Biological Conservation 254 (2021) 108940

Contents lists available at ScienceDirect

Biological Conservation

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

Overexploitation and behavioral changes of the largest South Atlantic parrotfish (*Scarus trispinosus*): Evidence from fishers' knowledge

Pedro Henrique Cipresso Pereira [a,*], Maria Laura F. Ternes [b], José Anchieta C.C. Nunes [c], Vinicius J. Giglio [d]

[a] Projeto Conservação Recifal (Reef Conservation Project), Recife, PE, Brazil
[b] Aquatic Ecology and Fisheries Post-Graduate Program, Universidade Federal do Pará (UFPA), Belém, PA, Brazil
[c] Reef Ecology Group, 42 Desembargador Demétrio Tourinho, CEP 40155-010 Salvador, Brazil
[d] Marine Ecology and Conservation Lab, Instituto do Mar, Universidade Federal de São Paulo (UNIFESP), Santos, SP, Brazil

ARTICLE INFO

Keywords:
Local ecological knowledge
Scarus trispinosus
MPA Costa dos Corais
Flight initiation distance
Small-scale fisheries

ABSTRACT

Assessing species conservation status and population trends is challenging especially on low and low-middle income countries mostly due to high costs. Therefore, long-term information about species gained through local ecological knowledge, can reveal threatening and overexploitation scenarios aiming to generate information for extinction risk reduction and conservation priority targets. The greenbeak parrotfish, *Scarus trispinosus*, is an endemic and endangered Brazilian species with records of local extinction along its distribution, however limited data on its fisheries is available. We investigated fisher's local ecological knowledge on *S. trispinosus* on the largest Brazilian coastal multiple-use marine protected area. We interviewed small-scale fishers regarding catches to verify temporal changes in abundance and body size. Additionally, we verified if *S. trispinosus* flight initiation distance, proxy of tolerance from fisher's approximation has changed over different fishers' generations. Our results revealed that the number of individuals decreased 64% over time from 1980s to 2010s with a constant decrease through time. The weight of the largest individual ever caught also decreased 67% over time. Flight initiation distance, when fishers firstly engaged on fishing activity, was smaller for more experienced fishers. Implementation of small-scale co-management strategies, together with creation and enforcement of no-take zones are essential to safeguard the remaining populations and allow the greenbeak parrotfish recovery. Our study demonstrated that local ecological knowledge on species population and behavioral changes can be used as an alternative and inexpensive approach for assessing impact on threatened species and could be applied on conservation strategies for several species and ecosystems worldwide.

1. Introduction

Fishing is one of the most ancient exploration forms on marine ecosystems. Fishing activities globally provide food, income, and employee for millions of people (Mora et al., 2009; Teh and Sumaila, 2013). However, the extractive activity may cause negative impacts on fish populations and ecosystems. Records of impact have been reported since prehistoric times affecting species diversity and size (Lotze and Worm, 2009; Erlandson and Rick, 2010; Seersholm et al., 2018). It is assumed that fishing is currently responsible for fish populations reduction worldwide and fishing down marine food webs process have been demonstrated for several different fishing groups (Pauly et al., 1998; Freire and Pauly, 2010; Graham et al., 2017). In recent decades, based on the collapse of many coral reef fishes, parrotfishes have emerged as an important fisheries resource throughout the tropics (Mumby, 2006; Bender et al., 2014). However, increasing evidence of overexploitation has concerned managers and scientists regarding the losses on key parrotfish functional role as grazers and bioeroders on coral reefs (Hoey and Bonaldo, 2018). Studies have documented a worldwide dramatic near extinction scenario of parrotfish species with some records of local extinction (e.g. Comeros-Raynal et al., 2012; Bender et al., 2014).

A combination of field-based data and local ecological knowledge (LEK) of resource users may be a robust approach for guiding decision makers dealing on terrestrial and marine ecosystems (Mclean and Forrester, 2017; Berkström et al., 2019; Camino et al., 2020). Additionally,

* Corresponding author at: Rua dos Navegantes n-767 (Apt 801), Boa Viagem, Pernambuco, Brazil.
E-mail addresses: pedrohcp2@yahoo.com.br, pedrohcp2@gmail.com (P.H.C. Pereira).

https://doi.org/10.1016/j.biocon.2020.108940
Received 18 March 2020; Received in revised form 8 December 2020; Accepted 20 December 2020
Available online 12 January 2021

due to the absence of fisheries temporal data, relevant information on the fisheries effects on coral reef communities have been acquired through fishers' empirical knowledge (Harborne et al., 2008). When traditional scientific information is absent or incomplete, LEK, i.e. the information that resource users provide about their local ecosystems, particularly among small-scale fishers, may be the only source of relevant information available to researchers and managers (Gerhardinger et al., 2009; Azzurro et al., 2011). Therefore, resource users LEK has been applied as an alternative approach to understand multiple ecological aspects for many marine fields such as fisheries (Gerhardinger et al., 2009; Bender et al., 2014), fish behavior (Herbst and Hanazaki, 2014), connectivity and seascape management (Berkström et al., 2019) as well as environmental changes (Bart, 2006). Specifically, for fisheries, LEK has been extensively used on low and low-middle income countries where long-term monitoring data are commonly absent (Wilson et al., 2006; Begossi et al., 2017; Giglio et al., 2017). For instance, LEK has been used recently in Brazil to map marine habitats (Teixeira et al., 2013) and fishing grounds (Bourguignon et al., 2018).

Previous studies have been conducted applying fishers' LEK to better understand the effects of fisheries on parrotfish population worldwide (Aswani and Hamilton, 2004; Bender et al., 2014; Hamilton et al., 2016). Those studies have demonstrated large reduction in population size and near local extinctions (Bender et al., 2014; Hamilton et al., 2016). Additionally, researchers have also used fishers LEK data to better understand parrotfishes' behavioral aspects such as spawning aggregations and movement patterns (Hamilton et al., 2019). However, little research has been applied using LEK analyzing behavior changes on parrotfishes due to fisheries impact. Fishes that are actively hunted by people during diving activities with spear guns (e.g. spearfishing) should respond to people differently, becoming more frightened, than those that are not. Hence, recent studies have been using fish escape responses to humans as a metric of fishing pressure (Nunes et al., 2018; Pereira et al., 2020).

