targeted by hook and line having small home ranges, which increased the likelihood that our analysis could detect (local) fishing effects on size structure. More mobile species would be expected to spatially "disperse" local fishing effects, making it harder to detect them.

We note that our size-spectra analysis based on hook and line fishing data does not assume that the size data are descriptive of the whole fish assemblage as in other studies based on less selective sampling methods (Bianchi et al., 2000). Rather, our analysis makes two assumptions: (i) the data is roughly representative of the small portion of the assemblage that is selected by hook and line, and (ii) that representativity is (roughly) the same across the fishing grounds analyzed. The second assumption is supported by the characteristics of hook and line fishing, which exhibited no discernable variability across the fishing grounds, helping eliminate possible biases of gear selectivity in our analyses. Ninety-three and a half percent of the fishers used small hooks and 6.5% used medium size hooks. Our methods align with other studies that have successfully used fisheries-dependent data for size-spectra analysis (Rice and Gislason, 1996; Fabré et al., 2017; Leitão, 2019).

2.3. Data analysis

We assessed the effect of fishing on the exploited portion of the coral reef fish assemblage (i.e., exploited fishes) using the data on fishing effort and fish body size. We estimated fishing effort in each fishing ground by calculating the median density of fishers (i.e., number of fishers divided by area of reef area in km^2) for all survey days during the 13 month-period. To estimate size spectra descriptors of fish assemblage size structure for each of the 18 fishing grounds, we inspected the body size data and set bin size class at 15 mm and the lower and upper size limits at 141 and 320 mm (Fig. 2). We log-transformed each size class as well as the abundance of individuals per size class using log10 (x+1; following Edwards et al., 2017). For each fishing ground, we fitted linear regressions that modeled logarithmic abundance as a function of size. Finally, we assessed whether fishing affected the size structure of the exploited coral reef fishes by fitting a linear regression with the slopes of the size spectra for each fishing ground as the response and fishing effort for the same fishing grounds as the predictor variable.

Because size spectra analysis informs on assemblage-, not species-level, effects, we complemented our main analysis with an assessment of whether and how fishing affected the body size of each of the most abundant species. We separated the body size data per fishing ground for each of the eight most abundant species (*Alphestes afer, Cephalopholis fulva, Epinephelus adscensionis, Haemulon aurolineatum, Haemulon squamipinna, Halichoeres sp., Holocentrus adscensionis,* and *Sparisoma axillare*). For each species, we fitted linear regressions with average TL for each fishing ground as the response and fishing effort for the fishing grounds as the predictor. All data analyses were performed using R Studio (R Core Team, 2017) and Microsoft Excel, with a significance level of 5%.

Finally, we investigated whether potential shifts in species composition occurred across our gradient of fishing effort by analyzing the catch data for the eight most harvested species. We plotted fishing grounds over a gradient of fishing effort and assessed the percent contribution of each species to the total catch in kilograms (Fig. 1S, Supplementary Material).

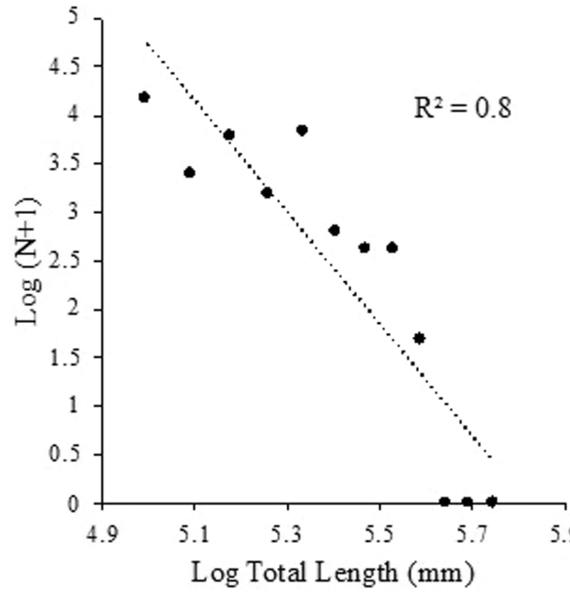

Fig. 2. Scatter plot showing an example of size spectra analysis, where abundance was modeled as a function of size class for one fishing ground. For all fishing grounds, the abundance of individuals in each size class was transformed using log10 (x+1) and plotted against the log of the total length of individuals per size class (mm).

