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Traditional fisher perceptions on the regional disappearance of the largetooth sawfish *Pristis pristis* from the central coast of Brazil

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ABSTRACT: Overfishing is considered one of the main threats to the health of global marine fish populations. Elasmobranchs that are characterized by low reproductive outputs may be particularly sensitive to intense fishing pressures. The sawfishes stand out as a highly threatened group, due in part to their life history in shallow coastal waters and their ease of capture. In Brazil, sawfish populations are now virtually extinct and these declines have gone undocumented, leaving their precise causes and timing poorly understood. Here, based on ecological and fisheries knowledge of local fishers, we document the disappearance of largetooth sawfish *Pristis pristis* from 5 estuaries on the central Brazilian coast. Fisher knowledge, combined with an estuarine morphology perspective, revealed important insights on this species, along with a timeline of its decline. Furthermore, fishers' accounts of the protracted decline revealed clear inter-estuary differences in the timing of population declines, potentially influenced by local geomorphological features. The onset of sawfish population decline appears to have been earlier in estuaries with a direct connection to the sea than in estuaries connected to an inner bay, occurring in the former case from the 1930s onward. A second wave of intensifying decline began in the 1970s in more structurally complex estuaries. Pressures from artisanal and modern fishery practices appear to have led to an earlier population decline in structurally less complex estuaries, while in larger and more complex ones this decline occurred decades later. The replacement of traditional by more modern fishing practices may have triggered the initial phase of local sawfish extinctions.

KEY WORDS: Largetooth sawfish · Population decline · Overfishing · Estuarine morphology · Local ecological knowledge · Brazil

INTRODUCTION

Overfishing is a major challenge for the sustainable use of global oceanic resources (Anticamara et al. 2011, Watson et al. 2012). Whilst over the last few decades, 32% of global fish stocks may have been overexploited or depleted (Yates 2014), the unsustainable exploitation of elasmobranchs has resulted

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in one of the most drastic declines of any taxonomic group (Ferretti et al. 2008, Dulvy et al. 2014, Davidson et al. 2015). Late age of maturity, slow growth and slow reproductive rate (Baum et al. 2003, Ward-Paige et al. 2010) have contributed to the vulnerability of elasmobranchs to unregulated fishing. In spite of their high trophic position and their critical importance for regulating marine food webs (Ferretti et al. 2010, Heithaus et al. 2012), elasmobranchs have seldom received any effective protection. As a result, the collapse of their populations has led to cascading effects on lower trophic levels, resulting in unbalanced and depleted marine ecosystems (Baum et al. 2003, Myers & Worm 2003, Ferretti et al. 2008).

One of the most threatened elasmobranch groups is the sawfishes (family Pristidae; Faria et al. 2013). Sawfishes are comprised of 2 genera, *Anoxypristis* and *Pristis*; the latter is divided into 2 distinctive groups, namely the smalltooth and largetooth sawfishes (Nelson 2006). Over the past centuries, sawfishes were often targeted for extraction of their fins and liver, while the ornamental trade has also contributed to their decline (Hoover 2008, Froese & Pauly 2009). As early as 1867, the intensity of the ornamental fishery was documented by the naturalist J.V.C. Smith who commented on the common practice of displaying rostrums not only in 'museums and cabinets of learned societies' but also in barber shops and curiosity shops (Smith 1867). In Brazil the earliest historical records of sawfish date back to the 16th century when sawfishes were captured by native indigenous populations using artisanal harpoons. The capture of sawfishes intensified with the arrival of Europeans in the 18th century, in response to demand for the oil contained in their liver for street illumination and boat repair (Sousa 1938). Although fishing created early pressures on sawfish populations, more recently habitat loss has contributed significantly to the decline of these species (Peverell 2005).

While overfishing and habitat degradation are likely reasons for the decline of sawfish populations, many uncertainties remain regarding long-term changes in their abundance and distribution, chiefly as a result of the paucity of fisheries data (Hoover 2008). Particularly with regard to declines of sawfish at a local level, the relative contribution of each of these 2 aforementioned factors remains obscure. This lack of data is concerning given the depletion of sawfish that is occurring globally (e.g. in Brazil, the USA, Mexico and Australia; Simpfendorfer 2000, Seitz & Poulakis 2002, Monte-Luna et al. 2009, Simpfendorfer et al. 2011) often prevents a basic understanding of the direct mechanisms with which the evolution of declines at population level can be analyzed.

The need for indicators of the propensity of a species to go extinct locally is particularly evident when fisheries data are lacking, as may often be the case for tropical species associated with coastal habitats (e.g. estuaries). In this sense, the local geomorphology of coastal areas represents a significant source of variability in terms of abiotic and biotic conditions (Moyle & Cech 1988, Romero et al. 1997) that may affect a species' resilience in the face of exploitation (Vilar et al. 2015). For instance, the area of potential refuge/nursery and spawning habitat may vary considerably along with the geomorphological attributes of coastal systems (Vinagre et al. 2008, 2010). In species whose distribution is defined by geographical limits and clear hydrological conditions, refuge habitat could potentially buffer the deleterious effects of fishing pressures. Thus, the typology and the variability of coastal areas may be important predictors of the local depletion of marine resources subject to over-exploitation.

