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Local ecological knowledge to assist conservation status assessments in data poor contexts: a case study with the threatened sharks of the Brazilian Northeast

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Abstract

The list of threatened species (Red List), established by the International Union for Conservation of Nature (IUCN), aims to provide global assessments on the extinction risk of species. However, protecting vulnerable populations requires establishing threat criteria at sub-global scales, e.g., national Red Lists. In data-poor contexts, typical of many developing countries, assessing threat status by applying IUCN criteria constitutes a major challenge, which may be one reason for mismatches between national and global Red List assessments. Despite the intense harvesting of threatened elasmobranchs species in Brazilian waters, Brazilian fisheries monitoring has ceased to exist for nearly a decade. This jeopardizes accurate assessment of species' conservation status at a local scale. In the absence of fisheries records, local ecological knowledge (LEK) provides an alternative option to obtain reliable information on targeted species. We interviewed 186 fishers from four Brazilian Northeastern states, whose recollections spanned six decades and documented catches or sightings of 19 shark species. For eight species with sufficient data, temporal trends in maximum length of sharks caught by fishers of different age-classes were statistically tested. Four species' maximum length declined over time, while four were primarily captured by elderly fishers, with few or no recent catches reported. Of these species, one is classified more conservatively in the national Red List vs. IUCN Red List, which is supported by LEK results. Contrastingly, two species are classified less conservatively at the national level than by IUCN, such that upgrading and matching IUCN's conservation criteria is warranted. We suggest that LEK provides support for conservation status listing in data-poor contexts.

Keywords Tropical fisheries · Elasmobranchs · Traditional ecological knowledge · South-America · Marine conservation · Data-poor management

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Introduction

The conservation status of species, i.e. categorizing species as endangered vs. least concern based on various data sources and expert opinion was established to provide a method to monitor and highlight the extinction risk of species, and to direct conservation measures (Rodrigues et al. 2006; Miller et al. 2007; IUCN 2019). Typically, the status of species is established at the global scale by the International Union for Conservation of Nature (IUCN) Red List, which is arguably the most authoritative source of information on the extinction risk of biota. Given that many species are distributed across large spatial areas and consist of numerous geographically connected or distinct populations under different localized threats, the status of a species at local and national levels can often differ from that of the global assessment (Gardenfors 2001).

Variation in the conservation status of species amongst assessments may be driven by numerous factors, including national legislation, the level of protection offered and local harvesting pressure (Gardenfors 2001; Miller et al. 2007; Zamin et al. 2010). As a result, regional working groups of the IUCN undertake classification of country-specific population status using region-specific data and local expert knowledge. When Red Lists status are established at a regional scale (e.g., National Red List), mismatches between global and sub-global assigned status often occurs (Brito et al. 2010; Bender et al. 2012; Helfman 2013; Ceretta et al. 2020). This is expected because the status of a species at local or national levels can differ from the average status of a species globally, either due to local extirpations or well-protected healthy populations in specific localities. However, the lack of appropriate data may also lead to misclassification by national groups. Nonetheless, incongruences between assigned status at global vs. regional scales may lead to people questioning the credibility of the need for conservation actions at a regional scale, and/or purposely use this to limit or reduce the likelihood for the implementation of conservation actions (Rodríguez et al. 2000; Helfman 2013).

Assigning the status of species to IUCN Red List categories requires meeting quantitative criteria, for example, based on distribution, abundance and the trajectory of harvested biomass (IUCN 2019). At the national level, many developing tropical countries lack these basic data (Paglia and Fonseca 2009; Castro Pena et al. 2014; Reis-Filho and Leduc 2017). Simultaneously, human pressures are commonly elevated in these regions, given reduced enforcement and monitoring as a result of limited economic resources, combined with most of these countries harbouring high biodiversity (Andrew et al. 2007). In fact, stock assessments are expensive, even for developed countries, and especially where diversity is much higher. When considering commercially important fish species, for example, the importance of assigning status classifications may be a central requirement to establish fishing quotas or to determine whether a stock may or may not be exploited (sensu Gardenfors 2001; Camhi et al. 2007).

Where basic scientific data is lacking or incomplete, the information held by primary resource users (e.g., fishers) may provide the only approach to accurately assess the present status of resources (e.g., population trends, sensu Anadon et al. 2009; Reis-Filho et al. 2016). Termed, local ecological knowledge (LEK), this constitutes a body of information held by local people on the resource to which they closely interact (Berkes et al. 2000). This knowledge involves how natural resources are perceived, their specific composition and abundance patterns, along with numerous biological and ecological aspects such as size, diet and distribution (Drew 2005; Giglio and Bornatowski 2016; Lopes et al. 2019). When considering fisheries, a wealth of knowledge points to the positive role LEK may play in improving management decisions and promoting adequate conservations actions (Ainsworth and Pitcher 2005; Castellanos-Galindo et al. 2011; Armitage et al. 2011; Tesfamichael et al. 2014; de Morais Cardoso da Silva et al. 2020). This occurs because fishers can provide new and relevant information (e.g., ecology, behaviour, trends in abundance) on aquatic species that they interact with on a daily/lifetime basis, the potential influences of those species on other fishing resources and the ecosystem as a whole (Johannes 1981, 1998; Johannes et al. 2000; Silvano et al. 2006, 2008; Silvano and Valbo-Jorgensen 2008; Berkström 2019). When used together with complementary information (e.g., scientific or grey literature, Red Lists, experts' opinion), this information can provide guidance toward establishing the status of species/populations or even form the base of conservation and management strategies (Johannes et al. 2000; O'Donnell et al. 2010; Castellanos-Galindo et al. 2011; Armitage et al. 2011; Zapelini et al. 2017; de Morais Cardoso da Silva et al. 2020).

Globally, elasmobranchii is one of the most threatened taxonomic groups (Dulvy et al. 2014; Queiroz et al. 2019). Their life-history, often involving low fecundity/reproductive output (Simpfendorfer and Kyne 2009; Pardo et al. 2016), contributes to these species' vulnerability to overexploitation (Camhi et al. 2008). In fact, since 2003 global landings have declined despite reductions in fishing efforts (Dulvy et al. 2008; Davidson et al. 2015), particularly in coastal species (Baum et al. 2003; Queiroz et al. 2019). These insidious effects are frequently compounded by a chronic lack of robust data on population abundance, making it difficult to establish appropriate conservation priorities at a national scale. Concurrently, given their high costs, stock assessments are typically limited to a small number of high capacity nations in the global North (Simpfendorfer and Dulvy 2017). Contrastingly, the world's largest shark fishing countries are concentrated in the global South, where data and resources for sophisticated science-based monitoring are limited, while the complexity of their fisheries is often neglected (Booth et al. 2019). Under these conditions, and considering that data is needed to appropriately manage this species group (Davidson et al. 2015), LEK has already provided essential information and guidance on elasmobranch fisheries (Leeney and Downing 2015; Giglio and Bornatowski 2016; Barbosa-Filho et al. 2017).