3. Results

3.1. Assemblage size spectra analysis

We found that fishing effort decreased the body size of exploited fishes, as indicated by the fish catch data. The slopes of size spectra were negatively related to fishing effort (p-value = 0.045; b = −0.1524; Fig. 3). This pattern was held across a wide span of variation on fishing effort and size spectra. Fishing effort varied by one order of magnitude across all fishing grounds (Fig. 4), while the slopes of size spectra varied by a factor of two (Fig. 3). The coefficient of determination ($R^2 = 0.22$)

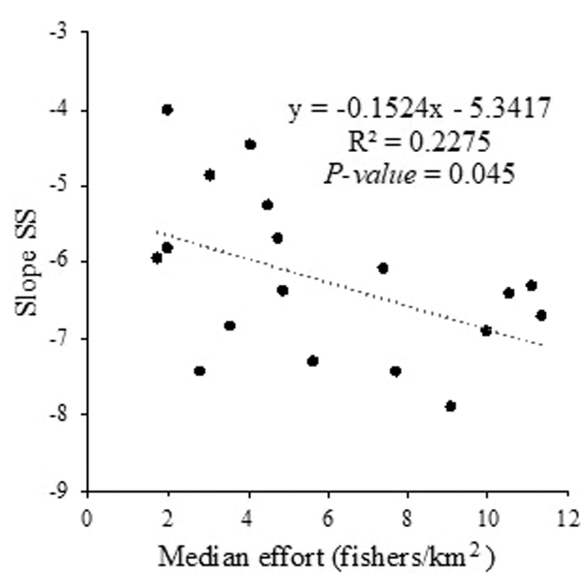

Fig. 3. Fishing effect on the body size of exploited fishes in coral reef of Northeastern Brazil. Scatter plot shows the slopes of the size spectra regressed against fishing effort in 18 coral reef fishing grounds.

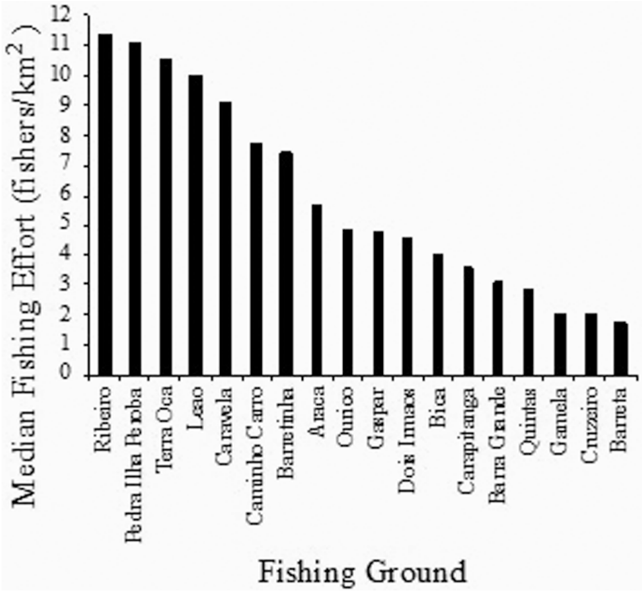

Fig. 4. The gradient of median fishing effort for each of the 18 fishing grounds in the Environmental Protected Area "Costa dos Corais" (Coast of Corals). Effort was calculated by counting the number of individuals in each fishing ground and dividing it by reef area (km^2) of each ground.

of the regression model between fishing effort and the slopes of size spectra was low, however, indicating that variables not considered in this study affected fish size structure. Size spectra analyses for each fishing ground generally had good fits, with average coefficients of determination (R^2) of 0.63 for the linear regressions of log abundance vs log body size (Table 1; Fig. 2).