When traditional scientific information is absent or incomplete, local ecological knowledge (LEK), i.e. the information that people have about their local ecosystems, particularly among artisanal fishers, may be the only source of relevant information available to researchers and managers (Gerhardinger et al. 2006, Azzurro et al. 2011). Currently, traditional fishers of the northeastern coast of Brazilian continue to report the occasional presence of the sawfish; these fishers may be able to provide crucial information on the causes of ongoing decline of largetooth sawfish. By using LEK, researchers can also access missing information on insights on the timing and causes of historical population declines of overexploited marine resources (Pinnegar & Engelhard 2008, Sáenz Arroyo et al. 2005).

Similarly to this study, Giglio et al. (2015) documented fishers' perceptions on the decline of the largetooth sawfish *Pristis pristis* from an estuary in eastern Brazil. While their work provided insightful data, the probabilistic tests used by these authors do not provide any definitive evidence on local sawfish extinction in the study area. Furthermore, given that no inter-estuary comparisons were made, their work hardly provides any spatial information on habitat use or intensity of exploitation. Overall, historical patterns of depletion of *P. pristis* in areas of importance for the species remain unevaluated. In this work, we aim to provide records of the population decline of *P. pristis* from 5 estuaries of the central coast of Brazil, and determine the most likely factors

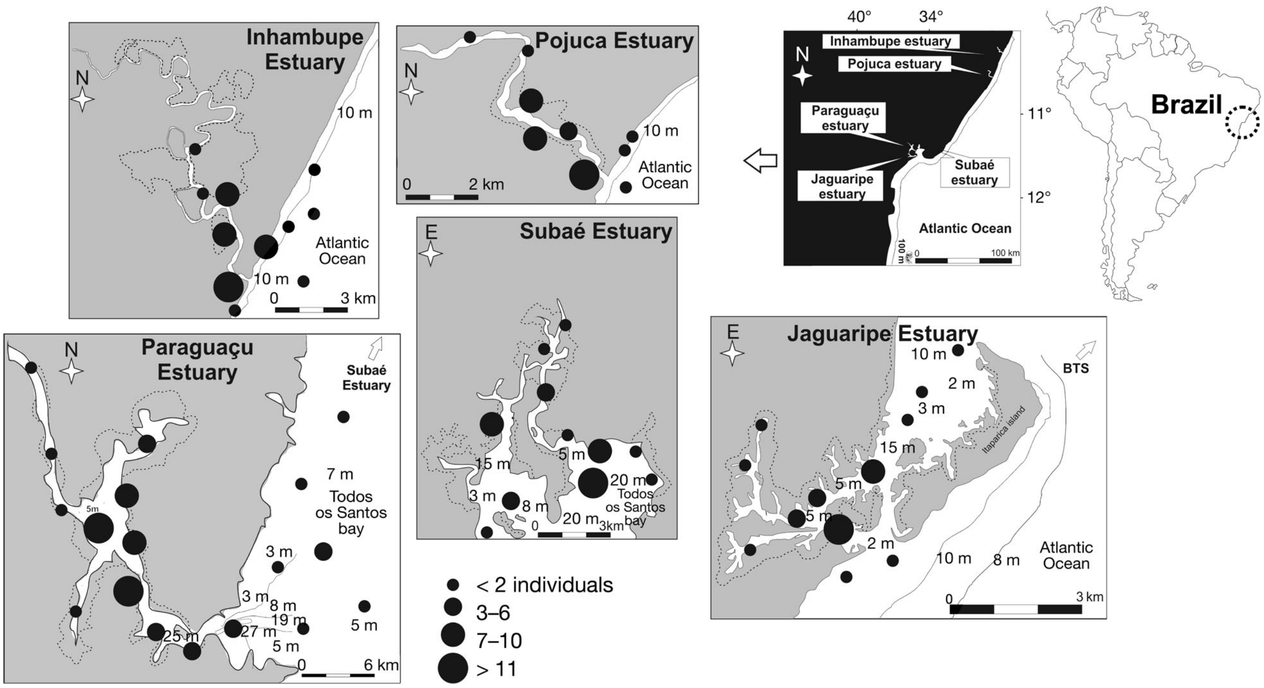

Fig. 1. Areas of historical importance for the largetooth sawfish *Pristis pristis* fisheries in 5 estuaries on the central Brazilian coast where interviews were carried out to document the disappearance of the species. The importance of areas within and nearby each estuary is represented by the size of circles, based on numbers of individuals sighted and/or caught. Dotted and dashed lines represent mangrove forest boundaries and isobaths, respectively

involved in the local and regional extinction of this species. Throughout the study area, fishers and residents of traditional communities were interviewed to determine (1) the relationship between fishing gear and sawfish disappearance, (2) habitat use and estuary morphology of importance to this species, and (3) a timeline for the decline of *P. pristis* populations along the central Brazilian coast.

Table 1. Morphological characteristics of estuaries on the central Brazilian coast where interviews were carried out to document the disappearance of of the largetooth sawfish *Pristis pristis.* DOC: direct ocean connection; WDB: well-defined bay; AE: adjacent embayment

Estuary	Average depth (m)	Water area (km^2)	Connection with ocean	Average salinity (PPT)	Geographic location
Inhambupe	4.6	25.6	DOC	26	12° 05′ S, 37° 41′ W
Pojuca	5.2	32.2	DOC	28	12° 35′ S, 38° 01′ W
Subaé	5.9	56.9	WDB	30	12° 35′ S, 38° 01′ W
Paraguaçu	20.1	127.4	WDB	30	12° 45′ S, 38° 53′ W
Jaguaripe	7.2	65.2	AE	31	13° 07′ S, 38° 49′ W