Flight initiation distance (FID), the distance of an approaching predator at which prey first initiate an escape, is a commonly applied metric in the studies on antipredator behavior on multiple ecosystems (Weston et al., 2012; Nunes et al., 2016, 2018). In a fishing context, humans are predators, thus information on FID can provide a useful tool to assess impacts of fishing because it is sensitive to differences in fishing pressure according to depth (Januchowski-Hartley et al., 2012; Pereira et al., 2020). It is expected that as fishing pressure increases, fish tolerance from human approach will also increase (Nunes et al., 2018). Therefore, fish species that are fishery targets, display an avoidance behavior against spearfishers likely as a consequence of fishing pressure. To our knowledge, FID was never studied from an empirical knowledge perspective, which could provide valuable temporal information on fish escape behavior based on local community data, and such approach can be applied to other taxa as well.

The greenbeak parrotfish, *Scarus trispinosus*, is a Brazilian endemic species. This species is reef associated and along its distribution range is known to occur on coral reefs, rocky reefs and algal beds (Freitas, 2016). *Scarus trispinosus* is the largest excavator parrotfish on Brazilian waters and plays a critical functional role on reducing algae-coral competition (Lellys et al., 2019). Based on measured declines in some locations, population of the species is estimated to have declined by at least 50% over the past 20 to 30 years (three generation lengths) being categorized as Endangered under International Union for Conservation of Nature's Red List Criterion A2d (Padovani-Ferreira et al., 2012). Additionally, *S. trispinosus* is highly vulnerable to overexploitation due to its large size, long life, and slow growth (Freitas et al., 2019); and considering that it recruits in shallow waters being vulnerable while juveniles. Therefore, *S. trispinosus* is known as one of the most threatened parrotfish on Earth mostly due to habitat degradation and overfishing, being targeted by both commercial and recreational fisheries mainly through spearfishing, gill nets and traps (Nunes et al., 2012; Bender et al., 2014; Roos et al., 2016; Freitas et al., 2019). Lack of scientific information on the species ecology and behavior and on temporal fisheries reduce the efficiency of fisheries management plan and conservation initiatives.

The present study aims to investigate the fishers' LEK regarding fisheries and behavioral temporal trends of *S. trispinosus* in tropical Brazilian reefs. Specifically, we conducted interviews with small-scale fishers to investigate fisheries perspective on population and individuals' size through time and changes in escape behavior. Additionally, LEK was used to investigate if *S. trispinosus* FID has changed over fisher generations.

2. Material and methods

2.1. Study area

The present study was conducted at the largest multiple-use Brazilian coastal marine protected area (MPA Costa dos Corais), created in 1997 to protect coral reef systems on Brazilian waters. This MPA stretches from 120 km in the northeastern Brazil encompassing two states and 12 municipalities (Fig. 1). MPA Costa dos Corais covers a large range of different ecosystems such as shallow reefs, mangroves, seagrass beds, rhodolith beds and mesophotic reefs from the coast to the break of the continental shelf (Maida and Ferreira, 1997). The multiple-use MPA allows different activities such as small-scale fishing and tourism and its management plan was published in 2013; with a revised version of the management plan being currently under revision by Brazilian government (Pereira et al., 2016; Miranda et al., 2020; authors personal observation).

2.2. Data collection

Data sampling was carried out between January 2018 and November 2019 in six fishing communities at different municipalities of the states of Pernambuco and Alagoas within the MPA Costa dos Corais: São João da Coroa Grande, Japaratinga, Porto de Pedras, São Miguel dos Milagres, Barra de Camaragibe and Barra de Santo Antônio. We collected data on different fishing communities (e.g. municipalities) aiming to understand *S. trispinosus* fishing trend considering that this data could support a better local management strategy for the species. The most common fishing gear for catching *S. trispinosus* in the MPA Costa dos Corais territory is spearfishing; therefore, all the interviewed fishers are related to this fishing method and for fishing activity performed during the day. A total of 122 face-to-face personal interviews were applied using structured questionnaires (minimum 20 per municipality) regarding the endemic Brazilian parrotfish *S. trispinosus* (Fig. 2). The respondents were selected through the snowball method (Bailey, 1982), a non-probabilistic sampling that aims to assess knowledge held by local experts, where each interviewee indicates another potential informant to be contacted. Questions encompassed: i) fishers' age and experience years on fishing; ii) fisher perception on *S. trispinosus* behavior regarding flight initiation distance; iii) largest weight (kg) and year such individual was captured; iv) largest number of individuals ever caught and year of capture. During interviews we used photos of the species and all the fishers interviewed properly identified the species. Interviews were conducted under full approval of the Sistema Nacional de Informação sobre Biodiversidade (SISBIO), permit #67684-1, and under consent of each informant after the interviewer's explaining the study objectives and providing contact information.

2.3. Data analysis

Linear regression models were fitted to test the relationship between i) the best captures (no. of individuals) and respective year; ii) weight of the largest individual ever caught and respective year; and iii) fishers' perception of FID values when they first engaged on spearfishing activity (past) compared to current days vs. experience (years) on parrotfish fisheries. The value of captures and flight initiation distance were