Here, our objective was to determine whether the LEK of fishers could be used to help establish the status of shark populations in the Brazilian Northeast. By interviewing small-scale fishers for information on the maximum length and spatiotemporal catch records of 19 shark species (i.e., those with records of catch by SSF in the area), we aimed to determine the value of LEK to generate ecologically-relevant quantitative information to assist conservation status assessment in data-limited regions. In turn, we identify how LEK may be integrated with globally-available knowledge, such as the IUCN's Red List and scientific literature to provide guidance on species' conservation status set at the national level. The present work forms a basis against which future conservation actions and risk categorizations can be evaluated for several shark species, and identifies future avenues for the incorporation of LEK to assess the conservation status of elasmobranch populations elsewhere.

Material and methods

Brazil as a case study

In Brazil, classification schemes for the conservation status of biota are established by the Institute Chico Mendes for Conservation of Biodiversity (ICMBio), which provides national conservation objectives and guidance for the sustainable management of harvested populations (Peres et al. 2011). Establishing the conservation status of species is made by experts' opinion under the umbrella of ICMBio and follows the basic categories and guidelines of the IUCN (2019). Despite harbouring large-scale active marine and freshwater fishery sectors, Brazilian fishery monitoring effectively ceased in 2011 (Previero et al. 2013; Reis-Filho and Leduc 2017), which has complicated the process of establishing adequate conservation status assessments of species at the national level.

The Brazilian marine small-scale fishery sector (SSF) is virtually completely unmanaged (Damasio et al. 2016; Reis-Filho and Leduc 2017) despite representing a basic means of livelihood and sustenance for nearly one million people (Mills et al. 2011; Bornatowski et al. 2014). In fact, the tropical Brazilian Northeast coast (Fig. 1) is chiefly exploited by SSF, which accounts for nearly 97% of a 225 K t annual fish production (FAO 2013). Signs of overfishing in this region are characterized by increased fishing effort (Giglio et al. 2014; Damasio et al. 2016), reduced CPUE and shifts to

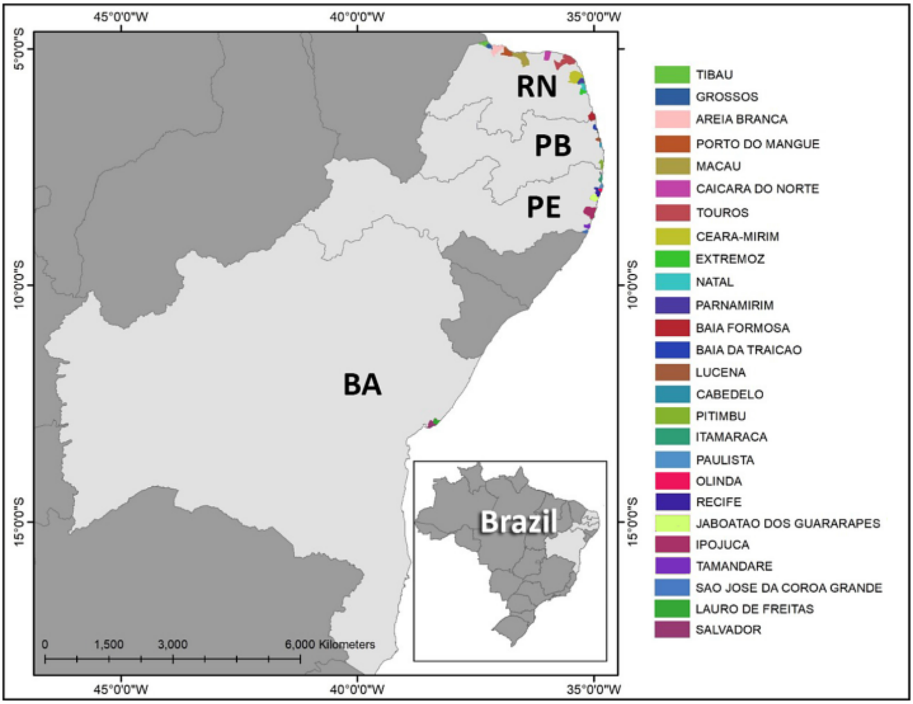

Fig. 1 Map of the four Brazilian Northeastern states (light grey) in which small-scale fishers were interviewed; RN, PB, PE, and BA stand for Rio Grande do Norte, Paraíba, Pernambuco and Bahia, respectively. The different colour areas show the municipalities in which fishers were interviewed. The inset map of Brazil shows the relative location of these states

deeper fishing grounds, which are more distant from the coast (Damasio et al. 2020). Several shark species are often caught as bycatch (Molina and Cooke 2012), but are also purposely targeted (Doherty et al. 2014), particularly as a result of the illegal fin trade (Barbosa-Filho et al. 2017; Martins et al. 2018), as is the case for many coastal regions of the developing world (Jaiteh et al. 2016, 2017; Baker-Médard and Faber 2020). While recent data for shark fishing in this region are scarce, data from 2000 to 2007 reveal that the average regional landing of elasmobranchs accounted for more than 20 K t annually (Camhi et al. 2007). Thus, ongoing exploitation of shark populations in Brazil without accurate national conservation assessments could have major implications for regional populations, some of which have reportedly undergone global declines as a result of fishing malpractices (e.g., overfishing, fining; Dulvy et al. 2008; Davidson et al. 2015). Such harvesting pressure identifies that a precautionary approach to shark conservation is warranted (Johannes 1998), which includes conservation assessment in the context of current pressures.

Here, we interviewed 186 fishers (Table 1) from 26 municipalities of the States of Bahia, Paraíba, Pernambuco and Rio Grande do Norte (Table 1; Fig. 1). In these municipalities, fishing may be considered a traditional livelihood, which typically includes the use of traditional vessels (i.e., both non-motorized and motorized, less than 10 m in length) and fishing gears such as seine nets, traps, hooks and lines, longlines and harpoons (Paiva 1997; Silva et al. 2019).

Table 1 Number of fishers interviewed per age-class and their relative experience

States	Young	Middle-age	Elderly	Total # fishers	Mean age (± SD)	Total years of age
RN	2	40	40	82	54.2 (13.1)	4350
PB	5	17	17	39	50.2 (15.1)	1956
PE	1	22	14	37	49.9 (10.7)	1823
BA	4	12	13	28	49.9 (14.4)	1327
Relative contribution (%)	6.5	48.9	45.2	100	–	–
States	**Novice**	**Experienced**	**Very-experienced**	**Total # fishers**	**Mean years of experience (± SD)**	**Total years of experience**
RN	0	15	67	82	40.2 (13.2)	3293
PB	1	13	25	39	36.5 (17.1)	1424
PE	0	7	30	37	34.9 (11.4)	1268
BA	2	5	21	28	35.9 (16.1)	1004
Relative contribution (%)	1.6	21.5	76.8	100	–	–

All interviewed fishers were males and belonged to one of three age-classes, specifically 15–30 y–o (Young), 31–54 y–o (Middle-Age) and 55 + y–o (Elderly). Years of fishers' experience ranged from 2 to 10 y (Novice), 11–25 y (Experienced) and 26 + y (Very-Experienced). Fishers mean age and experience (± SD) for each state, and their combined years of age and years of fishing experience are presented

Data collection

From October 2017 to August 2018, interviews were conducted at beaches near fishing boats or fishing infrastructures, and followed standard recommendations on conducting respectful interviews with low disturbance (Brunce et al. 2001; Maia et al. 2018). In each locality, we did not target specific numbers of fishers of each age-class, but rather haphazardly sampled people who conduct a livelihood and/or obtain sustenance from fishing. Following a description of the project objectives and obtaining a fishers' verbal willingness to participate, a semi-structured verbal survey was conducted (see full questionnaire in Supplementary material S1 and S2). The protocol and mode of interviews conducted with fishers followed criteria approved by the Federal University of Rio Grande do Norte Research Ethics Committee (CAAE 73739917.3.0000.5537).