3.2. Species-level analyses

Our main finding that fishing effort shrunk the body size structure of exploited fishes, as indicated by fish catch data, was partly supported by species-level changes in body size. Fishing effort decreased the average size of seven of the eight most harvested species (Table 2). However, those results are based on regressions which were not significant and had very low coefficients of determination (average $R^2 = 0.04$), again indicating that other variables affected fish size structure.

Table 1
Eighteen fishing grounds using hook and line gear in the Environmental Protected Area Coast of Corals. We show the fishing effort estimated as the median of the daily density of fishers per km^2. Slopes (b) for each linear regression between fishing effort and the average size (cm) per species are shown along with other regression outputs (F-statistic, p-value and R^2).

Fishing ground	Effort	b	F	*p-value*	R^2
Araçá	5.7	-6.98	79.79	0.000	0.88
Barra Grande	3.1	-4.85	27.62	0.000	0.73
Barreta	2.6	-5.91	27.80	0.000	0.73
Barretinha	11.1	-5.90	33.78	0.000	0.77
Bica	2.3	-4.49	34.35	0.000	0.77
Caminho do Carro	9.8	-7.47	57.90	0.000	0.85
Carapitanga	3.5	-6.87	87.72	0.000	0.89
Caravela	9.1	-7.91	45.30	0.000	0.90
Dois Irmãos	6.8	-5.30	35.72	0.000	0.78
Cruzeiro	2.0	-4.04	20.43	0.000	0.67
Gamela	4.0	-5.84	22.95	0.000	0.69
Gaspar	7.1	-5.69	39.26	0.000	0.79
Leão	16.7	-7.29	45.88	0.000	0.82
Ouriço	4.9	-6.42	80.00	0.000	0.88
Pedra da Ilha Peroba	13.9	-6.25	20.52	0.002	0.67
Quintas	8.3	-5.68	56.31	0.000	0.84
Ribeiro	13.6	-6.71	39.22	0.001	0.79
Terra Oca	15.2	-6.39	30.27	0.007	0.76
Average	7.76	-6.11	43.60	0.000	0.79

Table 2
Main fish species caught with hook and line at the Coast of Corals. We show the slopes (b) for each linear regression between fishing effort and the average size (cm) per species. Fishing effort was estimated as the median of the daily density of fishers with hook and line per km^2. We also show sample size (n), and other regression outputs (F-statistic, p-value and R^2).

Species	n	b	F	*p-value*	R^2
Alphestes afer	120	-0.058	0.001	0.973	0.00
Cephalopholis fulva	220	-0.060	0.267	0.612	0.02
Epinephelus adscensionis	521	-0.367	0.171	0.684	0.01
Haemulon aurolineatum	223	-1.561	1.411	0.253	0.09
Haemulon squamipinna	157	-0.960	0.678	0.425	0.05
Halichoeres sp.	225	1.368	1.234	0.283	0.07
Holocentrus adscensionis	950	-0.356	0.280	0.604	0.02
Sparisoma axillare	1138	-1.427	2.731	0.118	0.15
Average	444.2	-0.427	0.847	0.494	0.05

3.3. Species composition in the catch

We found no evidence of shifts in species composition in our gradient of fishing effort (Fig. 1S, Supplementary Material). The percent contribution of each species remained relatively stable across all fishing grounds, suggesting that the decrease in fish size with increasing effort was due to fishing.

4. Discussion

Our results document fishing effects on the size structure of the exploited portion of coral reef fish assemblages in the southwestern Atlantic Ocean. These results are based on fisheries-dependent data and lack support from fisheries-independent data such as underwater visual census. Despite this limitation, they provide circumstantial evidence that hook and line fishing pressure increased the mortality rates of larger fishes, which are known to be the main targets of these reef fisheries (Carvalho et al., 2021). By 'larger,' we refer to those species within our observed catch that are relatively larger compared to others, though they do not include the largest species known in the region, such as *Mycteroperca bonaci* or *Lutjanus jocu*. Our results are in line with prior studies in Brazil (Floeter et al., 2006; Bender et al., 2013) and the Pacific and Indian oceans (Graham et al., 2017; Zgliczynski and Sandin, 2017; Campbell et al., 2020), reporting fishing impacts on the size structure of coral reef fish assemblages.