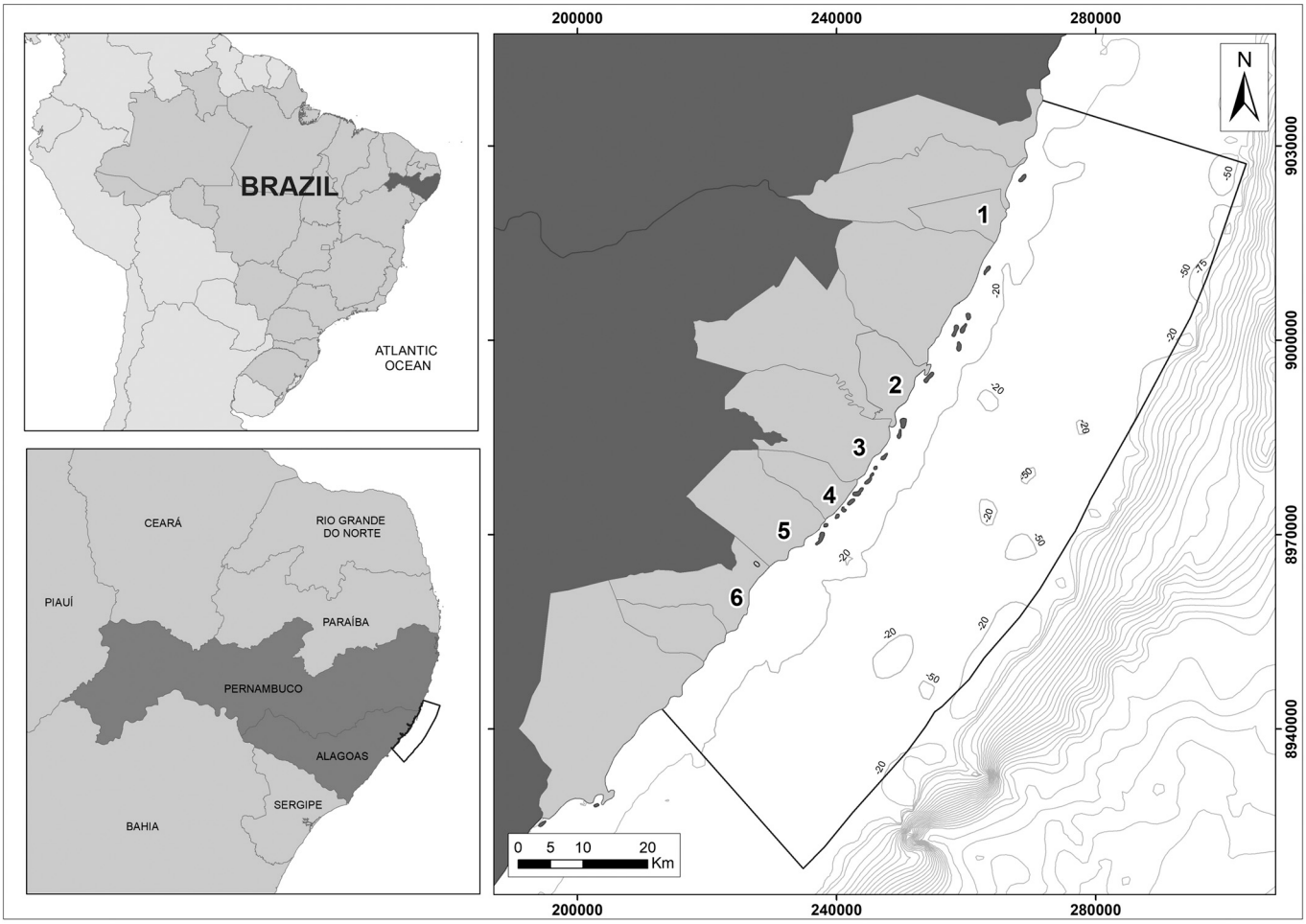

Fig. 1. Map of MPA Costa dos Corais. Numbers represent fishing communities where interviews were conducted. (1) São José da Coroa Grande, (2) Japaratinga, (3) Porto de Pedras, (4) São Miguel dos Milagres, (5) Barra de Camaragibe e (6) Barra de Santo Antônio.

transformed through ln (x + 1) prior to statistical analysis to reach assumptions of parametric model. Normality was tested using diagnostic plots, as well as Shapiro-Wilk W test and the homogeneity of variance was tested using Bartlett's test. Non-parametric one-way ANOVAs (Kruskal-Wallis test) were used to verify differences between municipalities (e.g. fishing communities) for the average weight of individuals from the best fishing event and the weight and size of large individual ever caught among municipalities. The differences between groups were verified through Dunn post-hoc test. A two-sample *t*-test was fitted to test for flight initiation distance to when spearfishers began fishing and the current approximation distance. All analyses were performed in R software v.3.5.1 (R Core Development Team, 2018) with a significance level of $P < 0.05$.

3. Results

The age of interviewed fishers varied from 23 to 82 years old (average ± s.d. = 50.5 ± 12.9) and the experience ranged from 8 to 70 years of fishing (32.2 ± 13.2). A significant relationship was verified between the number of individuals captured in best fishing event and the year it occurred ($r^2 = 0.21$, F = 23.1; $P < 0.001$) where the number of individuals decreased over time from 28 ± 14 ind. in the 1980s to 10 ± 9 ind. in the 2010s (Fig. 3A). A decrease on number of individuals caught also was observed between generations where fishers with more than 30 years of experience caught an average of 19 ± 8.8 individuals, while those with 0–15 years of experience mentioned 14 ± 10.2 individuals. The weight (kg) of the largest individual ever caught also significantly decreased over time ($r^2 = 0.26$, SE = 0.004, $P < 0.001$; Fig. 3B). Weight decreased from an average of 5.2 ± 2.8 kg in the 1980s to 1.7 ± 0.7 kg in 2010s.

Considering the different municipalities within the MPA Costa dos Corais, significant differences were verified among locations for the average weight (kg) of individuals from the best fishing event (H = 12.7, $P = 0.02$; Fig. 4A), however; not significant for the weight of larger individual ever caught (H = 9.9, $P = 0.07$; Fig. 4B). For the average weight of individuals from the best fishing event, larger individuals were caught in São José da Coroa Grande municipality.

Flight initiation distance (e.g. proxy of tolerance from fisher approximation) on previous decades ranged from 1 to 5 m (average = 1.9 ± 0.9 m) and the current distance of approximation ranged from 0 to 15 (average = 5.3 ± 2.8 m). There is a significant negative relationship among past FID when fishers firstly engaged on fishing activity where less experienced fishers perceived longer FID than those more experienced ($r^2 = 0.04$, F = 5.6; $P = 0.01$; Fig. 5A). However, such relationship was not verified when fishers were asked about current FID (Fig. 5A). A significant difference was found between past and current FID values ($t = -12.5$, P < 0.001; Fig. 5B). A total of 80.3% of interviewed fishers reported a current increase in FID compared to when they begin to fish *S. trispinosus* (Fig. 5C).

4. Discussion

By assessing a long-term fishers' local ecological knowledge, we demonstrated marked declines in captures over the last decades

Fig. 2. A-B) Greenbeak parrotfish (*Scarus trispinosus*) individuals captured through spearfishing at the MPA Costa dos Corais; C-D) *Scarus trispinosus* individuals recorded on the reefs.