The interview involved presenting photographs of focal shark species (detailed below). Photographs for the eight focal shark species were first presented to each interviewee to confirm species identification. These selected species were deemed to be the most abundant in the region and consequently should represent a higher proportion of landings/sightings. The focal species were: the Nurse shark (*Ginglymostoma cirratum*), shortfin Mako shark (*Isurus oxyrinchus*), Scalloped hammerhead (*Sphyrna lewini*), Tiger shark (*Galeocerdo cuvier*), Whale shark (*Rhincodon typus*), Blue shark (*Prionace glauca*), Silky shark (*Carcharhinus falciformis*) and Lemon shark (*Negaprion brevirostris*). When a fisher recognized a species presented in the photographs, the interviewer asked for the following information: (*i*) the species' popular name, and (*ii*) the length and year of the largest individual captured. While most sharks landed (i.e., over 90%) were directly measured, there were instances (approx. 20 individuals) where fishers reported the maximum length of free-swimming sharks, such as for some whale sharks that are commonly encountered at the surface and for other species that were reported 'stealing' the bait from a hook at the surface and close to the vessel. In these few cases, length estimation was done by comparing the individual against the size of the vessel or in terms of arm-lengths (locally referred as "*braçadas*" or "*braças*"). Fish length estimated by 'arm-span' can be reliably converted to metric units, as an arm-span is roughly equal to a persons' height (Quanjer et al. 2014), which is typically a known value. Fishers also presented the above data for additional shark species (i.e., non-focal), which they identified by their common name and by describing their morphological attributes. We took into consideration that common names of shark species differ among localities, which ensured more accurate species' identification (sensu Barbosa-Filho et al. 2021).

Reported catches were assigned to two distinct classes of fishers, based on age and years of fishing experience. This yielded the following two categories: young (15–30 y–o), middle-aged (31–54 y–o), elderly (55 + y–o) and; novice (2–10 y), experienced (11–25 y) and very-experienced (26 + y; Table 1) fishers. In addition to providing information on species captured and maximum length, fishers also detailed the distance from the coast where such captures/sightings occurred and the main gear employed (e.g., seine nets, hooks and lines, harpoons). Finally, fishers were questioned on basic socioeconomic and personal information including place of birth, age and whether the person fished at the same location for their entire 'experience period' or at different localities (e.g., following a move to a new village).

Data analysis

We first determined the level of current agreement/disagreement over the assigned conservation status of shark species between global and national Red Lists (i.e., IUCN vs. ICMBio) through comparing assigned criteria [i.e., critically endangered (CR), endangered (EN), vulnerable (VU), near threatened (NT) and least concern (LC)].

To detect whether LEK revealed a significant trend in maximum length of each shark species across years (i.e., increasing, stable or declining), regressions analyses were conducted with maximum length and date (year) as variables. Three regression types were fitted to the data (exponential, polynomial and linear), and r^2 values compared to assess the best-fit model in relation to the distribution of data (following Md Ghani and Ahmad 2010). The level of statistical significance was set at $p < 0.05$.

To investigate whether the six focal and two non-focal shark species caught varied in response to fisher groups (i.e., fishers' years of experience) and accounting for the fishing gear employed and location of capture, an analysis of principal coordinates (CAP) was undertaken. This analysis followed the approach of Anderson and Willis (2003) and Anderson (2008), whereby a constrained ordination technique produces predictive models that maximize the differences among a priori groups and discerns patterns that may be otherwise cryptic in unconstrained ordinations. The ability of the model to discriminate an a priori group was assessed by an allocation and cross-validation test (Lachenbruch and Mickey 1968; Anderson 2008). A Spearman correlation value of at least 0.7 was used as an arbitrary limit for the inclusion of potential correlations between length variation across years and categories relative to the canonical axes (Anderson 2008).

Finally, we tested for potential differences of the mean year that captures/sightings occurred (response variable) for the largest shark species (six focal and two non-focal) amongst fishers of the three age classes (i.e., young, middle-aged and elderly; factor). We predicted that elderly fishers would be more likely to have captured/sighted the largest individuals of most species in earlier years, when compared to young and middle-age fishers. Given lack of normality, we used a Generalized Linear Model (GLM) with gamma error distribution and a log-link function. In case of a significant effect, we conducted pairwise contrast tests of the GLM, for each of the studied species, to determine whether the mean year of captures/sightings of that species differed between elderly fishers (i.e., the most conservative age-class) against young and middle-age fishers. Analyses were conducted in R 2.13R (Core Team 2020) using the base package and via Permanova within the Primer 7 software.

Results

Interviewed fishers' age and years of fishing experience ranged from 25 to 89 and 2 to 78 years, respectively. The number of fishers ranged from 12 to 90 and 3 to 143, according to age-group and fishing experience-group, respectively (Table 1). Across the different states, the total number of fishers ranged from 28 to 83. The mean age, mean years of experience, total years of age and total years of experience of fishers ranged from 49.9 to 54.2 y, 34.9–40.2 y, 1327–4350 fisher · y and 1004 – 3293 fisher · y, respectively (Table 1).

The interviewed fishers reported a maximum length for a total of 447 sharks (Table 2). More than 90% of the records were composed of six of the focal species plus two species

Table 2 Number of sharks caught or sighted (#; total number = 447) of each species by the interviewed fishers in each respective states (RN, PB, PE, BA), the conservation status of each species established at the national (ICMBio) and international (IUCN) levels, and the fishers' age-classes (YO, MA, EL)

Species (common name)	#	RN	PB	PE	BA	ICMBio	IUCN	YO	MA	EL
*Sphyrna lewini**[n] (Scalloped hammerhead)	116	47	23	24	22	CR	CR	10	56	50
*Ginglymostoma cirratum** (Nurse)	107	24	34	28	21	VU	DD	7	50	50
*Galeocerdo cuvier** (Tiger)	61	25	15	13	8	NT	NT	0	30	31
*Rhincodon typus** (Whale)	42	16	9	12	3	VU	EN	1	21	20
*Isurus oxyrinchus** (Shortfin mako)	35	11	6	10	8	NT	EN	4	18	13
Carcharhinus leucas (Bull)	22	10	4	7	1	NT	NT	0	9	13
*Prionace glauca** (Blue)	19	11	3	3	2	NT	NT	1	8	10