MATERIALS AND METHODS

The study area includes 5 estuaries distributed along 500 km of the coast of Bahia state, from Todos os Santos Bay (TSB) to the northern limit of the State (Fig. 1). From north to south: Inhambupe and Pojuca are small estuaries up to 15 m deep with a direct connection to the ocean. The Subaé and Paraguaçu estuaries are larger and deeper (up to 50 m) and flow into an inner bay (i.e. TSB). And finally, the Jaguaripe estuary is connected to a relatively smaller bay that is heavily influenced by oceanic conditions. The characteristics of these estuaries, including general geomorphology, depth and drainage area are provided in Table 1. These estuaries are all characterized by the presence of well developed mangrove forests, which are dominated by *Avicennia schaueriana* and *Rhizophora mangle* and, to a lesser degree, by *Laguncularia racemosa*. The fishing practices occurring in these estuaries are typical of small-scale artisanal fisheries, including the use of traditional vessels (both non-motorized and motorized) for locomotion and seine nets, hooks and harpoons as fishing gears (Soares et al. 2011, Reis-Filho et al. 2014, Reis-Filho & Specht 2015).

Data collection

To obtain information about the historical presence of sawfish, we conducted interviews in 19 communities located alongside these 5 estuaries. Between August 2012 and March 2013, we conducted interviews with 261 local fishers (34, 43, 59, 81 and 44 from the Inhambupe, Pojuca, Subaé, Paraguaçu and Jaguaripe estuaries, respectively), who were asked to respond to a simple questionnaire (see the Supplement at www.int-res.com/articles/suppl/n029p189_supp.pdf). These fishers were aged from 17 to 88 yr and their fishing experience ranged from 7 to 75 yr. These factors influenced their knowledge and experience of fishing techniques and gears. These interviewees were all residents of the 19 localities along the 5 aforementioned estuaries and had ample fishing experience over the entire course of the estuarine fishing grounds and also in marine habitats. Interviews took place in the fishers' home towns (i.e. Baixio, Palame, Itacimirim, São Francisco do Conde, São Félix, Maragogipe, Cajaíba, Acupe, Encarnação, Fontes Island, Matarandiba, Capanema, Nagé, São Francisco do Paraguaçu, Santiago do Iguape, Saubara, Salinas da Margarida, Jeribatuba and Jaguaripe). Interviews were conducted by technicians who had been engaged in monitoring of multispecies landings by fisheries in these communities during the preceding 16 months. Technicians followed the technical and ethical recommendations provided by Bunce et al. (2000) regarding respectful and low disturbance interviewing techniques. This approach, along with the familiarity and trust previously established between the technicians and the fishers likely contributed to the reliability of the data collected. In order to obtain information about the impacts of fishing, along with other potential disturbances to the local environment of sawfish, we asked these fishers to give their opinions on the types of impacts that had most contributed to sawfish population decline.

To select a representative sample size of fishers to interview at each locality, we used data from the Bahia State Population Census (IBGE 2012). In essence, a 'representative' number of interviewees increased with a locality's population size. To obtain information on the largetooth sawfish we individually interviewed each fisherman using a semi-structured protocol that contained 13 questions (see the Supplement). The interviews took place in the fishing association headquarters, and/or in a fisherman's house, as one of the technicians' aims was to create an informal and friendly atmosphere, which is known to contribute to reliable LEK data collection (Bunce et al. 2000). Given that the common names of many fish species often vary between localities, we used photographs of *Pristis pristis* to clarify the identification of this species during interviewing processes (as described in Thomson et al. 2000). The choice of photographs of *P. pristis* (as opposed to other sawfish species) was based on Faria et al. (2013), which positively identifies this species in the study region.

The main questions we sought to answer from these interviews concerned (1) the kind of fishing gear used to capture sawfish, (2) the kinds of habitat in which the species was usually found, and (3) the timing of the population decline in each type of estuary (i.e. to determine whether estuarine typology was a relevant factor).

Data analysis

The dataset was divided into 3 sub-sets based on macrohabitat characteristics determined *a priori* based on connectivity to the ocean and the size of the water body (i.e. km^2) (Table 1). The Inhambupe and Pojuca estuaries, which had the smallest water bodies, low average depth and a direct connection to the ocean, were classified as estuaries with 'direct ocean connection' (DOC). The Subaé and Paraguaçu estuaries, which had the largest water bodies, higher average depth and flowed into an extensive and well-defined embayment (i.e. TSB, with an area of approximately 1000 km^2) before reaching the open ocean, were classified as estuaries with a 'well-defined bay' (WDB). Finally, Jaguaripe was considered intermediate with respect to these environmental features and was classified as an estuary with 'adjacent embayment' (AE). From the answers provided, we calculated Pearson's correlation coefficients to test if a correlation existed between age of the fishers and their prior knowledge of *P. pristis* (i.e. the ability to identify this fish). We similarly tested for a correlation between knowledge of *P. pristis* and estuary type, and between fishers' ages and whether or not they had directly observed *P. pristis* at least once in their lifetime. Data were tested for normality prior to analysis (Shapiro-Wilk test) and homoscedasticity (Levene's test). For tests relating to age, fishers were grouped into age classes: young (under 30 and 30 to 39 yr), middle-aged (40 to 49 and 50 to 59 yr) and old (more than 60 yr).

