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# Multidecadal fishers' knowledge reveals overexploitation of sharks in southeastern Brazil

**Correspondence:**
Carine O. Fogliarini
carine_fogliarini@hotmail.com

Carine O. Fogliarini[1], Vinicius J. Giglio[2], Mariana G. Bender[1] and Carlos E. L. Ferreira[3]

Assessing the impacts caused by fisheries requires long-term data series and continuous landing monitoring, which are still scarce in several low and middle-income countries. Alternative approaches, such as fishers' local ecological knowledge (LEK) have been employed to assess the history of marine resources and overcome the challenges of missing data. We documented temporal changes over the last 60 years in small-scale fisheries in Arraial do Cabo, Brazil. Interviews with 155 fishers revealed the capture of six shark species (one genus), all under extinction risk according to the global and the national Red Lists. Among these, *Carcharhinus brevipinna*, *Carcharhinus plumbeus*, and *Isurus oxyrinchus* are commercially important. While LEK suggests an increase in fishing efforts, with new fishing grounds emerging after 2006, the number of individuals caught has decreased over time. Historical shark exploitation has led to substantial declines in the catches of *C. plumbeus* and *C. brevipinna*, which have rare occurrences in the region. Although landing data are critical information for building local fisheries management plans and setting conservation strategies, monitoring in the region is discontinuous and should be prioritized by public policies.

Keywords: Anthropogenic impacts, Fisheries management, Local ecological knowledge, Shark populations, Small-scale shark fisheries.

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1 Laboratório de Macroecologia e Conservação Marinha, Departamento de Ecologia e Evolução, Universidade Federal de Santa Maria. Avenida Roraima, 1000, Bairro Camobi, 97105-900 Santa Maria, RS, Brazil. (COF) carine_fogliarini@hotmail.com (corresponding author), (MGB) marianabender.bio@gmail.com.

2 Universidade Federal do Oeste do Pará, Campus de Oriximiná, 68270-000 Oriximiná, PA, Brazil. (VJG) vj.giglio@gmail.com.

3 Laboratório de Ecologia e Conservação de Ambientes Recifais, Departamento de Biologia Marinha, Universidade Federal Fluminense, 24220-900 Niterói, RJ, Brazil. (CELF) carlosferreira@id.uff.br.

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Avaliar os impactos causados pela pesca requer dados de longo prazo e monitoramento contínuo das capturas, os quais ainda são escassos em vários países de baixa e média renda. Abordagens alternativas, como o conhecimento ecológico local dos pescadores (CEL), têm sido utilizadas para avaliar a história dos recursos marinhos e superar os desafios da ausência de dados. Documentamos mudanças temporais ao longo dos últimos 60 anos na pesca artesanal em Arraial do Cabo, Brasil. Entrevistas com 155 pescadores revelaram a captura de seis espécies de tubarões e um gênero, todas em risco de extinção de acordo com as Listas Vermelhas global e nacional. Entre essas espécies, *Carcharhinus brevipinna*, *Carcharhinus plumbeus* e *Isurus oxyrinchus* são comercialmente importantes. Embora o CEL tenha revelado um aumento nos esforços de pesca, com novos locais de pesca surgindo após 2006, o número de indivíduos capturados diminuiu ao longo do tempo. A exploração histórica de tubarões levou a declínios substanciais nas capturas de *C. plumbeus* e *C. brevipinna*, os quais possuem ocorrências raras na região. Embora os dados de desembarque sejam informações críticas para elaborar planos de gestão pesqueira local e estabelecer estratégias de conservação, o monitoramento na região é descontínuo e deveria ser priorizado por políticas públicas.

Palavras-chave: Conhecimento ecológico local, Impactos antrópicos, Manejo pesqueiro, Pesca artesanal de tubarões, Populações de tubarões.