We previously showed that there is little overlap in target species across fishing gears in our study area, so that each gear selects a unique portion of the assemblage function (Carvalho et al., 2021). Focusing on hook and line thus allowed us to document fishing effects on a sub-portion of the overall exploited fish assemblage, which is mainly composed of benthopelagic species with limited mobility (Carvalho et al., 2021), such as *Holocentrus adscensionis*, *Alphestes afer*, *Sparisoma* spp. and *Epinephelus* spp. The latter two species are particularly vulnerable to fishing as they exhibit complex life cycles (i.e., protogynous sex change). Protogynous hermaphrodites are highly vulnerable to size-selective fishing because of a potential lack of large male individuals capable of fertilizing the eggs produced by females (Côté, 2003; Blaylock and Shepherd, 2016).

However, several variables were not accounted for in our study. We note our analytical approach implicitly assumed that all reefs were comparable. Natural differences in fish assemblages across reefs could explain the low coefficients of determination of our regressions. These include differences in recruitment and hook size (i.e., gear selectivity; Bianchi et al., 2000; Tuda et al., 2016). Other unaccounted variables that can help explain differences in the size structure of fish assemblages is habitat quality as more structurally complex coral reefs provide shelter for small fishes (Rogers et al., 2014), and depth as reefs farther offshore are expected to be more pristine than reefs located in shallower waters that are closer to shore and hence more easily accessed by fishers and tourists. Finally, while hook and line was the most common gear in our study area, the size structure of the local fish assemblage was likely also affected by other fishing gears (e.g., nets, corrals and speargun) and even historical exploitation. Our size spectra analysis based on hook and line could thus serve as a starting point for future and more comprehensive studies encompassing additional fishing gears and larger spatial areas in Brazil and beyond.

The parrotfish *Sparisoma axillare* was the most frequently caught species by hook and line (Table 2) – yet it belongs to a group of species that are considered endangered and under special management plans in Brazil due to population declines (Pinheiro et al., 2021). While *S. axillare* is known for its role in reef ecosystems, primarily through the removal of filamentous and turf algae, its role in facilitating coral settlement and recruitment has not been explicitly demonstrated. This species contributes to the maintenance of reef health by controlling algal growth, which can otherwise outcompete coral for space and light (Bellwood et al., 2012; Bonaldo et al., 2014; Feitosa and Ferreira, 2014). Our results suggesting that fishing decreases the average body size of *S. axillare* (Table 2) provide a glimpse of the process by which fishing affects its populations and could be used to guide decisions to prevent or reverse their overfishing (Pinheiro et al., 2021).

Our findings suggest that size spectra derived from fisheries-dependent data may offer valuable insights into the impacts of fishing pressure on the exploited portion of fish assemblages. However, these insights must be interpreted with caution in the absence of fisheries-independent data from underwater visual censuses (UVC) or additional measures such as CPUE. While it is a valid concern that hook and line gear may be highly selective and produce catch data that may not fully represent the entire fished assemblage, the consistency of our findings with theoretical predictions and previous empirical studies reinforces the validity of using size spectra analysis in coral reefs based on fishery-dependent data. This is in line with other studies in marine and freshwater ecosystems that found fisheries-dependent data to provide sound results in size spectra analyses (Rice and Gislason, 1996; Fabré et al., 2017; Leitão, 2019). We do note that visual census data is also subject to biases including overestimation of planktivores and underestimation of large predators (Edgar et al., 2004; Robinson et al., 2017; Campbell et al., 2020).

The insights gained from our study can serve as a foundational basis for long-term monitoring of the size structure within the exploited portion of the fish assemblage. This approach is suitable for tropical developing nations, where the majority of coral reefs exist and resource constraints significantly limit monitoring efforts (Floeter et al., 2006; Tuda et al., 2016; Barlow et al., 2018). Our study highlights the pressing need for effective management strategies to sustain these critical ecosystems, while also providing a feasible framework for continual monitoring with accessible data to inform conservation and fishery management efforts.