Table 2 (continued)

Species (common name)	#	RN	PB	PE	BA	ICMBio	IUCN	YO	MA	EL
Carcharhinus limbatus (Blacktip)	12	6	2	4	0	NT	NT	0	4	8
*Carcharhinus falciformis** (Silky)	7	5	2	0	0	NT	VU	0	3	4
Carcharhinus acronotus (Blacknose)	5	4	0	5	0	NT	NT	0	2	3
*Negaprion brevirostris** (Lemon)	4	1	0	2	1	VU	NT	0	4	0
Carcharhinus plumbeus (Sandbar)	4	2	2	0	0	CR	VU	0	2	2

Table 2 (continued)

Species (common name)	#	RN	PB	PE	BA	ICMBio	IUCN	YO	MA	EL
Rhizoprionodon lalandii (Brazilian sharpnose)	3	2	1	0	0	NT	DD	0	1	2
Carcharhinus longimanus (Oceanic whitetip)	3	2	1	0	0	VU	CR	0	2	1
Mustelus schmitti (Narrownose smoothhound)	2	0	0	0	2	CR	EN	0	0	2
Carcharhinus perezi (Caribbean reef)	2	2	0	0	0	VU	NT	0	0	2

Table 2 (continued)

Species (common name)	#	RN	PB	PE	BA	ICMBio	IUCN	YO	MA	EL
Mustelus norrisi (Narrowfin smoothhound)	1	0	0	0	1	DD	DD	0	1	0
Squalus acanthias (Spiny dogfish)	1	0	1	0	0	CR	VU	0	1	0
Carcharhinus obscurus (Dusky)	1	1	0	0	0	EN	EN	0	0	1

Species marked with an asterisk (*) were identified based on photographs, while additional species were identified based on name and morphological descriptions provided by fishers. The acronyms RN, PB, PE and BA represent the states of Rio Grande do Norte, Paraíba, Pernambuco and Bahia, respectively. The fishers' age-classes are YO (young; 15–30 y–o), MA (middle age; 31–54 y–o) and EL (elderly; 55 + y–o). Conservation or endangerment status was based on the International Union for Conservation of Nature (IUCN) and the Brazilian List of Threatened Species (ICMBio) criteria, respectively

IUCN: (https://www.iucnredlist.org/, accessed August 2020)

ICMBio: MPA, Brazil Red Book of Threatened Species of Fauna. Volume VI, Fishes. Ministério do Meio Ambiente 1–1235

CR critically endangered, *EN* endangered, *VU* vulnerable, *NT* nearly threatened, *LC* least concern, *DD* data deficient

[n]May have occasionally included the Great hammerhead (*Sphyrna mokarran*)

that were not included in our photographic list, namely *Sphyrna lewini*, *Ginglymostoma cirratum*, *Galeocerdo cuvier*, *Rhincodon typus*, *Isurus oxyrinchus*, *Prionace glauca* and the non-focal *Carcharhinus limbatus* and *Carcharhinus leucas*. While middle-aged and elderly fishers each provided maximum length data for 212 sharks, younger fishers' records accounted for only 23 of all sharks. Relatively few young fishers were interviewed; this is likely a result of a loss in popularity amongst younger males to become fishers. Most fishers (i.e., 139 of 186) declared they had fished at the same locality where they were interviewed for their entire 'experience period' (i.e., did not move from other localities). Data is therefore representative of local ecological knowledge of fishing conditions at each sampling site.

Of all sharks identified through interviews, 12 species differed in conservation status when comparing the national (ICMBio) and global (IUCN) Red Lists (Table 2). For seven species, the national conservation criterion was deemed more severe (i.e., conservative) than that established for global populations, while the opposite was true for five species (Table 2). For example, the nurse shark (*G. cirratum*) is categorized as vulnerable (VU) at the national level, but data-deficient (DD) at the global scale. Moreover, 10 species are classified as 'endangered' (i.e., CR, EN, VU) on the Brazilian Red List, compared to nine on the global IUCN list (Table 2). When considering captures of endangered species (i.e., CR, EN, VU; Table 2), most were caught by middle-aged and elderly fishers (Fig. 2). Notably, when comparing the fishers' experience groups, regardless of their age or experience, the number of captures/sightings for each conservation status category varied markedly depending on whether the national or global Red List is considered (Fig. 2). This variation could yield different perceptions on the state of a fishery, which directly or indirectly target a given species. For example, many more captures/sightings of endangered species (i.e., EN, G in Fig. 2) occurred when the IUCN Red List is used, compared to the National Red List. Alternatively, one would consider that captures target more vulnerable species when using the National Red List (i.e., VU, N in Fig. 2). Given differences in assigned conservation status among Red Lists, the relative number of shark encounters of a given conservation status criteria is contingent on which Red List is considered.

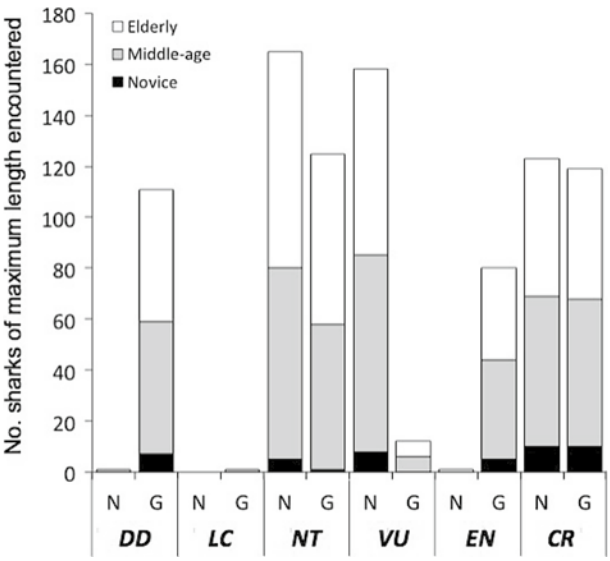

Fig. 2 Number of maximum length sharks encountered by fishers (and their age classes; elderly, white; middle-age, grey; novice, black). The tally for each endangerment criterion (DD, LC, NT, VU, EN, CR) is compared between the national (*N*) and global (*G*) Red Lists (i.e., Institute Chico Mendes vs. International Union for Conservation of Nature, respectively). For each endangerment criterion, the number of sharks encountered by fishers may vary as a function of the Red List considered. DD, LC, NT, VU, EN and CR = 'data-deficient', 'least concern', 'near threatened', 'vulnerable', 'endangered' and 'critically-endangered', respectively

The interviewed fishers acknowledged an overall trend of decreasing size of captured/sighted sharks over time, which our analysis confirmed (Fig. 3). Overall, the largest sharks of several species were caught along the Brazilian Northeast coast more frequently in the