Using permutational multivariate analysis of variance (PERMANOVA) (Anderson et al. 2001, 2008), we then compared the percentages of fishers that

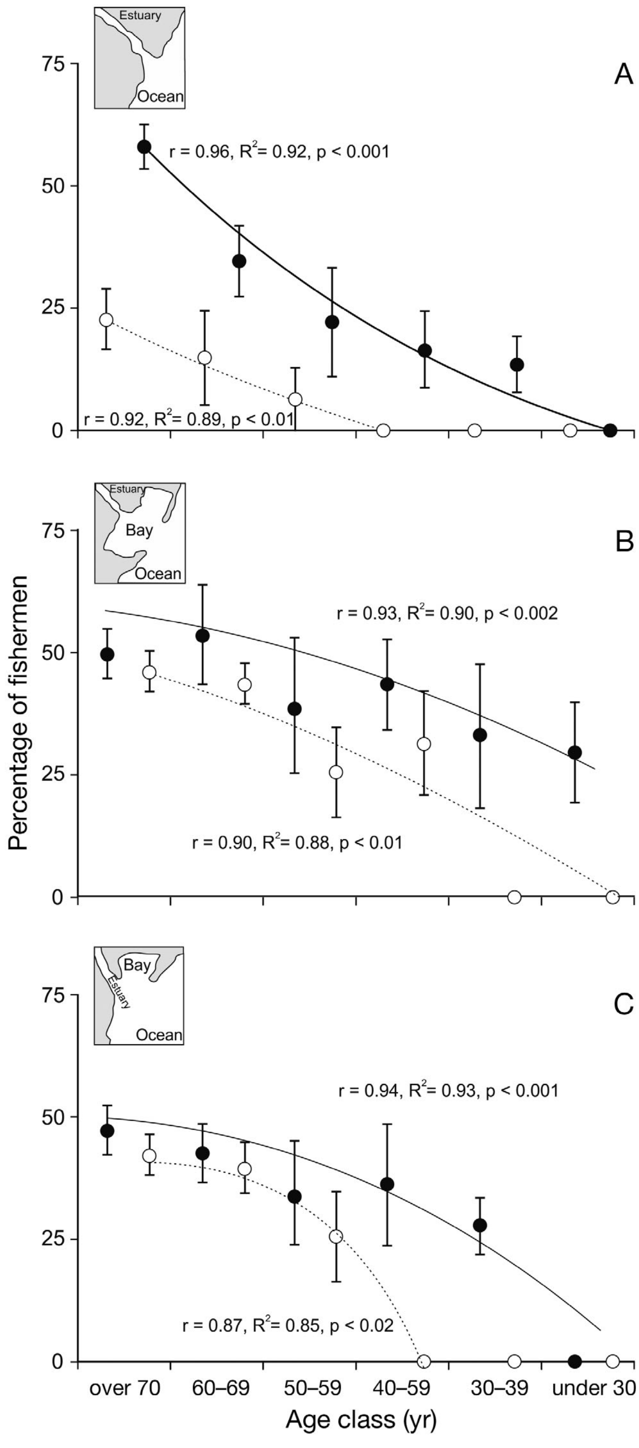

Fig. 2. Percentages of fishers of different age classes from 5 estuaries on the central Brazilian coast who reported prior knowledge (●) or direct observation (○) of *Pristis pristis* in (A) estuaries with direct ocean connection (DOC), (B) estuaries with well-defined bay (WDB) and (C) estuaries with adjacent embayment (AE). Bars represent standard deviation. For DOC, an exponential curve provided a better fit, while for the other 2 estuarine types, a logarithmic fit was chosen. All values for Pearson's correlation coefficient were statistically significant ($p < 0.05$)

reported on the suitability of one or more types of fishing gear (i.e. gillnet, seine net, hooks or harpoon) for capturing the sawfish. This was done in relation to each estuarine morphology type, in order to identify any potential statistically significant association between fishing gear and macrohabitat characteristics associated to the decline of sawfish. We also used PERMANOVA to test for correlations between the age of fishers and the habitat type in which *P. pristis* was most reported. For this correlation, habitat type was based on one of 3 possible choices, namely upper estuary, middle estuary and the mouth of the estuary and surrounding areas. When fishers identified more than one fishing gear or habitat types, we recorded their answers as 'multiple' or habitat type categories, respectively. For all these analyses, the significance level (α) was set at 0.05. Statistical significance was tested using 9999 permutations of residuals under a reduced model (Freedman & Lane 1983) and Type I (sequential) sums of squares (Anderson et al. 2008). Permutational analysis of multivariate dispersions (PERMDISP) was used to test for differences in multivariate dispersions for groups of estuary type, estuarine zone and fishing gear.

In order to investigate the timing and causes of regional population declines until the observed disappearance of sawfish, we used an alternative approach based on estimating trends in occurrence rather than verifying extinction (McPherson & Myers 2009, Luiz & Edwards 2011). This method fits a series of generalized linear models (GLM) that provide multiple estimates of decline under alternate scenarios over a determined reference period. Estimates were calculated from information on last records of sawfish obtained by fishers, whereby the relation years × records is fitted by GLM either from reports of parents of fishers, respected community members or by fishers themselves. This approach was used in Luiz & Edwards (2011) and its assumptions and programming codes are detailed in McPherson & Myers (2009). The selection of model followed Zuur et al. (2009), following which non-significant fixed effects terms (i.e. $p > 0.05$) were removed using log-likelihood tests based on maximum likelihood.