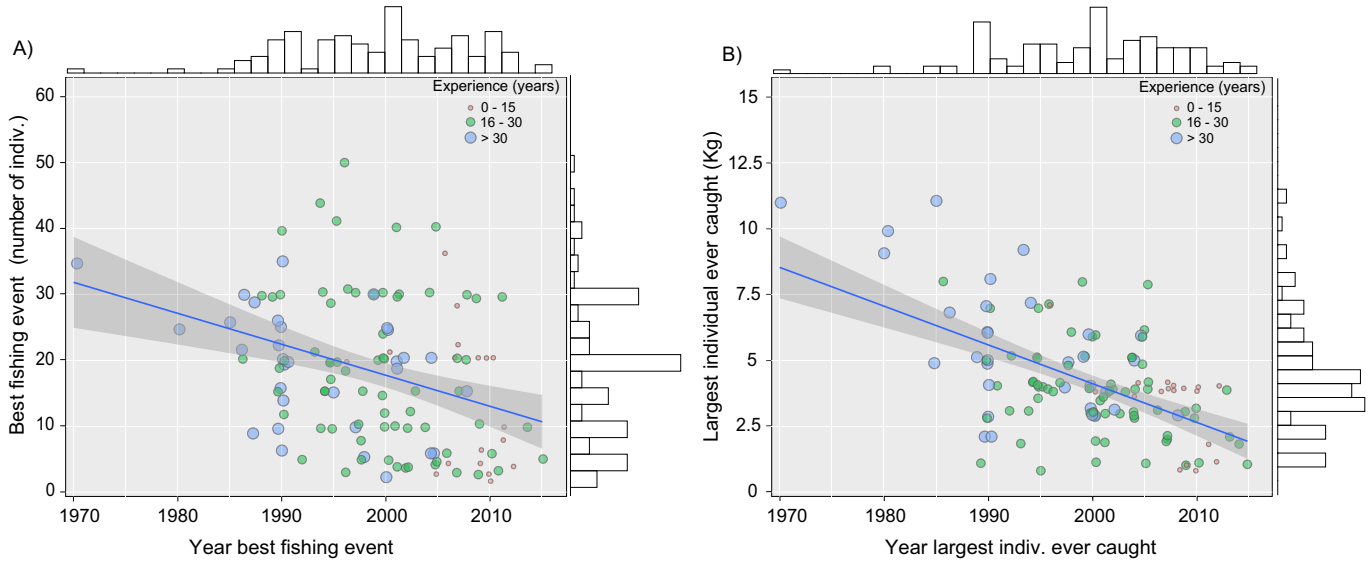

Fig. 3. A) Relationship between the number of individuals caught in the best fishing event and year; and B) weight of the largest individual ever caught (kg). The marginal histograms represent the data distribution. The deviation is the confidence interval (±95%).

suggesting a severe overexploitation for the largest Brazilian endemic parrotfish. Fishers perceived that both individual catch and largest fish weight has been dramatically reduced in the last three decades inside a multiple-use MPA. Continuous decrease on individual body size over the decades was recorded, matching the species conservation status on the Brazilian red list of threatened species (Padovani-Ferreira et al., 2012). Previous studies have demonstrated a fishing collapse of the largest Brazilian endemic parrotfish fisheries in southeastern Brazil (Bender et al., 2014) and suggested the species is currently functionally extinct in the region (Floeter et al., 2008). Hence, our findings highlight the importance of survey methods based on local ecological knowledge analyzing threatening and overexploitation scenarios and supporting conservation initiatives that can the applied to a wide range of species and ecosystems worldwide.

Parrotfish fisheries was intensified recently due to increased demand in local markets and tourism, and declines have been recorded worldwide (Hoey and Bonaldo, 2018). *S. trispinosus* catch on our study area is currently multi-species and multi-gear fisheries based on nets, traps, and spearfishing. This fishery was intensified in late 1980's and early 1990's likely following a decrease on other macro carnivore fisheries such as

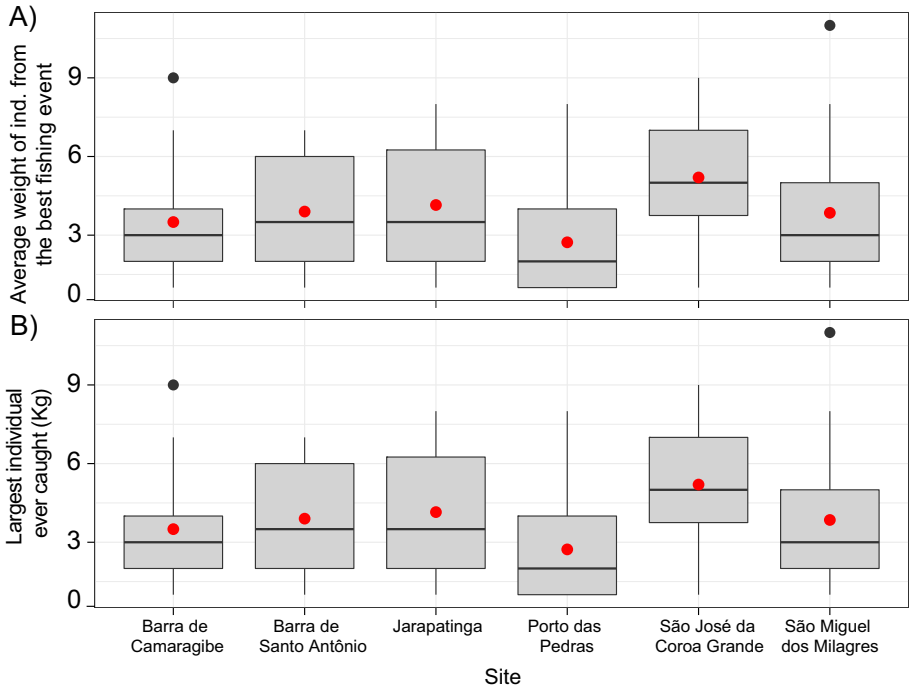

Fig. 4. A) Average weight of individuals from the best fishing event and B) weight of the largest individual ever caught (kg) between the fishing communities. The red dot represents the average. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

groupers and snappers (Bender et al., 2014). The fishing effort increased after the popularization of GPS and illegal usage of scuba for spearfishing (Freitas et al., 2019). Following this trend other parrotfish species such as the genus *Sparisoma* have now become target on Brazilian reefs (Floeter et al., 2006; Pinheiro et al., 2010; Nunes et al., 2012; Pinheiro and Joyeux, 2015) with evident decline in shallow waters and a possible near future threat scenario (Pereira et al., 2018). In fact, it was also observed that outer-shelf reefs currently sustained larger individuals and higher biomasses for different *Sparisoma* species on Brazilian reefs compared to shallow reefs (Freitas et al., 2019; Roos et al., 2019).

The escape behavior of *S. trispinosus* has also been altered since most of the interviewed fishers confirmed that flight initiation distance (FID) increased over time. As expected, *S. trispinosus* FID increased following intensification of fishing pressure. Surprisingly, such increase was not correlated with fisher experience, suggesting that FID variation could be occurring in few years scale. The increase on FID observed in this study could have implications on reef dynamics and on the species distribution. Previous studies have suggested that other reef fish species tolerated closer diver approach in deeper waters (Stamoulis et al., 2019; Pereira et al., 2020), considering that fish on larger depth probably never saw a diver before and do not perceive them as a threat. This could be supporting the hypothesis that a proportion of *S. trispinosus* fish population could be more tolerant to human presence in deeper water and that fishing pressure on shallow reefs has been altered reef fish behavior aspects. Further studies on *S. trispinosus* ecology using behavior observations and acoustic telemetry could be relevant to better understand these assumptions.