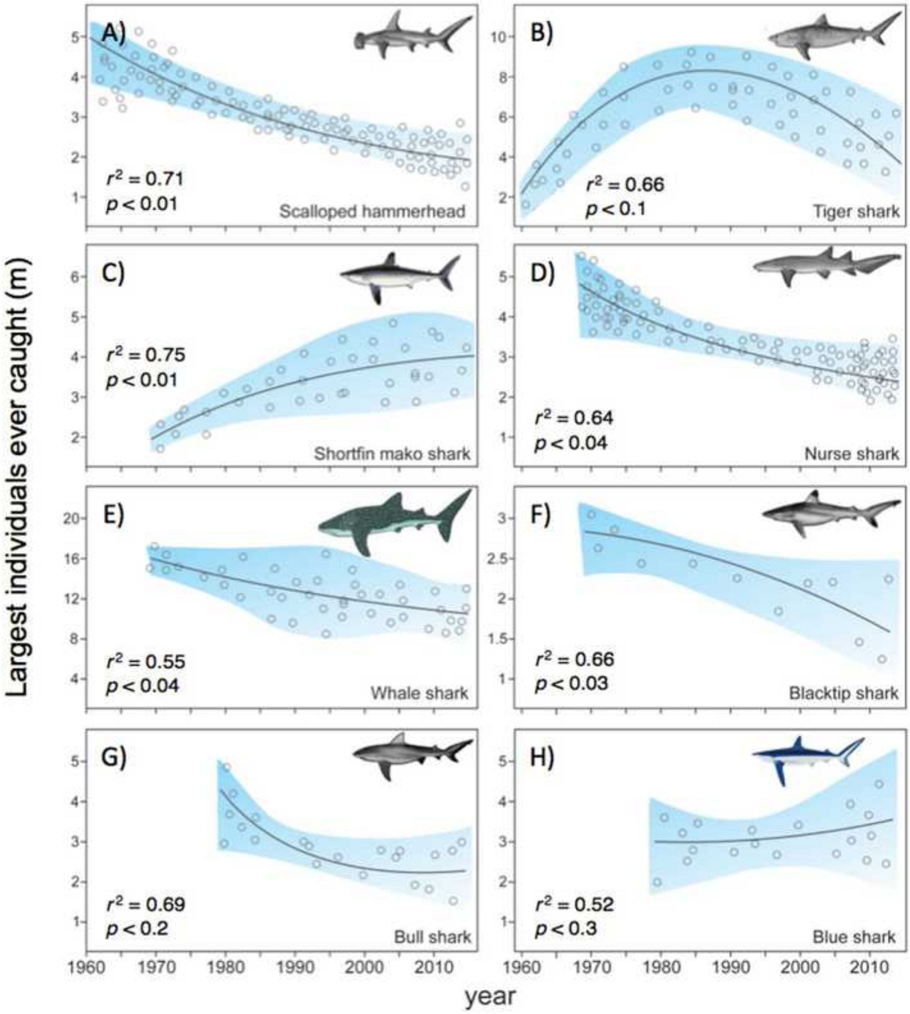

Fig. 3 The largest sharks (m) caught/sighted by fishers, from 1960 to 2018. A statistically significant decline in maximum length occurred over time for four species; the whale (*Rhincodon typus*, **e**); exponential regression), blacktip (*Carcharhinus limbatus*, **f**); binominal regression), nurse (*Ginglymostoma cirratum*, **d**); exponential regression) and scalloped hammerhead sharks (*Sphyrna lewini* **a**); exponential regression). In contrast, the maximum length of the shortfin mako (*Isurus oxyrinchus*, **c**); binomial regression) increased during this period. The maximum length of the bull shark (*Carcharhinus leucas*, **g**); binominal regression) and tiger shark (*Galeocerdo cuvier*; **b**), polynomial regression) appeared to decline between 1980 and 1990 (respectively), but no statistically-significant trend was found. The maximum length of the blue shark (*Prionace glauca*, **h**); exponential regression) did not change. Hashed area in the graphs indicates the 95% confidence limit. The number of fishers having caught/sighted each of these species is presented in Table 2

1970s and to a lesser extent in the1980s. A statistically significant decreasing trend in maximum length was found for four species: *S. lewini*, *G. cirratum*, *C. limbatus* and *R. typus* (Fig. 3). Note that data pertaining to the Scalloped hammerhead (*S. lewini*) may include the Great hammerhead (*Sphyrna mokarran*), as these species can be difficult to differentiate when sighted. However, the latter species is far less common than the former, and as such, for this analysis we consider the Scalloped hammerhead as the dominant species. In recent decades, two species, *C. leucas* and *G. cuvier*, also appear to have decreased in their maximum length (from 1980 to 1990, respectively), although a significant trend was not detected. In contrast, for *I. oxyrinchus* our analysis revealed a statistically-significant positive trend, whereby the length of the largest individuals increased over time (Fig. 3). For *P. glauca*, no apparent trend was observed.

Our CAP analysis revealed partitioning between the fishers' experience category responsible for catching the eight aforementioned largest sharks species (as detailed above), the relative distance from the coast where the captures occurred, and the fishing gears most commonly used (Fig. 4). The distance from the centroid of vectors indicates greater weight for the variable considered. The very-experienced fisher category (i.e., >30 years of fishing) is most represented at the ends of vectors, indicating these fishers were primarily responsible for capturing the largest individuals of most species (Fig. 4). The relative distance from the coast where captures/sightings occurred is highlighted by each vector's direction (Fig. 4). The CAP analysis also revealed a horizontal separation among fishing gear (CAP 1−X-axis), whereby hook and line accounted for the highest capture of sharks, followed by spearfishing (harpoon) and nets. The sizes of the first two axes were CAP 1 $\delta_1=0.918$ and CAP 2 $\delta_2=0.898$ over five (*m*) principal coordinate axes, indicating a high level of confidence in the trends observed (Anderson 2003). The estimation of misclassification error also identified high allocation success (78%; Table 3). When all sharks were considered together, the maximum length of combined species has decreased over time (Fig. 4, insert figure).

Finally, when considering the interaction between fishers' age-class and species on the mean year that captures/sightings of the largest sharks occurred, a statistically significant effect was found (Likelihood Ratio Chi-Square $=66.797$, df $=21$, $p<0.001$; the model did not show overdispersion). Species-specific pairwise comparisons found that captures/sightings of elderly fishers (55 + y–o) occurred in earlier years of our experience period when compared to other fishers' age-class(es). This trend was observed for *R. typus, G. cuvier, S. lewini, I. oxyrinchus, P. glauca and C. limbatus* (Table 5).

Discussion

The process of determining a species' conservation status is more rigorously achieved through quantitative data assessments (Rodrigues et al. 2006; IUCN 2019). The paucity of such information, a commonality in many developing countries, results in a conservation status, or more specifically, a species threatened state that may not accurately reflect their actual risk of extinction (Helfman 2013). Under such data-poor situations, the difficulty of assessing conservation status implies that a precautionary approach is warranted (Johannes 1998; O'Donnell et al. 2010; Alofs et al. 2014).