CRediT authorship contribution statement

Madeline V. Wood: Formal analysis, Investigation, Methodology, Project administration, Visualization, Writing – original draft, Writing – review & editing. **Leandro Castello:** Conceptualization, Methodology, Supervision, Validation, Writing – review & editing. **Felipe Carvalho:** Data curation, Formal analysis, Investigation, Methodology, Resources, Supervision, Visualization, Writing – review & editing.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Felipe Carvalho reports financial support was provided by Rufford Foundation.

Data availability

Data will be made available on request.

Acknowledgements

This work was supported by Rufford Small Grants (Grant No. 24442-1) and Lavazza. We thank Lays Nascimento, Eduardo Santos, Pamela and Gideão Santos for data collection.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.fishres.2024.107029.

References

Abesamis, R., Green, A., Russ, G., Jadloc, C.R., 2014. The intrinsic vulnerability to fishing of coral reef fishes and their differential recovery in fishery closures. Rev. Fish. Biol. Fish. 24 (4) https://doi.org/10.1007/s11160-014-9362-x.

Araújo, J., Bernard, E., 2016. Management effectiveness of a large marine protected area in Northeastern Brazil. Ocean Coast. Manag. 130, 43–49. https://doi.org/10.1016/j.ocecoaman.2016.05.009.

de Araújo, M.E., de Mattos, F.M.G., de Melo, F.P.L., Chaves, L.D.C.T., Feitosa, C.V., Lippi, D.L., Hackradt, F.C.F., Hackradt, C.W., Nunes, J.L.S., Leão, Z.M.D.A.N., de Kikuchi, R.K.P., 2020. Diversity patterns of reef fish along the Brazilian tropical coast. Mar. Environ. Res. 160, 105038 https://doi.org/10.1016/j.marenvres.2020.105038.

Barlow, J., Franca, F., Gardner, T.A., et al., 2018. The future of hyperdiverse tropical ecosystems. Nature 559, 517–526. https://doi.org/10.1038/s41586-018-0301-1.

Bellwood, D.R., Hoey, A.S., Hughes, T.P., 2012. Human activity selectively impacts the ecosystem roles of parrotfishes on coral reefs. Proc. R. Soc. B Biol. Sci. 279, 1621–1629. https://doi.org/10.1098/rspb.2011.1906.

Bender, M.G., Floeter, S.R., Hanazaki, N., 2013. Do traditional fishers recognize reef fish species declines? Shifting environmental baselines in Eastern Brazil. Fish. Manag. Ecol. 20, 58–67. https://doi.org/10.1111/fme.12006.

Benevides, L., Pinto, T., Nunes, J., Sampaio, C., 2017. Fish escape behavior as a monitoring tool in the largest Brazilian multiple-use Marine Protected Area. Ocean Coast. Manag. 152, 154–162. https://doi.org/10.1016/j.ocecoaman.2017.11.029.

Bianchi, G., Gislason, H., Graham, K., Hill, L., Jin, X., Koranteng, K., Manickchand-Heileman, S., Payá, I., Sainsbury, K., Sanchez, F., Zwanenburg, K., 2000. Impact of fishing on size composition and diversity of demersal fish communities. ICES Mar. Sci. 57 (3), 558–571. https://doi.org/10.1006/jmsc.2000.0727.

Blaylock, J., Shepherd, G.R., 2016. Evaluating the vulnerability of an atypical protogynous hermaphrodite to fishery exploitation: results from a population model for black sea bass (*Centropristis striata*). Fish. Bull. 114, 476–489. https://doi.org/10.7755/FB.114.4.9.

Bonaldo, R.M., Hoey, A.S., Bellwood, D.R., 2014. The ecosystem roles of parrotfishes on tropical reefs. Oceanogr. Mar. Biol. Annu. Rev. 52, 81–132. https://doi.org/10.1201/b17143-3.