Ecological functioning of parrotfishes on coral reefs worldwide is indubitable (Bonaldo et al., 2014). However, the excavation functional role of *Scarus* species on Brazilian reefs and its potential bioerosion has only recently been demonstrated (Lellys et al., 2019). The heavy premaxilla and large body size of *S. trispinosus* along with previous information on their feeding behavior (Francini-Filho et al., 2013), suggest they play unique roles as excavating parrotfishes on the Abrolhos region. On the other hand, *S. trispinosus* is highly vulnerable to overexploitation due to its large size, long life and slow growth (Freitas et al., 2019; Roos et al., 2020). Therefore, current management strategies must be urgently revised to maintain populations of a vital functioning parrotfish on Brazilian reefs.

Extinction scenario of different taxa is a doubtless reality worldwide, with examples in marine and terrestrial habitats (Webb and Mindel, 2015). For instance, African mammals are severely threated by hunt and habitat degradation (Di Marco et al., 2014; Crooks et al., 2017). Additionally, birds in the Amazon have a strong extinction rate due to deforestation and climate change (Stouffer et al., 2009; Moraes et al., 2020). Hence, data from local ecological knowledge is vital to record long-term population reduction of already endangered species at both marine and terrestrial habitats (Bender et al., 2014; Camino et al., 2020). Monitoring programs *in situ* are scarce or absent on low and low-middle income countries mostly due to high costs. Therefore, long-term information about species gained through LEK, such as the endemic Brazilian parrotfish as herein demonstrated, can reveal threatening and overexploitation scenario aiming for extinction risk reduction and conservation priority targets.

Considering the drastic declines in abundance and overexploitation scenario for *S. trispinosus*, recovery strategies should be urgently implemented on the MPA Costa dos Corais and in Brazilian coast through fishing ban. However, this strategy is likely to be ineffective in a country with a large and complex coastline and poor norms compliance and enforcement like Brazil (e.g. Palmeira et al., 2013; Giglio et al., 2014). Therefore, other management initiatives could be also implemented if a ban scenario is unrealistic. For instance, Brazilian government has recently introduced an alternative management strategy for sustainable catch of threatened parrotfish species. This innovative strategy allows threatened species to be fished by traditional communities inside managed areas, such as multiple-use MPAs; however, banning their capture anywhere else in Brazilian coast (Freitas et al., 2019). If effectively implemented and supervised, such small-scale management in priority conservation areas could be a valuable strategy for threatened populations recovery and could be implemented engaging local fishers through co-management. In Brazil there is the iconic successful case of pirarucu *Arapaima* sp. community-based fisheries management in Amazon freshwaters (Petersen et al., 2016). Pirarucu populations were able to increase and recover while fishers benefit

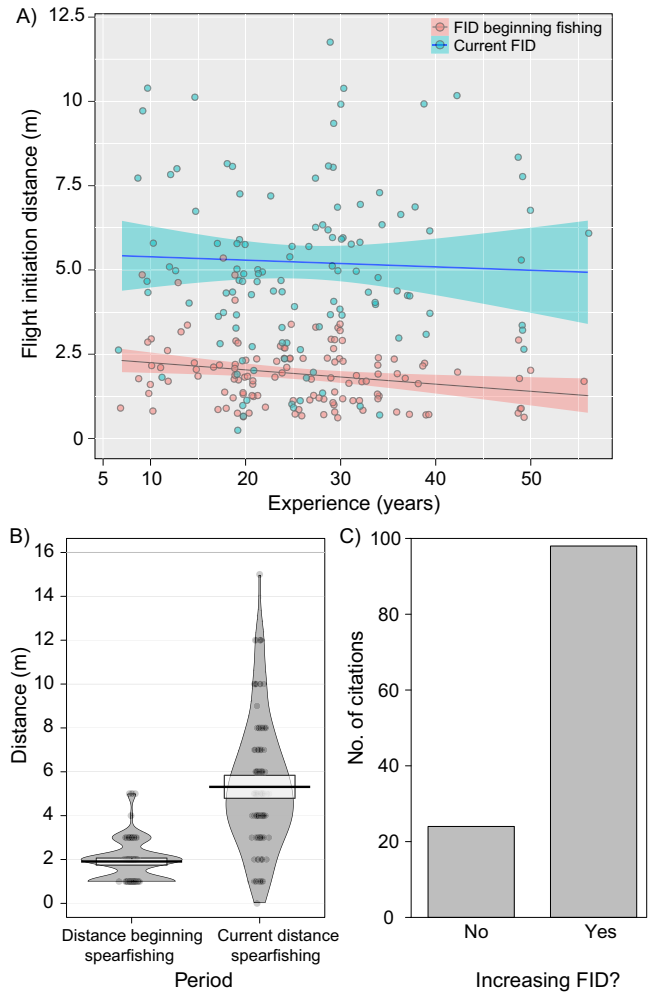

Fig. 5. A) Relationship between the past (when spearfishers first engaged on fishing activity) and current parrotfish flight initiation distance vs. experience (years) on parrotfish fisheries. Points were jittered to avoid overplotting B) flight initiation distance in the past and current. Points are the raw data, the black line illustrates the mean flight initiation distance, the bean is the density, the band is the inference interval and deviations the 10th and 90th percentiles. C) Perception about increasing on flight initiation distance.

from the sustainability and conservation-value of those managed fisheries. This supervised management plan to be implemented inside MPA Costa dos Corais like a co-management strategy should encompass size catch restrictions, quota per fish and catch ban on specific periods (e.g. reproduction seasons). For instance, based on fisher's suggestions and literature data (Freitas et al., 2019), *S. trispinosus* catch would be only allowed during the day and for individuals larger than 40 cm and weighting over 3 kg. A season ban would be also recommended during February–March and August–September (spawning peaks). Lastly, fish may be landed eviscerated but never in fillets which makes identification of the species difficult during monitoring.

An additional conservation strategy for the species should be the implementation and enforcement of no-take zones on shallow and deeper reefs inside the MPA Costa dos Corais and along Brazilian coast to safeguard the remaining populations of the species and allow a long-term recovery. The functional role of *S. trispinosus* and iconic importance as the largest endemic parrotfish in the southwestern Atlantic is indubitable and its extinction could compromise Brazilian reefs sustainability.