RESULTS

Influence of age on perceptions

Interviews revealed that prior knowledge of *Pristis pristis*, together with direct observations of caught individuals increased with a fisherman's age (Fig. 2). This relation remained constant regardless of estuarine morphology. However, in estuaries without direct ocean connection (WDB and AE), sightings or capture of sawfish were recorded by fishers younger than 40 yr old. By contrast, for DOC the percentage of fishers that had observed sawfish was lower than in the former estuarine morphology. Incidentally, in AE and DOC only fishers older than 50 yr of age had any prior direct observation of *P. pristis* specimens (Fig. 2). Among younger fishers, knowledge of sawfish was higher in WDB than in AE and DOC. This result suggests that the disappearance of *P. pristis* occurred earlier in AE and DOC than in WDB.

Table 2. Results of 3-factor PERMANOVA test on the number of fishers who reported having seen a specimen of *Pristis pristis* and/or having knowledge of the species, in relation to the factors estuarine morphology (Em), estuarine habitat (Eh) and fishing gear (Fg). %: % of positive answers. Significant p-values ($p < 0.05$) are shown in bold type

Factor	df	SS	MS	Pseudo-*F*	p-value	Square root (component of variation)	%
Em	2	75 498	75 498	9.36	**0.041**	25.78	23.74
Eh	2	36 854	36 854	2.64	0.092	8.56	2.14
Fg	3	44 568	44 568	15.67	**0.001**	42.65	32.67
Fg × Eh	3	19 875	15 477	1.34	0.245	4.14	1.83
Fg × Em	3	24 587	20 354	1.69	0.224	3.69	1.32
Eh × Em	2	18 758	14 555	1.14	0.209	2.65	1.11
Residuals	246	456 877	1965.8			24.56	19.58
Total	261	668 714					

Differences in estuarine morphology

The proportion of fishers that reported having seen or captured sawfish differed significantly between estuary types (PERMANOVA, $p < 0.04$; Table 2). Likewise, significant differences in reported fishing gear efficiency were also observed (PERMANOVA, $p < 0.001$; Table 2). Finally, analysis of data on fishers' prior knowledge of *P. pristis* revealed no significant difference among portions of the estuarine seascape in which sawfish were observed or captured (PERMANOVA, $p < 0.09$; Table 2). Partitioning of the variance suggests that fishing gears explain 32.6 % of the variance, while estuarine types explain 23.7 % of the variance of the model. By contrast, estuarine habitat types (i.e. longitudinal estuarine gradient) and their interactions explained less than 10 % of the variance. The PERMDISP analysis revealed larger dispersion related to data variability in DOC than in estuaries directly connected to bays ($F = 10.3$, $p < 0.001$). Although fishing effort with a given gear varies considerably over both long- and short time scales, interviews with fishers suggested that gillnets represented the most efficient and widely used fishing gear for capturing *P. pristis* ($F = 9.3$, $p < 0.01$), while seine nets outperformed hooks and harpoons (which were equal in effectiveness) (Fig. 3). In terms of reported habitat preferences for the largetooth sawfish, our results show no difference among the 3 habitat types. It appears that the largetooth sawfish was observed slightly more frequently in the middle and the upper estuary (33.5 and 27.3 % of sightings, respectively) compared to the estuarine mouth and surrounding coastal areas. Based on sightings from fishers and the number of sawfish caught in each of the 5 estuaries (Fig. 1), all areas were of importance, with the exception of the Paraguaçu estuary for which the middle section of the estuary was the most valuable.

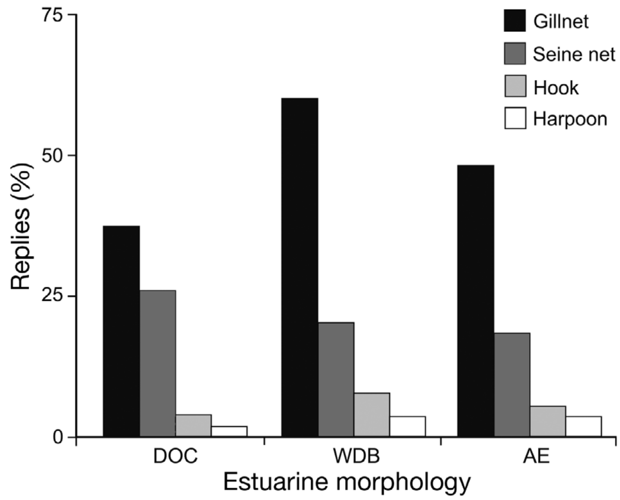

Fig. 3. Types of fishing gear used to capture sawfish, based on information provided by fishers from 5 estuaries on the central Brazilian coast, classified according to their morphology. Heights of bars represent the percentage of fishermen questioned who mentioned the fishing gear type. See Fig. 2 legend for key to abbreviations of estuary types

Of all the 261 fishers interviewed, only 78 provided any explanations for the disappearance of largetooth sawfish in the study region. Fishers suggested that destructive fishing practices, i.e. explosives (n = 8 in WDB) and overfishing with nets (n = 59 in all estuaries types), were the 2 most important factors explaining the decline of the sawfish populations. Fishers