Campbell, S.J., Darling, E.S., Pardede, S., Ahmadia, G., Mangubhai, S., Estradivari, A., Maire, E., 2020. Fishing restrictions and remoteness deliver conservation outcomes for Indonesia's coral reef fisheries. Conserv. Lett. 13 (2) https://doi.org/10.1111/conl.12698.

Carvalho, F.M., Castello, L., Ferreira, B., McDonald, G., Power, M., 2021. Gear selectivity of functional traits in coral reef fisheries in Brazil. Coral Reefs. https://doi.org/10.1007/s00338-021-02192-w.

R. Core Team, 2017. R: A language and environment for statistical computing. R Foundation for Statistical Computing. http://www.R-Project.org/ (accessed 20 October 2020).

Costa, P., Costa Braga, A., Roha, L., 2002. Reef fisheries in Porto Seguro, eastern Brazilian coast. Fish. Res. 60, 577–583. https://doi.org/10.1016/S0165-7836(02)00145-5.

Daan, N., Gislason, H., Pope, J.G., Rice, J.C., 2005. Changes in the North Sea fish community: evidence of indirect effects of fishing. ICES J. Mar. Sci. 62 (2), 177–188. https://doi.org/10.1016/j.icesjms.2004.08.020.

Dulvy, N., Polunin, N., Mill, A.C., Graham, N., 2004. Size structural change in lightly exploited coral reef fish communities: Evidence for weak indirect effects. Can. J. Fish. Aquat. Sci. 61, 466–475. https://doi.org/10.1139/f03-169.

Edgar, G., Barrett, N., Morton, A., 2004. Biases associated with the use of underwater visual census techniques to quantify the density and size-structure of fish populations. J. Exp. Mar. Biol. Ecol. 308, 269–290. https://doi.org/10.1016/j.jembe.2004.03.004.

Edwards, A., Robinson, J., Plank, M., Baum, J., Blanchard, J., 2017. Testing and recommending methods for fitting size spectra to data. Methods Ecol. Evol. 8, 57–67. https://doi.org/10.1111/2041-210X.12641.

Fabré, N., Castello, L., Isaac, V., Batista, V., 2017. Fishing and drought impacts on size spectra of fish assemblages in Amazon Rivers. Fish. Res. 188, 157–165. https://doi.org/10.1016/j.fishres.2016.12.015.

Feitosa, J.L.L., Ferreira, B., 2014. Distribution and feeding patterns of juvenile parrotfish on algal-dominated coral reefs. Mar. Ecol. 36, 462–474. https://doi.org/10.1111/maec.12154.

Ferreira, B., Cava, F., 2001. Ictiofauna marinha da APA Costa dos Corais: Lista de espécies através de levantamento da pesca e observações subaquáticas. Boletim Técnico Científico do CEPENE, 9 (1), 167–180.

Floeter, S.R., Halpern, B.S., Ferreira, C.E.L., 2006. Effects of fishing and protection on Brazilian reef fishes. Biol. Cons. 128, 391–402. https://doi.org/10.1016/j.biocon.2005.10.005.

Graham, N., Dulvy, N., Jennings, J., Polunin, N., 2005. Size-spectra as indicators of the effects of fishing on coral reef fish assemblages. Coral Reefs 24, 118–124. https://doi.org/10.1007/s00338-004-0466-y.

Graham, N., McClanahan, T., MacNeil, A., Wilson, S., Cinner, J., Huchery, C., Holmes, T., 2017. Human Disruption of Coral Reef Trophic Structure. Curr. Biol. 27 (2), 231–236. https://doi.org/10.1016/j.cub.2016.10.062.

Hatton, I.A., Heneghan, R.F., Bar-On, Y.M., Galbraith, E.D., 2021. The global ocean size spectrum from bacteria to whales. Sci. Adv. 7 https://doi.org/10.1126/sciadv.abh3732.

Leitão, F., 2019. Mean size of the landed catch: a fishery community index for trend assessment in exploited marine ecosystems. Front. Mar. Sci. 6, 302. https://doi.org/10.3389/fmars.2019.00302.