LEK may provide an alternative data stream to assist this process, whereby ecologically relevant information can be used to establish conservation status at national levels. Of practical relevance, this information may be obtained at low cost from users that

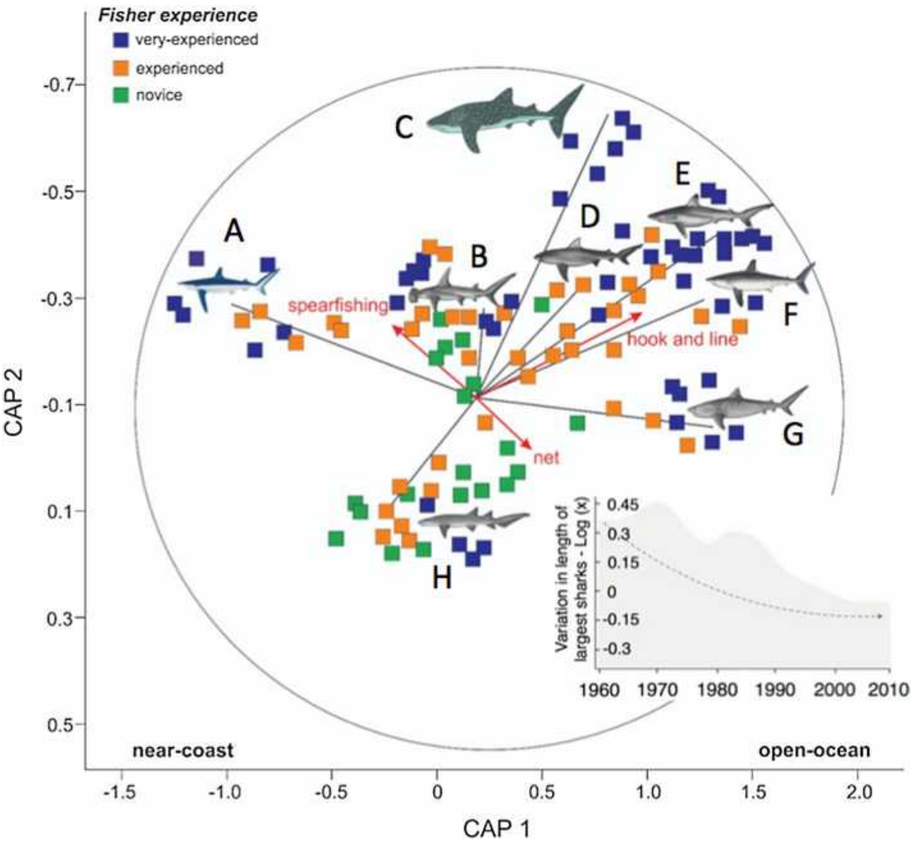

Fig. 4 Canonical analysis of principal coordinates of the largest shark captures/sightings of eight species (six focal and two non-focal), as a function of the relative distance from the coast and fishers' experience. Letters **a**–**h** indicate the following species: Blue shark (*Prionace glauca*), Hammerhead (*Sphyrna lewini*), Whale shark (*Rhincodon typus*), Bull shark (*Carcharhinus leucas*), Blacktip Shark (*Carcharhinus limbatus*), Shortfin Mako (*Isurus oxyrinchus*), Tiger shark (*Galeocerdo cuvier*) and Nurse shark (*Ginglymostoma cirratum*), respectively. Vectors' orientation indicates the relative distance from the coast where captures/sightings occurred, whereby the left and right sides of the figure indicate near-coast and open-ocean, respectively. Coloured squares represent categories of fishers' experience (i.e., orange < 10; green 11–25; blue > 26 years). The importance of the variable "fishers' experience" for catching/sighting a given species increases with distance from the vectors' centroid; very-experienced fishers (blue squares) are most represented at the extremities of vectors suggesting these fishers were most responsible for capturing/sighting *R. typus*, *G. cuvier*, *P. glauca*, *S. lewini* and *C. limbatus*. The red vectors indicate the fishing gear most responsible for capturing these species, as a function of distance from the coast. The overall variation in maximum length of all captured/sighted sharks through time (exponential regression, shaded area, expressed as a log-x) is shown in the inset, with the dashed line representing the adjusted regression for these data

directly interact with the resource. Despite the high landings of elasmobranchs in Brazilian fisheries, some of which are fuelled by the fin trade (Barbosa-Filho et al. 2017), virtually no effective regional monitoring or conservation programs are in place for this taxonomic group (Barreto et al. 2017; Dulvy et al. 2017). Consequently, Red Lists (i.e., global and national) are some of few available tools upon which future conservation and

Table 3 Canonical Analysis of Principal Coordinates (CAP) leave-one-out allocation success (%) of the largest sharks recorded captured/sighted by fishers of assigned experience levels in the Brazilian Northeast

Species	P(perm)			Prop	Allocation
	Very-experienced	Experienced	Novice	Total	% Correct
Sphyrna lewini	43	31	19	93	17
Galeocerdo cuvier	39	37	24	100	15
Isurus oxyrinchus	38	21	14	73	11
Ginglymostoma cirratum	24	28	23	75	10
Rhincodon typus	18	21	4	43	10
Carcharhinus limbatus	26	24	14	64	8
Carcharhinus leucas	28	24	22	74	5
Prionace glauca	19	15	8	42	2

management actions can be established to limit adverse human impacts on population status (Possingham et al. 2002; Helfman 2013).

The LEK obtained here relates to the past 60 years and points to statistically significant declining trends in maximum length of four shark species captured by fishers, specifically, *S. lewini*, *G. cirratum*, *R. typus* and *C. limbatus*. These results are aligned with studies reporting that during periods of their life cycle, some of the largest sharks that occur in shallow waters (i.e., accessible to fisheries) have undergone population declines on average by at least 60% across global oceans, both as bycatch in pelagic longline fisheries and as targets in directed fisheries (Baum et al. 2003; Dulvy et al. 2014). When these trends are integrated with the two Red Lists [i.e., global (IUCN) and national (ICMBio)] and current state of knowledge on global shark populations, these LEK data may provide valuable guidance on the conservation status of local shark populations.

Despite that the maximum length of caught individuals may be considered a simple indicator, we suggest these data may be useful to establish conservation/management schemes for exploited fishes (Froese 2004). Nevertheless, it is important to contextualize the present results in relation to the changes in Brazilian SSF that have occurred during the time period considered here. Specifically, these fisheries have experienced drastic increases in effort, via a marked increase in the number of boats in the fishery, many of which are equipped with more powerful motors, allowing higher mobility to target offshore waters and deeper fishing grounds (Damasio et al. 2020). However, despite the expansion of fishing grounds into pelagic areas, intense fishing pressure continues to occur in coastal regions. Consequently, contemporary greater fishing effort on sharks in the region implies that our results of declining maximum length are likely to be conservative. When LEK identifies support for a precautionary approach (e.g., fishers report declining body size and/or abundance), adopting a more careful conservation status assessment or endangerment criterion (global, IUCN vs. national, ICMBio) is warranted. Recommendations on conservation status listing at a national scale, relative to the IUCN list, based on LEK data are presented in Table 4 and detailed below, based on the findings of the current study.