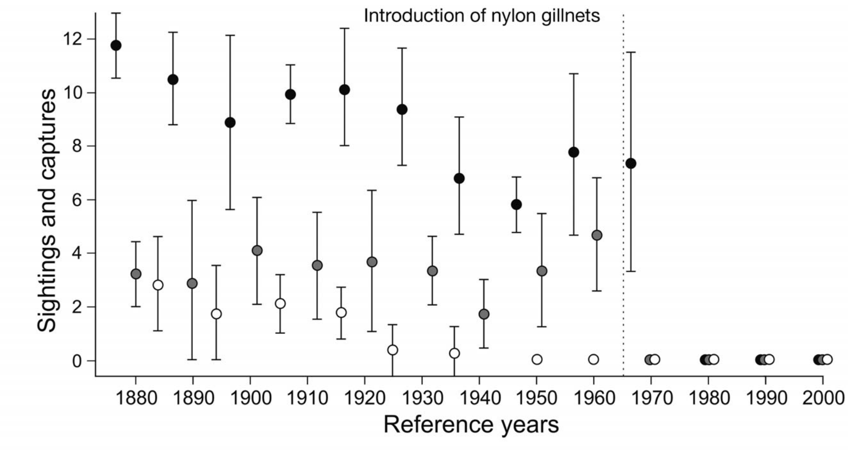

Fig. 4. Combined sightings of largetooth sawfish *Pristis pristis* and numbers of fish caught in 5 estuaries on the central Brazilian coast, classified according to their morphology, between 1880 and 2000. Estuary types: (●) WDB; (●) AE; (○) DOC. See Fig. 2 legend for key to abbreviations. Bars represent standard error. The dotted line represents the onset of the use of nylon gillnets in the region (Cordell 1989)

With respect to sawfish captures and sightings, our results revealed significant differences between different estuary types (PERMANOVA). The highest capture numbers were reported for estuaries flowing into bays (i.e. WDB) with, however, a steadily declining trend over the years (Fig. 4). Based on sighting records, our GLM model fitted to years indicated that sharp declines of sawfish abundance may have occurred over the 1930s and 1940s, with an additional and more pronounced decline that started in the 1970s in WDB and in AE, respectively (Fig. 5). From sightings of *P. pristis* (Fig. 4), the population of this species appears to have remained relatively stable from 1930–1960 until the occurrence of a sharp decline around 1970, likely the result of the use of nylon nets (i.e. industrial monofilament) that were introduced around this time (Figs. 4 & 5). This analysis also reinforced the factor 'estuarine morphology' as intrinsically linked to an estimated reduction of the sawfish population, given that in DOC estuaries, the reduction in both the sightings and decline estimates occurred sooner than in the other two other types of estuary (Figs. 4 & 5).

from the Paraguaçu estuary also pointed to the construction of the Pedra do Cavalo dam (around 1985) as a significant factor in the disappearance of sawfish in this estuary. Finally, most fishers who provided explanations also mentioned pollution, mangrove deforestation leading to siltation, decreasing abundance of prey and increased fishing pressure (i.e. numbers of fishers) as important factors responsible for the disappearance of sawfish in the region.

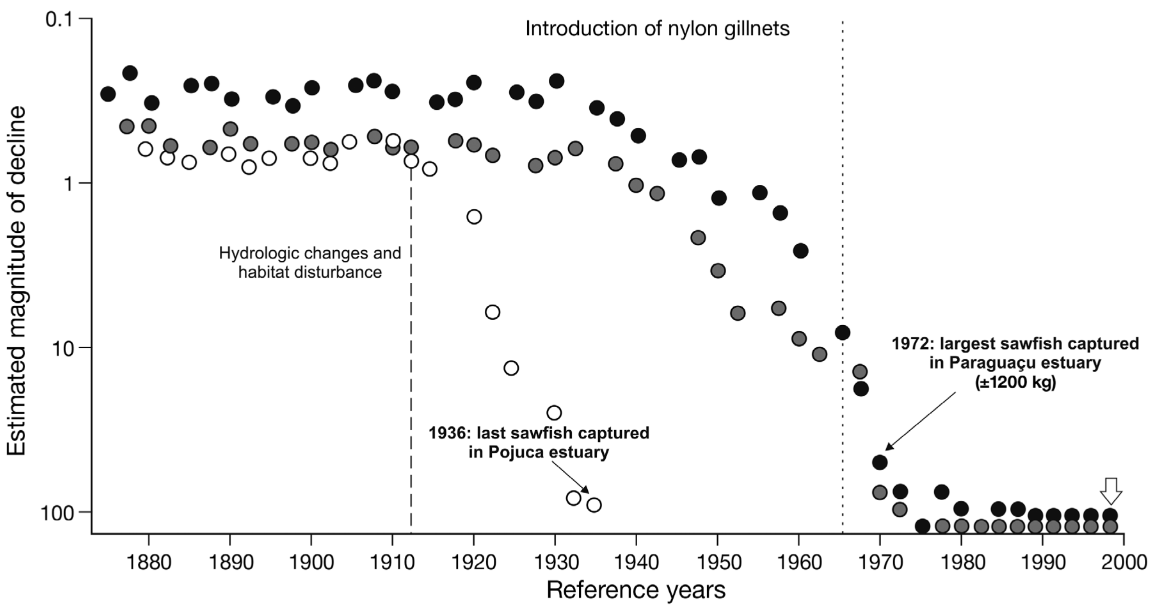

Fig. 5. Estimated magnitude of decline of largetooth sawfish *Pristis pristis* in 5 estuaries on the central Brazilian coast, classified according to their morphology, between 1880 and 2000. Estuary types: (●) WDB; (●) AE; (○) DOC. See Fig. 2 legend for key to abbreviations. The dashed and dotted lines mark the approximate onset of hydrologic changes in Inhambupe and Pojuca estuaries (see Fig. 1) (Costa-Neto 2001) and the onset of the use of nylon gillnets in the region (Cordell 1989), respectively