MacNeil, M., Graham, N., Cinner, J., et al., 2015. Recovery potential of the world's coral reef fishes. Nat 520, 341–344. https://doi.org/10.1038/nature14358.

Mehner, T., Lischke, B., Scharnweber, K., Attermeyer, K., Brothers, S., Gaedke, U., Hilt, S., Brucet, S., 2018. Empirical correspondence between trophic transfer efficiency in freshwater food webs and the slope of their size spectra. Ecol 99, 1463–1472. https://doi.org/10.1002/ecy.2347.

Petchey, O., Belgrano, A., 2010. Body-size distributions and size-spectra: Universal indicators of ecological status. Biol. Lett. 6, 434–437. https://doi.org/10.1098/rsbl.2010.0240.

Pinheiro, H.T., Rocha, L.A., Macieira, R.M., Carvalho-Filho, A., Anderson, A.B., Bender, M.G., Di Dario, F., Ferreira, C.E.L., Figueiredo-Filho, J., Francini-Filho, R., Gasparini, J.L., 2018. South-western Atlantic reef fishes: Zoogeographical patterns and ecological drivers reveal a secondary biodiversity centre in the Atlantic Ocean. Divers. Distrib. 24, 951–965. https://doi.org/10.1111/ddi.12729.

Pinheiro, H.T., Nunes, J.A., Coni, E.O.C., Almeida, E.C.G., Sampaio, C.L.S., Ferreira, C.E., Ferreira, C.M., 2021. An Inverted Management Strategy for the Fishery of Endangered Marine Species. Front. Mar. Sci. 8, 172. https://doi.org/10.3389/fmars.2021.604108.

Rice, J., Gislason, H., 1996. Patterns of change in the size spectra of numbers and diversity of the North Sea fish assemblage, as reflected in surveys and models. ICES J. Mar. Sci. 53, 1214–1225. https://doi.org/10.1006/jmsc.1996.0146.

Roberts, C., Hawkins, J., Gell, F., 2005. The role of marine reserves in achieving sustainable fisheries. Philos. Trans. R. Soc. Lond. B. Biol. Sci. 360, 123–132. https://doi.org/10.1098/rstb.2004.1578.

Robinson, J., Williams, I., Edwards, A., et al., 2017. Fishing degrades size structure of coral reef fish communities. Glob. Change Biol. 23, 1009–1022. https://doi.org/10.1111/gcb.13482.

Rogers, A., Blanchard, J.L., Mumby, P.J., 2014. Vulnerability of coral reef fisheries to a loss of structural complexity. Curr. Biol. 24 (9), 1000–1005.

Rudorff, F., Gherardi, D., 2008. Coral reef detection using SAR/RADARSAT-1 images at Costa dos Corais, PE/AL, Brazil. Braz. J. Oceanogr. 56 (2), 85–96. https://doi.org/10.1590/S1679-87592008000200002.

Stuart-Smith, R., Barrett, N., Crawford, C., et al., 2008. Spatial patterns in impacts of fishing on temperate rocky reefs: Are fish abundance and mean size related to proximity to fisher access points. J. Exp. Mar. Biol. Ecol. 365 (2), 116–125. https://doi.org/10.1016/j.jembe.2008.08.002.

Tuda, P.M., Wolff, M., Breckwoldt, A., 2016. Size structure and gear selectivity of target species in the multispecies multigear fishery of the Kenyan South Coast. Ocean Coast. Manag. 130, 95–106. https://doi.org/10.1016/j.ocecoaman.2016.06.001.

Wilson, S., Fisher, R., Pratchett, M., et al., 2010. Habitat degradation and fishing effects on the size structure of coral reef fish communities. Ecol. Appl. 20 (2), 442–451. https://doi.org/10.1890/08-2205.1.

Zgliczynski, B., Sandin, S., 2017. Size-structural shifts reveal intensity of exploitation in coral reef fisheries. Ecol. Indic. 73, 411–421. https://doi.org/10.1016/j.ecolind.2016.09.045.