Of the four species for which our analysis found declining maximum length, *G. cirratum,* has a conservation status set more conservatively nationally (ICMBio; VU) than globally (IUCN; DD). Novice (young) fishers reported catching/sighting this species, suggesting that despite their national high-risk conservation status, *G. cirratum* is captured

Table 4 Precautionary recommendations for using LEK data to assist listing conservation status of threatened species based upon disagreement between national and global Red List classifications

Global list	National list	LEK metric	Population composition	Recommendation for listing the conservation status of threatened species
−	+	Decline	Multiple	Maintain or increase national list category
−	+	Decline	Single	Increase global list category
+	−	Decline	Multiple	Increase national list category
+	−	Decline	Single	Match national list with global list category
−	+	Stable/increase	Multiple	Maintain national list category; Probe trends in harvest (e.g., effort, target, location of harvest)
−	+	Stable/increase	Single	As above but at a global scale (i.e., may involve multiple adjacent countries)
+	−	Stable/increase	Multiple	Maintain global and national list categories; Investigate reasons for population increase
+	−	Stable/increase	Single	Maintain global and national list categories; Investigate reasons for population increase

The symbol '−' and '+' refer to comparatively lower and higher conservation category listing (i.e., less and more conservative, respectively) when two scales (i.e., global vs. national) are considered. The classification approach also considers whether a species is endemic or is composed of multiple populations by fishers of all age classes. This potentially indicates their vulnerability to capture in a wide range of fisheries (Robinson and Sauer 2013; Dulvy et al. 2014) and/or their common occurrence where fishing is concentrated. Nevertheless, the fact that this species is captured by all experience levels, coupled with its declining maximum body length (potentially indicating declining capacity for replenishment under ongoing fishing pressure) indicate that the stricter national conservation status is warranted (e.g., first scenario in Table 4).

In contrast, the conservation status of *R. typus* is less strict at the national versus the global level (VU vs. EN, respectively; Table 2). Our analysis revealed a declining maximum length through time, with very-experienced fishers the most responsible for reported captures/sightings (Fig. 4). Moreover, mean year of captures/sightings by elderly fishers occurred early on in the study period when compared with young and even middle-age fishers (Table 5). These data indicate this species is becoming rarer and the reducing size could have implications in terms of reproductive potential (Camhi et al. 2007). As such, we recommend that the lesser categorization of risk set at the national scale is not suitable, and modifying this categorization to match that of the global IUCN is advisable (e.g., third scenario in Table 4).

Table 5 Mean year (±Standard Error) of capture/sighting reported by fishers of each age-classes (i.e., young [YO; 15–30 y–o], middle-age [MA; 31–54 y–o] and elderly [EL; 55+y–o]) for the largest sharks of each of the eight species analysed

Species	Age-class	Mean year (±SE)	Difference with EL
Sphyrna lewini	YO	2016.4 (3.78)	**P<0.001**
	MA	2009.7 (1.33)	**P=0.001**
	EL	2003.0 (1.36)	
Rhincodon typus	YO	2018.0 (10.01)	**P<0.001**
	MA	2010.7 (2.17)	**P=0.042**
	EL	2005.1 (2.22)	
Ginglymostoma cirratum	YO	2011.9 (3.77)	P=0.460
	MA	2011.9 (1.41)	P=0.188
	EL	2009.4 (1.42)	
Galeocerdo cuvier	YO	2010.0 (2.23)	**P=0.015**
	MA	2004.5 (1.81)	P=0.232
	EL	1998.6 (2.98)	
Carcharhinus limbatus	MA	2014.5 (4.99)	**P<0.001**
	EL	1994.5 (3.49)	
Prionace glauca	YO	2003.0 (9.93)	**P=0.040**
	MA	2011.6 (3.52)	P=0.451
	EL	2008.8 (3.15)	
Carcharhinus leucas	MA	2009.1 (3.32)	P=0.469
	EL	2006.7 (2.76)	
Isurus oxyrinchus	YO	2012.7 (4.99)	**P=0.021**
	MA	2006.8 (2.34)	P=0.207
	EL	2001.6 (2.75)	

A pairwise test following a Generalized Linear Model (detailed in "Results" section) compares the mean year elderly fishers reported having captured/sighted the largest individual of each species against the mean year reported by two other (younger) fishers' age-classes. Bold results indicate a significant difference has been found in the mean year of capture/sighting between these age-classes

Declining maximum length over time was further reported for two species, *S. lewini* and *C. limbatus* for which the respective endangerment criterion (CR and NT, respectively) is the same nationally and globally. Similar to *R. typus*, both species were captured/sighted by elderly fishers in the earlier time frame of the study period. In fact, no young fishers reported interacting with the latter species, suggesting it has become rarer (Table 5). In the context of the IUCN global assessment, *S. lewini* is a priority species in terms of risk, given its frequent capture in poorly regulated coastal fisheries (Camhi et al. 2007; Dulvy et al. 2017) and reported global population declines (Baum et al. 2003; Dulvy et al. 2008). Here, the observed reduction in maximum length of *S. lewini* informed through LEK warrants the precautionary approach with the stringent CR endangerment criterion. Furthermore, *C. limbatus* is typically an open water reef-associated species that has likely been overfished in coastal areas, and may be under intense fishing effort further offshore (sensu Fig. 4). Although categorized under a lesser strict endangerment criterion (VU), *C. limbatus* is likewise considered of conservation concern in the region.

Two other species considered, *G. cuvier* and *C. leucas*, showed non-significant, yet decreasing maximum lengths over the study period (Fig. 3). These species are classified under the same conservation status at the national and the global scale (i.e., NT). Considering the largest individuals of *G. cuvier* were primarily captured by very-experienced fishers (Fig. 4), similar to *C. limbatus*, this may suggest increased scarcity of large adults. Given the reported declines in abundance and size in other geographical regions, such as Australia (Roff et al. 2018; Pirog et al. 2019; Brown and Roff 2019), but also discrepancies to this trend, for example, increasing catch rates off South Africa (Dicken et al. 2016), the NT status would seem appropriate. However, our analysis revealed earlier mean year of captures/sightings of largest individuals by elderly fishers, compared with young fishers (Table 5). Up-scaling the endangerment criterion for this species would nonetheless provide a proactive approach to conservation. By itself, *C. leucas* is frequently caught as bycatch and sold in Northeastern Brazilian fish markets (Martins et al. 2018). The fact that critical coastal habitat for this species, (e.g., nursery areas, MPAs; Rosa and Gadig 2014) often overlaps with intense fishing activities, implies that they are under relatively high sustained fishing pressure in the region. For this species, young fishers did not report captures or sightings (Table 5). Given this, up-scaling the endangerment criterion may be advisable.