DISCUSSION

In this study, we attempted to gain a basic idea of the influence of estuarine typology (i.e. geomorphology and size) on sawfish decline. While fishers identified no clear habitat preferences for the sawfish, our results indicate that the timing of the disappearance of this species may have been related to estuarine morphology. This suggests that the size of an estuary and/or its geomorphological structural complexity (i.e. connection to a well-defined bay before flowing into the ocean) may affect the resilience of sawfish populations to anthropogenic effects. Estuarine typology is recognized as playing a major role in structuring species abundance and patterns of diversity in estuarine fish communities (Harrison & Whitfield 2006, Sheaves 2006). Our results suggest that in smaller estuaries and those with a direct connection to the ocean, anthropogenic pressures may be felt more intensely, leading in this case to an earlier decline in sawfish populations (Figs. 2 & 5). This conclusion emerges from the result that younger fishers had directly observed sawfish in WDB compared to DOC/AE (i.e. 40 and 50 yr, respectively), and the fact that fewer fishers had previous knowledge of the species in DOC and AE. Mechanistically, 2 possible scenarios may account for differences in extinction rates due to fishing pressure in smaller estuaries. Firstly, due to their size, smaller estuaries may simply harbor smaller sawfish populations, which in turn may be able to sustain high fishing pressure for shorter periods. Secondly, 'simpler' habitat characteristics (i.e. absence of a connecting bay) may provide less refuge habitat, exposing individuals to a more constant fishing pressure and/or not allowing efficient recruitment (Davis et al. 2012). Furthermore, in DOC estuaries, changes in hydrological regime that occurred around 1910, coinciding with the intense siltation of the river bed (Costa-Neto 2001), likely due to the construction of several small dams, may have led to the sharp decline in sawfish abundance (Fig. 5). Overall, our results suggest that differences in sensitivity to human pressures among estuary types may have influenced rates of extinction of this fish.

Recently it has been suggested that no largetooth sawfish has been captured in the southernmost region of Bahia State within the last 10 yr (Giglio et al. 2015). As corroborated by our results, these authors highlight that the onset of decline of this species coincided with the widespread use of gillnets. However, given their inconclusive probabilistic tests, Giglio et al. (2015) do not provide any definite evidence for the timing of local extinctions of *Pristis pristis* (although records of historical sightings suggest a population decline to a level close to the threshold for probable extinction). While our findings are mostly in agreement with those of Giglio et al. (2015), they advance on previous knowledge by providing an integrative assessment that takes account of estuarine morphology features that may affect the propensity of sawfish populations to decline in the face of severe human disturbances (including fishing). In addition to geomorphological attributes, characteristics associated with, for example, tidal regimes may have fundamental effects on biogeographic processes (Igulu et al. 2014). Thus, our study also considered the relationship between the vulnerability of sawfish and habitat typology.

In contrast to the inter-estuary comparisons, within a given estuary, interviews with local fishers revealed no clear habitat preferences for *P. pristis.* There were no significant differences in the frequency of sighting of *P. pristis* among habitat types (i.e. the upper, middle estuary, mouth and surrounding coastal areas). These observations highlight the euryhaline nature of this species and reinforce existing knowledge of the life history of the sawfish, i.e. that it is a generalist species able to live in a wide variety of habitats (Compagno & Cook 1995). Furthermore, our results highlight the importance of the different estuarine habitats, since sawfish of diverse age classes (e.g. adults and juveniles) were captured in all these habitats. This concurs with previous studies (Allen 1982, Deynat 2005, Monte-Luna et al. 2009) which highlighted that sawfish require a variety of estuarine habitats as feeding, nursery and/or mating grounds.

Based on fishers' age classes, our results suggest that younger fishers (<40 yr) did not have any prior knowledge of *P. pristis*. From this, we deduce that the sawfish populations underwent a drastic decline prior to 40 yr ago in estuaries with surrounding embayment (WDB), while this decline may have been more dramatic (i.e. occurring sooner) in smaller and structurally less complex estuaries that are directly connected to the ocean (i.e. DOC and AE). In DOC and AE, middle-aged fishers (i.e. 40 to 59 yr) had knowledge of the existence of the species while never having directly observed or captured a live specimen. By contrast, in WDB some middle-aged fishers had seen or captured specimens of *P. pristis*, suggesting an earlier disappearance in small and structurally less complex estuaries. In all the estuary types, most older fishers (>60 yr) reported having had at least one direct encounter with sawfish. This is consistent with the results of Giglio et al. (2015) from the Cassurubá Extractive Reserve in eastern Brazil.

Overall, these results show that the disparity in knowledge of *P. pristis* is strongly correlated with a fisher's age and provide a reliable indication that this species started to decline along the central Brazilian coast approximately 60 (± 5) yr ago (Figs. 2 & 5).

Alongside the environment features associated with estuarine morphology, our results indicate that fishing gear had an influence on population declines, specifically the increased use of gillnets (Fig. 3), following the introduction of nylon monofilament. Indeed, the widespread use of nylon coincides with the most pronounced decline of sawfish from the studied estuaries (around 1970; Figs. 4 & 5). As such, changes in the use of fishing gears over time may be important for elucidating causes of the regional disappearance of *P. pristis* in all estuary types (Fig. 3). Local knowledge accumulated over generations may provide a valuable source of information on fisheries trends (Bender et al. 2014), and insights on species extinctions into local and regional scales (Luiz & Edwards 2011).