Our study demonstrated that local ecological knowledge data on species capture (number of individuals caught, weight of the largest individual ever caught) together with behavioral changes (flight initiation distance) can be an effective low-cost alternative for assessing impact on threatened species. Therefore, it could be broadly applied for several ecosystems worldwide. Although it is a challenging task to implement a collaborative work with local stakeholders, it is important to emphasize that studies based on LEK may improve local capacity and raise the chances of success of further conservation actions especially on protected areas (Camino et al., 2020).

CRediT authorship contribution statement

Pedro Pereira: Conceptualization, Methodology, Writing - Original Draft; Writing - Review & Editing **Maria Laura**: Writing - Review & Editing. **José Anchieta**: Visualization, Investigation. Writing - Review & Editing. **Vinicius Giglio**: Software, Validation. Writing - Review & Editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

We would like to thank Diego Santos and Edvaldo Nascimento for interviews logistics and support. MPA Costa dos Corais (APACC) management team and Projeto Conservação Recifal staff for support. VJG received a post-doctoral grant #2017/22273-0, São Paulo Research Foundation (FAPESP), MLFT received a grant from Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES) – finance code 001. This study was financed by Rufford Small Grants, Conservation Leadership Program (CLP), Marine Conservation Action Fund, Mohamed Bin Zayed Species Conservation and The Prince Bernhard Nature Fund (PBNF) grants for PHCP and Reef Conservation Project (Projeto Conservação Recifal - PCR).

References

Aswani, S., Hamilton, R.J., 2004. Integrating indigenous ecological knowledge and customary sea tenure with marine and social science for conservation of bumphead parrotfish (*Bolbometopon muricatum*) in the Roviana Lagoon, Solomon Islands. Environ. Conserv. 31 (1), 69–83. https://doi.org/10.1017/S037689290400116x.

Azzurro, E., Moschella, P., Maynou, F., 2011. Tracking signals of change in Mediterranean fish diversity based on local ecological knowledge. PLoS One 6 (9), e24885. https://doi.org/10.1371/journal.pone.0024885.

Bailey, K.D., 1982. Methods of Social Research. The Free Press, McMillan Publishers, New York (553 pp.).

Bart, D., 2006. Integrating local ecological knowledge and manipulative experiments to find the causes of environmental change. Front. Ecol. Environ. 4 (10), 541–546. https://doi.org/10.1890/1540-9295(2006)4[541:ILEKAM]2.0.CO;2.

Begossi, A., Salivonchyk, S., Hallwass, G., Hanazaki, N., Lopes, P.F., Silvano, R.A., 2017. Threatened fish and fishers along the Brazilian Atlantic Forest Coast. Ambio 46 (8), 907–914. https://doi.org/10.1007/s13280-017-0931-9.

Bender, M.G., Machado, G.R., de Azevedo Silva, P.J., Floeter, S.R., Monteiro-Netto, C., Luiz, O.J., Ferreira, C.E.L., 2014. Local ecological knowledge and scientific data reveal overexploitation by multigear artisanal fisheries in the Southwestern Atlantic. PLoS One 9 (10), e110332. https://doi.org/10.1371/journal.pone.0110332.

Berkström, C., Papadopoulos, M., Jiddawi, N.S., Nordlund, L.M., 2019. Fishers' local ecological knowledge (LEK) on connectivity and seascape management. Front. Mar. Sci. 6, 130. https://doi.org/10.3389/fmars.2019.00130.

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

Bourguignon, S.N., Bastos, A.C., Quaresma, S.V., Vieira, F.V., Pinheiro, H.T., Amado-Filho, G.M., Moura, R.L., Teixeira, J.B., 2018. Seabed morphology and sedimentary regimes defining fishing grounds along the Eastern Brazilian Shelf. Geosci. 8, 91. https://doi.org/10.3390/geosciences8030091.

Camino, M., Thompson, J., Andrade, L., Cortez, S., Matteucci, S.D., Altrichter, M., 2020. Using local ecological knowledge to improve large terrestrial mammal surveys, build local capacity and increase conservation opportunities. Biol. Conserv. 1, 108450.

Comeros-Raynal, M.T., Choat, J.H., Polidoro, B.A., Clements, K.D., Abesamis, R., Craig, M.T., Nañola Jr., C.L., 2012. The likelihood of extinction of iconic and dominant herbivores and detritivores of coral reefs: the parrotfishes and