Finally, our LEK assessment of *I. oxyrinchus* and *P. glauca* identified that the maximum length of these species were increasing and stable over time, respectively (Fig. 4). In addition, we found that elderly fishers more readily captured/sighted these species in earlier years compared to young fishers (Table 5). *I. oxyrinchus* is classified under a stricter endangerment status at the global versus the national level (i.e., EN vs. NT, respectively). *I. oxyrinchus* has been identified as a priority species for conservation given ongoing exploitation rates (Dulvy et al. 2017), including its recent inclusion on the CITES appendix List II (Anonymous 2019). The observed trend of increasing maximum length is contradictory to expectations. This trend may result from a combination of factors, including a reduction in the number of larger individuals of other species (i.e., potential competitors such as *G. cuvier*) along the Brazilian coast, but more likely relates to increasing and concentrated fishing effort in the pelagic environment, further from the coast (Damasio et al. 2020), where this species is more likely to be encountered. Modifications in top-down control through the removal of other large shark species could have important ramifications in terms of ecosystem function (e.g., cascading trophic effects; Myers et al. 2007; Hammerschlag et al. 2019). Despite our result of increasing maximum length for *I. oxyrinchus*, a precautionary approach dictates maintaining the national endangerment criterion to match that of IUCN (seventh scenario in Table 4). In contrast, for *P. glauca*, given its much greater reproductive capacity and resilience to fishing pressure (Camhi et al. 2008), the current endangerment criteria match expectations.

In the current study, temporal trends in maximum body length of sharks caught in the Brazilian Northeast were used as a quantitative metric to assess conservation status. This metric has two advantages in the context of LEK. Firstly, such information is typically easily remembered by primary users as it constitutes an unusual event. In fact, autobiographical memories of exceptional events (e.g., biggest fish or catch) tend to be vivid and accurate (Rubin and Kozin 1984; Bradburn et al. 1987) and are retained as long-term memories (Tourangeau 2000). Such recalled data have been shown to be comparable to data obtained from traditional scientific methods (Daw 2008; Tesfamichael et al. 2014; Damasio et al. 2015; Bevilacqua et al. 2016). Secondly, size and reproductive output are frequently correlated in fish, such that reduced maximum length provides a coarse proxy for reduced population replenishment/replacement capacity (Walker et al. 1998; Carr and Kaufman 2009; Hussey et al. 2010). Overall, approaches aiming to use LEK as a data stream should consider the ecological/biological relevance of the data obtained, and its broader (i.e., global) context. Clearly, the reliability of data obtained from fishers experience hinges on assumptions that memory recall is sufficiently accurate. As such, validating these 'memory reports' with more traditional scientific methods should be undertaken, which in many data-poor regions of the developing world may be challenging, but is possible. In the context of conservation and management, data obtained from LEK should be used in a precautionary manner, for example, to upgrade an endangerment criterion. Doing the contrary (i.e., downgrading an endangerment criterion) should be based on data that fully satisfy IUCN requirements.

Fishers' experience and age is a well-known source of LEK, which can provide clues on the relative scarcity (or even local extinction) of species through time (Blythe et al. 2013; Reis-Filho et al. 2016). Here, very-experienced fishers were the primary group that interacted with the majority of at least three shark species (e.g., *R. typus, C. limbatus*, *G. cuvier*; Fig. 4). In fact, captures/sightings by fishers of different age-classes (or years of experience) has been shown to indicate contemporary rarity, such as when encounters have mostly occurred with elderly fishers (Reis-Filho et al. 2016). Our analysis of principal coordinates (Fig. 4) also identified a relationship between captures of most species and the use of hook and line, which concurs with other studies conducted in Brazil (e.g., Giglio et al. 2014; Reis-Filho 2020). In agreement, studies assessing the importance of SSF off the coast of Mexico, Madagascar and Indonesia further revealed the prevalence of hook and line in these types of fisheries for catching sharks (Castillo-Géniz et al. 1998; White and Cavanagh 2007; Robinson and Sauer 2013).

Increasingly, LEK is providing an alternative and well-established quantitative data stream that is cost-effective and directly involves resource users to support conservation status assessments that can complement ongoing research (Damasio et al. 2015; Lavides et al. 2016; Begossi et al. 2016; Silvano and Hallwass 2020). In fact, there are an increasing number of examples where LEK is incorporated into management approaches in both developed (i.e., the Canadian and Alaskan Arctic; Armitage et al. 2011; Huntington 2011) and developing countries (i.e., Brazil and the Caribbean; Castello 2004; Fisher et al. 2015; de Morais Cardoso da Silva et al. 2020). While LEK may be an important data source (Gilchrist et al. 2005; Brook and McLachlan 2008; Anadon et al. 2009), studies are demonstrating its potential for detecting various changes in fish populations (Calamia 1999; Fraser et al. 2006; Reis-Filho et al. 2016; Lavides et al. 2016; Hallwass et al. 2019), which appear particularly well suited to long-term capture trends (Ainsworth and Pitcher 2005). Consequently, this information may set the stage for establishing precautionary approaches while awaiting more expensive, longer-term scientific data collection (Cochrane 1999; Charles 2001). For example, based on LEK and grey literature, Castellanos-Galindo et al. (2011) established the extinction risk of estuarine species that had not been previously assessed. Here we suggest that regional IUCN expert groups could use these type of data streams to make conclusions regarding species' conservation status, especially in developing countries which often lack infrastructure and capacity.

Many conservation and management initiatives require community engagement (i.e., working with primary users) to identify solutions to complex problems in management and conservation (Leduc and Hussey 2019a; Booth et al. 2019). LEK may help building such relationships, while furthering our understanding of socio-economic drivers of overfishing. When considering shark conservation, international cooperation to impose management measures at the national level is essential. Several options are available for improved conservation actions at a local scale; educating primary users on the conservation status of threatened species is a natural first step, for which Red Lists and these type of LEK data streams could play a central role.

Up-scaling endangerment criteria may be a source of conflict between fishers and scientists, by concomitantly making captures of a given species an illegal action (sensu Di Dario et al. 2015). Although the continued wellbeing of fishers is tied with maintaining adequate stocks for harvest (i.e., avoiding population collapse), which is likely promoted when working in direct collaboration with regulating agencies, short-term conflicts should nonetheless be minimized. This may be achieved by a number of actions, for example, providing financial incentives to fishers to release alive by-caught individuals (i.e., pay-for-release; Leduc and Hussey 2019a). This method has recently been applied by the Indian Maharashtra state government to incentivize fishers to release incidentally-captured sharks, dolphins and sea-turtles (Leduc and Hussey 2019b). To undertake and monitor assessments of species conservation status at the national level, strategies that value the livelihood and collaboration of primary users for conservation are a priority. To this end, LEK constitutes a valuable tool to aid the conservation assessment process particularly in data-poor regions/contexts, and to design conservation interventions to alleviate threats while actively collaborating with coastal communities.

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Data availability This data can be made available on demand.

Compliance with ethical standards

Conflict of interest The authors report no conflict of interest.

Ethical approval The protocol and mode of interviews conducted with fishers followed criteria approved by the Federal University of Rio Grande do Norte Research Ethics Committee (CAAE 73739917.3.0000.5537).

Informed consent All consent to participate in the interview process were verbal.

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