## INTRODUCTION

Elasmobranchs, which include sharks and rays, are one of the planet's most ancient vertebrate groups, dating back approximately 400 million years (Andreev *et al*., 2015). Sharks play fundamental ecological roles in marine environments, shaping the structure of marine food webs and contributing to the maintenance of balance and diversity in marine ecosystems (Roff *et al*., 2016). However, the future of elasmobranch species has been threatened due to the global expansion of fishing practices (Myers, Worm, 2005). In addition, life history traits such as slow growth and reproductive rates make them highly vulnerable to overexploitation (Worm *et al*., 2013). On the other hand, there are several examples of non-extractive use of sharks through diving tourism, generating economic benefits while promoting shark conservation (Torres *et al*., 2017; Zimmerhackel *et al*., 2019). Despite that, fishing pressure and human consumption continue to pose threats to shark populations at a global scale (Dulvy *et al*., 2014; Dent, Clarke, 2015; Davidson *et al*., 2016; Pacoureau *et al*., 2021). This pressing issue highlights the immediate necessity for conservation efforts and sustainable management strategies to protect these ancient and ecologically vital species.

Brazil is one of the world's largest consumers and importers of shark meat and other by-products (Dent, Clarke, 2015; Bornatowski *et al*., 2018). For example, the average annual production of elasmobranchs represented 21,127 tons from 2000 to 2003, which corresponded to ~4.3% of the total fish production for that period (Brasil, 2014). Such catches mostly supply meat consumption and the fin trade (Barreto *et al*., 2017), both

of which have been shown to be major drivers of shark population decline worldwide. Over the past few decades, the shark meat trade has seen a rise, which is closely associated with the increased import of shark meat into Brazil (Dent, Clarke, 2015). This increase in demand could be an outcome of the implementation of shark finning restrictions, as it has incentivized the complete utilization of sharks, thus exposing the resource to a new source of exploitation (Pincinato *et al*., 2022). Despite the growing shark meat trade in Brazil, there is a lack of accurate, species-specific fishing data, which often hampers quantitative stock assessment.

Landing data are fundamental for assessing and managing fisheries. However, long-term data series are mostly available for high-income countries in the northern hemisphere (Beaudreau *et al*., 2014). In low and middle-income countries, it is typical to have either non-existent monitoring or fragmented data where landings are not described at species level (Bornatowski *et al*., 2014a; Freire *et al*., 2021). Implementing fisheries monitoring programs in countries with limited resources, where fisheries are complex and involve multiple gears and species, poses a significant challenge (Beaudreau *et al*., 2014). Data-poor scenarios hide the magnitude of impacts derived from fishing activities. Alternatively, non-conventional approaches have been used to circumvent the difficulties imposed by the lack of fisheries landing data (Eddy *et al*., 2010; Paterson, 2010; Tesfamichael *et al*., 2014). These include historical information accessed from the gray literature, local ecological knowledge (LEK) of resource users (Sáenz-Arroyo *et al*., 2005; Taylor *et al*., 2017), old photographs (McClenachan, 2009), and logbooks (Martínez-Candelas *et al*., 2020), all can be valuable sources. Fisher's LEK may reveal fisheries catch trends, habitat preference, migration patterns, and changes in body size of targeted species (Braga *et al*., 2018; Leduc *et al*., 2021). Indeed, fishers' LEK studies have been proved critical to inform on the collapse of marine resources (Venkatachalam *et al*., 2010; Nazareth *et al*., 2022). In Brazil, fishers' knowledge has helped to reveal past scenarios of marine stocks, circumventing the difficulties caused by the lack of fishing data (Giglio *et al*., 2015; Silvano *et al*., 2017; Fogliarini *et al*., 2021).