surgeonfishes. PLoS One 7 (7), e39825. https://doi.org/10.1371/journal.pone.0039825.
Crooks, K.R., Burdett, C.L., Theobald, D.M., King, S.R.B., Di Marco, M., Rondinini, C., Boitani, L., 2017. Quantification of habitat fragmentation reveals extinction risk in terrestrial mammals. P. Natl. Acad. Sci. USA 114, 7635–7640. https://doi.org/10.1073/pnas.1705769114.
Di Marco, M., Buchanan, G.M., Szantoi, Z., Holmgren, M., Grottolo Marasini, G., Gross, D., Rondinini, C., 2014. Drivers of extinction risk in African mammals: the interplay of distribution state, human pressure, conservation response and species biology. Philos. T. R. Soc. B. 369, 20130198. https://doi.org/10.1098/rstb.2013.0198.
Erlandson, J.M., Rick, T.C., 2010. Archaeology meets marine ecology: the antiquity of maritime cultures and human impacts on marine fisheries and ecosystems. Annu. Rev. Mar. Sci. 2, 231–251. https://doi.org/10.1146/annurev.marine.010908.163749.
Ferreira, B.P., Floeter, S.R., Rocha, L.A., Ferreira, C.E.L., Francini-Filho, R.B., Moura, R. L., Gaspar, A.L., Feitosa, C., 2012. *Scarus trispinosus*. IUCN red list of threatened species, v. 2013. http://www.iucnredlist.org/. (Accessed 14 January 2020).
Floeter, S.R., Halpern, B.S., Ferreira, C.E.L., 2006. Effects of fishing and protection on Brazilian reef fishes. Biol. Conserv. 128 (3), 391–402. https://doi.org/10.1016/j.biocon.2005.10.005.
Floeter, S.R., Rocha, L.A., Robertson, D.R., Joyeux, J.C., Smith-Vaniz, W.F., Wirtz, P., Edwards, A.J., Barreiros, J.P., Ferreira, C.E.L., Gasparini, J.L., Brito, A., 2008. Atlantic reef fish biogeography and evolution. J. Biogeogr. 35 (1), 22–47. https://doi.org/10.1111/j.1365-2699.2007.01790.x.
Francini-Filho, R.B., Coni, E.O.C., Meirelles, P.M., Amado-Filho, G.M., Thompson, F.L., Pereira-Filho, G.H., Bastos, A.C., Abrantes, D.P., Ferreira, C.M., Gibran, F.Z., Güth, A. Z., 2013. Dynamics of coral reef benthic assemblages of the Abrolhos Bank, eastern Brazil: inferences on natural and anthropogenic drivers. PLoS One 8 (1), e54260. https://doi.org/10.1371/journal.pone.0054260.
Freire, K.M., Pauly, D., 2010. Fishing down Brazilian marine food webs, with emphasis on the east Brazil large marine ecosystem. Fish. Res. 105 (1), 57–62. https://doi.org/10.1016/j.fishres.2010.02.008.
Freitas, M.O., 2016. Plano de Recuperação para o budião-azul (*Scarus trispinosus*), peixe-papagaio-banana (*Scarus zelindae*) e peixes-papagaio-cinza (*Sparisoma axillare* e *Sparisoma frondosum*) (Curitiba, 71 pp.).
Freitas, M.O., Previero, M., Leite, J.R., Francini-Filho, R.B., Minte-Vera, C.V., Moura, R. L., 2019. Age, growth, reproduction and management of Southwestern Atlantic's largest and endangered herbivorous reef fish, *Scarus trispinosus* Valenciennes, 1840. PeerJ. 7, e7459 https://doi.org/10.7717/peerj.7459.
Gerhardinger, L.C., Godoy, E.A., Jones, P.J., 2009. Local ecological knowledge and the management of marine protected areas in Brazil. Ocean Coast. Manage. 52 (3–4), 154–165. https://doi.org/10.1016/j.ocecoaman.2008.12.007.
Giglio, V.J., Bertoncini, A.A., Ferreira, B.P., Hostim-Silva, M., Freitas, M.O., 2014. Landings of goliath grouper, *Epinephelus itajara*, in Brazil: despite prohibited over ten years, fishing continues. Nat. Conserv. 12 (2), 118–123. https://doi.org/10.1016/j.ncon.2014.09.004.
Giglio, V.J., Bender, M.G., Zapelini, C., Ferreira, C.E.L., 2017. The end of the line? Rapid depletion of a large-sized grouper through spearfishing in a subtropical marginal reef. Persp. Ecol. Cons. 15 (2), 115–118. https://doi.org/10.1016/j.pecon.2017.03.006.
Graham, N.A., McClanahan, T.R., MacNeil, M.A., Wilson, S.K., Cinner, J.E., Huchery, C., Holmes, T.H., 2017. Human disruption of coral reef trophic structure. Curr. Biol. 27 (2), 231–236. https://doi.org/10.1016/j.cub.2016.10.062.
Hamilton, R.J., Almany, G.R., Stevens, D., Bode, M., Pita, J., Peterson, N.A., Choat, J.H., 2016. Hyperstability masks declines in bumphead parrotfish (*Bolbometopon muricatum*) populations. Coral Reefs 35 (3), 751–763. https://doi.org/10.1007/s00338-016-1441-0.
Hamilton, R.J., Hughes, A., Brown, C.J., Leve, T., Kama, W., 2019. Community-based management fails to halt declines of bumphead parrotfish and humphead wrasse in Roviana Lagoon, Solomon Islands. Coral Reefs 38 (3), 455–465. https://doi.org/10.1007/s00338-019-01801-z.
Harborne, A.R., Mumby, P.J., Kappel, C.V., Dahlgren, C.P., Micheli, F., Holmes, K.E., Brumbaugh, D.R., 2008. Tropical coastal habitats as surrogates of fish community structure, grazing, and fisheries value. Ecol. Appl. 18 (7), 1689–1701. https://doi.org/10.1890/07-0454.1.
Herbst, D.F., Hanazaki, N., 2014. Local ecological knowledge of fishers about the life cycle and temporal patterns in the migration of mullet (*Mugil liza*) in Southern Brazil. Neotrop. Ichthyol. 12 (4), 879–890. https://doi.org/10.1590/1982-0224-20130156.
Hoey, AS, Bonaldo, RM (Eds.), 2018. Biology of parrotfishes, CRC Press, Taylor & Francis Group, Boca Raton, 420 pp.
Januchowski-Hartley, F.A., Graham, N.A.J., Cinner, J.E., Russ, G.R., 2012. Spillover of fish naïveté from marine reserves. Ecol. Lett. 16 (2), 191–197. https://doi.org/10.1111/ele.12028.
Lellys, N.T., Moura, R.L., Bonaldo, R.M., Francini-Filho, R.B., Gibran, F.Z., 2019. Parrotfish functional morphology and bioerosion on SW Atlantic reefs. Mar. Ecol. Prog. Ser. 629, 149–163. https://doi.org/10.3354/meps13102.
Lotze, H.K., Worm, B., 2009. Historical baselines for large marine animals. Trends Ecol. Evol. 24 (5), 254–262. https://doi.org/10.1016/j.tree.2008.12.004.
Maida, M., Ferreira, B., 1997. Coral reefs of Brazil: An overview. Proc 8th Int Coral Reef Sym 1, 263–274.
Mclean, E.L., Forrester, G.E., 2017. Comparing estimates of size-at-maturity and maximum body size made by fishers and scientists as indicators of potential overfishing. In: Marine Affairs Data Sets. Paper 1. https://doi.org/10.23860/dataset-mclean-2017.