Interviews with fishers may provide reliable ecological knowledge on target species, and on the usefulness of fishing gears and techniques. In our study, interviewees of all ages agreed that gillnets were the most effective fishing gear for sawfish fishery. The prominent rostrum, characteristic of this group, can easily be caught up in the mesh, enhancing the success of this fishing technique (Hoover 2008). In addition to the relative ease of capture, interviewees mentioned increased fishing pressure (i.e. increased numbers of fishers), and the extensive use of destructive fishing gear such as bombs (in Paraguaçu and Subaé estuaries) and trawl-nets as factors that may have contributed significantly to the local depletion of sawfish.

The range of fishing practices and capture techniques employed by inhabitants of the Brazilian coast expanded in the mid-sixteenth century following the arrival of Europeans, which led to the adoption of iron hooks and cast nets by indigenous inhabitants, along with the establishment of fish markets (Bueno 2006). More recently, the onset of the large-scale herring fishery (using huge seine nets) led to a profound modification of fishing practices in Brazil (Diegues 1983). Cordell (1989) provides insights on the production and use of gillnets, and the replacement of artisanal gillnets made from plant fibers (*Astrocaryum* sp., known locally as 'tucum') by nylon monofilaments that occurred from the 1960s onward. Our results (Figs. 4 & 5) suggest that sawfish population underwent an observable decline before this date, when fishers still used artisanal fishing gear. This evidence underscores the susceptibility of sawfish to a broad range of fishing gears and thus their vulnerability to human fishing efforts. Overall, fishing pressure appears to be one of the main factors responsible for local extinctions of *P. pristis*, surpassing the potentially negative effects of habitat degradation. In Brazil, this species is now protected by laws that forbid its capture (Brazilian Federative Republic, Law 9.605/98; www.planalto.gov.br/ccivil_03/LEIS/L9605.htm, accessed 23 Sep 2015). However, the law is not effectively enforced and the remaining populations of sawfish in north Brazilian waters are still threatened by destructive fishing practices (Fig. S1 in the Supplement at www.int-res.com/articles/suppl/n029p189_supp.pdf).

While the global picture regarding the distribution of pristids remains uncertain, populations of this group are reported in a wide range of habitat types, including marine (e.g. the western Atlantic) and freshwater habitats (e.g. Australia and Nicaragua) (Thorson 1973, 1976, Thorburn et al. 2007, Cavanagh et al. 2003, Peverell 2005, Wiley et al. 2008). In Brazil and other parts of the world, populations of this group display euryhaline abilities, as indicated by their occurrence in estuarine habitats which undergo significant and frequent changes in ambient salinity. Given the wide range of habitats that pristids have historically occupied (i.e. from marine to freshwater), the disappearance of *P. pristis* is not trivial and may have far-reaching implications. While *P. pristis* is the only globally distributed sawfish, conservation efforts may have been hampered by, among other things, unsettled taxonomy (Wiley et al. 2008) and the practical difficulties associated with resolving the entire range of the species' habitat use.

Given its life-history and its high trophic position, *P. pristis* may be considered to be particularly vulnerable to human disturbances and to overfishing. For instance, (Dulvy et al. 2003) report that sawfish species have become locally extinct in 133 localities worldwide. Although it remains unclear whether the loss of *P. pristis* populations has given rise to any important functional modifications within its original habitat, species losses in general have well-documented effects that often lead to important reductions in the functional processes and services that ecosystems provide (Srivastava & Vellend 2005, Duffy 2009). In our study area, it may be difficult to unravel the functional effects of sawfishes' disappearance on estuarine ecosystem functioning. However, given that functionally distinct species may make a significant contribution to the structure and function of ecosystems (Lyons & Schwartz 2001, Pendleton et al. 2014, Leduc et al.

2015), it is likely that the disappearance of sawfish affects estuarine ecosystems. Furthermore, under current conditions, where overfishing, habitat degradation, pollution and destructive fishing practices all remain prevalent, it is likely that in addition to significant ecological impacts the local extinction of swordfish will have wider socio-economic effects along the Bahia coast, including important negative impacts on the livelihood of local populations (Barros et al. 2008, Reis-Filho & Oliveira 2014, Reis-Filho & Specht 2015).

Our results document the disappearance of the largetooth sawfish based on LEK, highlighting the onset and probable causes for its population collapse from the Brazilian central coast. Estuarine morphological differences appeared to have an important influence on the vulnerability of the largetooth sawfish to extinction. Furthermore, pressures from artisanal and modern fisheries appear to have led to earlier population declines in structurally less complex estuaries, while in larger and more complex estuaries, this decline occurred at least twenty years later. While destructive fishing practices, habitat loss, pollution, increased salinity in what were previously mixohaline environments and reduction in sawfish prey abundance may have contributed to the decline of this species, it is likely that the intensity of fishing pressure has been the principal cause of local extinctions of *P. pristis* over the last 60 years. Furthermore, our study underlines the relevance of LEK as a reliable source of information, when other data are unavailable and/or to complement 'classical' scientific sources. Given our results, we argue that managers and decision makers should seek to promote practices that protect estuarine habitats and their resources from persistent over-use by local inhabitants. To our knowledge, our results provide the broadest spatial perspective on population trends of a fish species, based on fishers' perceptions, among studies carried out to date in Brazil.

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