Mora, C., Myers, R.A., Coll, M., Libralato, S., Pitcher, T.J., Sumaila, R.U., Zeller, D., Watson, R., Gaston, K.J., Worm, B., 2009. Management effectiveness of the world's marine fisheries. PLoS Biol. 7, e1000131 https://doi.org/10.1371/journal.pbio.1000131.
Moraes, K.F., Santos, M.P.D., Gonçalves, G.S.R., Oliveira, G.L., Gomes, L.B., Lima, M.G. M., 2020. Climate change and bird extinctions in the Amazon. PLoS One 15, e0236103. https://doi.org/10.1371/journal.pone.0236103.
Mumby, P.J., 2006. The impact of exploiting grazers (Scaridae) on the dynamics of Caribbean coral reefs. Ecol. Appl. 16 (2), 747–769. https://doi.org/10.1890/1051-0761(2006)016[0747:TIOEGS]2.0.CO;2.
Nunes, J.A.C.C., Medeiros, D.V., Reis-Filho, J.A., Sampaio, C.L.S., Barros, F., 2012. Reef fishes captured by recreational spearfishing on reefs of Bahia State, northeast Brazil. Biota Neotrop. 12 (1), 179–185. https://doi.org/10.1590/S1676-06032012000100014.
Nunes, J.A.C.C., Loiola, M., Miranda, R.J., Sampaio, C.L.S., Barros, F., 2016. Are Abrolhos no-take area sites of naïve fish? An evaluation using flight initiation distance of labrids. Neotrop. Ichthyol. 14 (4), e160133 https://doi.org/10.1590/1982-0224-20160133.
Nunes, J.A.C.C., Costa, Y., Blumstein, D.T., Leduc, A.O.C., Dorea, A.C., Benevides, L.J., Barros, F., 2018. Global trends on reef fishes' ecology of fear: flight initiation distance for conservation. Mar. Environ. Res. 136, 153–157. https://doi.org/10.1016/j.marenvres.2018.02.011.
Palmeira, C.A.M., Rodrigues-Filho, L.F.S., Sales, J.B.L., Vallinoto, M., Schneider, H., Sampaio, I., 2013. Commercialization of a critically endangered species (largetooth sawfish, *Pristis perotteti*) in fish markets of northern Brazil: authenticity by DNA analysis. Food Control 34 (1), 249–252. https://doi.org/10.1016/j.foodcont.2013.04.017.
Pauly, D., Christensen, V., Dalsgaard, J., Froese, R., Torres, F., 1998. Fishing down marine food webs. Science 279 (5352), 860–863. https://doi.org/10.1126/science.279.5352.860.
Pereira, P.H.C., Santos, M., Lippi, D.L., Silva, P., 2016. Ontogenetic foraging activity and feeding selectivity of the Brazilian endemic parrotfish *Scarus zelindae*. PeerJ 4, e2536. https://doi.org/10.7717/peerj.2536.
Pereira, P.H.C., Macedo, C.H., Nunes, J.A.C.C., Marangoni, L.F., Bianchini, A., 2018. Effects of depth on reef fish communities: insights of a "deep refuge hypothesis" from Southwestern Atlantic reefs. PLoS One 13 (9). https://doi.org/10.1371/journal.pone.0203072.
Pereira, P.H.C., Macedo, C.H., Lima, G.V., Benevides, L.J., 2020. Effects of depth on reef fish flight initiation distance: implications of deeper reefs conservation. Environ. Biol. Fish 103, 1247–1256. https://doi.org/10.1007/s10641-020-01017-z.
Petersen, T.A., Brum, S.M., Rossoni, F., Silveira, G.F.V., Castello, L., 2016. Recovery of Arapaima sp. populations by community-based management in floodplains of the Purus River, Amazon. J. Fish. Biol. 89 (1), 241–248. https://doi.org/10.1111/jfb.12968.
Pinheiro, H.T., Joyeux, J.-C., 2015. The role of recreational fishermen in the removal of target reef fishes. Ocean Coast. Manag. 112, 12–17. https://doi.org/10.1016/j.ocecoaman.2015.04.015.
Pinheiro, H.T., Joyeux, J.-C., Martins, A.S., 2010. Reef fisheries and underwater surveys indicate overfishing of a Brazilian Coastal Island. Nat. Conservacao 08, 151–159. https://doi.org/10.4322/natcon.00802008.
R Core Development Team, 2018. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Austria: Vienna.
Roos, N.C., Pennino, M.G., Lopes, P.F.M., Carvalho, A.R., 2016. Multiple management strategies to control selectivity on parrotfishes harvesting. Ocean Coast. Manag. 134, 20–29. https://doi.org/10.1016/j.ocecoaman.2016.09.029.
Roos, N.C., Pennino, M.G., Carvalho, A.R., Longo, G.O., 2019. Drivers of abundance and biomass of Brazilian parrotfishes. Mar. Ecol. Prog. Ser. 623, 117–130. https://doi.org/10.3354/meps13005.
Roos, N.C., Taylor, B.M., Carvalho, A.R., Longo, G.O., 2020. Demography of the largest and most endangered Brazilian parrotfish, *Scarus trispinosus*, reveals overfishing. Endanger. Species Res. 41, 319–327. https://doi.org/10.3354/esr01024.
Seersholm, F.V., Cole, T.L., Grealy, A., Rawlence, N.J., Greig, K., Knapp, M., Tennyson, A. J., 2018. Subsistence practices, past biodiversity, and anthropogenic impacts revealed by New Zealand-wide ancient DNA survey. P. Natl. Acad. Sci. USA 115 (30), 7771–7776. https://doi.org/10.1073/pnas.1803573115.
Stamoulis, K.A., Harvey, E.S., Friedlander, A.M., Williams, I.D., Weng, K.C., Wiggins, C., Conklin, E.J., 2019. Flight behavior of targeted fishes depends on variables other than fishing. Ecol. Indic. 96, 579–590. https://doi.org/10.1016/j.ecolind.2018.09.006.
Stouffer, P.C., Strong, C., Naka, L.N., 2009. Twenty years of understorey bird extinctions from Amazonian rain forest fragments: consistent trends and landscape-mediated dynamics. Divers. Distrib. 15, 88–97. https://doi.org/10.1111/j.1472-4642.2008.00497.x.
Teh, L.C.L., Sumaila, U.R., 2013. Contribution of marine fisheries to worldwide employment. Fish Fish. 14, 77–88. https://doi.org/10.1111/j.1467-2979.2011.00450.x.
Teixeira, J.B., Martins, A., Pinheiro, H.T., Secchin, N., Moura, R.L., Bastos, A., 2013. Traditional ecological knowledge and the mapping of benthic marine habitats. J. Environ. Manag. 115, 241–250. https://doi.org/10.1016/j.jenvman.2012.11.020.

Webb, T.J., Mindel, B.L., 2015. Global patterns of extinction risk in marine and non-marine systems. Curr. Biol. 25, 506–511. https://doi.org/10.1016/j.cub.2014.12.023.

Weston, M.A., McLeod, E.M., Blumstein, D.T., Guay, P.J., 2012. A review of flight-initiation distances and their application to managing disturbance to Australian birds. Emu 112, 269–286.

Wilson, D.C., Raakjær, J., Degnbol, P., 2006. Local ecological knowledge and practical fisheries management in the tropics: a policy brief. Mar. Policy 30 (6), 794–801. https://doi.org/10.1016/j.marpol.2006.02.004.