Fishers' knowledge has contributed to our understanding of shark biology, ecology, and conservation in numerous cases. In Fiji (South Pacific), fishers' LEK revealed the presence of large sharks (*e.g*., *Sphyrna* spp.) near river mouths, providing reliable information on shark occurrence (Rasalato *et al*., 2010). In the Mediterranean Sea, the empirical knowledge of fishers helped reconstruct angel shark catches (*Squatina* spp.) in the last six decades, providing important data on a highly threatened fish taxonomic group (Giovos *et al*., 2019). In the Strait of Sicily, also in the Mediterranean Sea, interviews with fishers were used to reconstruct abundance trends of shark populations over six decades (Colloca *et al*., 2020). Fishers reported that shark catches have diminished since the 1940s and commercially important species have been depleted or locally extinct. In Brazil, fishers' LEK revealed historical decreases in the body size of sharks (Giglio *et al*., 2015; Leduc *et al*., 2021). Given the absence of historical data on shark catches, we investigated temporal and spatial patterns of catches of coastal sharks in Arraial do Cabo, Brazil, as determined by local ecological knowledge of fishers. We provide data that can inform conservation and management measures, and guide research focusing on these species.

## MATERIAL AND METHODS

**Study site.** Arraial do Cabo, located in the state of Rio de Janeiro, southeastern Brazil (Fig. 1), is known as a historical fishing area that is home to people that use of beach seine, line and hook, gill nets, and spears among other equipment types (Barreto *et al*., 2019). The use of beach seine is a secular fishing practice in the region and has been used to catch several pelagic species (*i.e*., jacks, blue fish, mullets, scombrids) and sharks. Historically, the most important species for local fishing are groupers (*e.g*., *Epinephelus marginatus* (Lowe, 1834), *Mycteroperca acutirostris* (Valenciennes, 1828)), jacks (*Caranx* spp.), *Seriola* spp.), mullets (*Mugil liza* Valenciennes, 1836) and blue fish (*Pomatomus saltatrix* (Linnaeus, 1766)) (Bender *et al*., 2014; Fogliarini *et al*., 2021). In 1997, Arraial do Cabo became a partially protected marine area, the Marine Extractive Reserve of Arraial do Cabo (RESEXMar). Despite its status as a marine protected area, the RESEXMar lacks designated no-take zones, and enforcement for threatened species is poorly applied. The region is influenced by upwelling events (Valentin, 2001) and is considered a transition zone between the tropical and subtropical provinces, rendering Arraial do Cabo a hotspot of marine biodiversity in the Brazilian Province (Cordeiro *et al*., 2016). In addition to fishing, the region has shown an intense coastal tourism, with consequences that include disturbance due to excessive noise, increasing production of solid and liquid wastes, compromising the health of corals (Rogers *et al*., 2014) and other benthic organisms (Cassola *et al*., 2016).

**Data collection.** Individual face-to-face interviews through semi-structured questionnaires were conducted with 155 small-scale fishers between July 2018 and July 2019 in six fishing communities: Figueira, Monte Alto, Praia Grande, Praia dos Anjos, Prainha, and Praia do Pontal (Fig. 1). Questionnaires included a general question (*e.g*., which species of sharks were the most frequently caught during their fishing careers) and specific questions targeting three shark species, the spinner shark (*Carcharhinus brevipinna* (Valenciennes, 1839)), the shortfin mako shark (*Isurus oxyrinchus* Rafinesque, 1810), and the sandbar shark (*Carcharhinus plumbeus* (Nardo, 1827)) (Tab. **S1**). Due to the richness of common names for Brazilian fish, we used photographs to enable shark species identification during the interviews (Freire, Carvalho-Filho, 2009). When fishers recognized and had already captured any of these species, he was asked about: i) the best day catch (number of individuals), ii) the site, iii) and the year in which this catch was made. In addition, we asked about the fisher's age and experience in fishing (*e.g*., years of practice). During interviews, fishers provided general information about the species' breeding season, feeding behavior and other ecological aspects. This information was registered as observations (Tab. **S2**). We assessed the threat categories according to the Global Red List (IUCN, 2023) and the National Red List of Threatened Species (MMA, 2018, 2023) for all species mentioned by fishers. The fishers were informed of the research purpose before each interview. We also informed them that all information provided in interviews would be anonymized.

**Data analysis.** From the information on the best day catch obtained through interviews with local fishers, we estimated the temporal decline in catches of each shark species. For that, we applied regressions and plotted the best day catch (number of individuals) versus the year in which such catch occurred. We tested distinct regression types (exponential, polynomial, and linear regressions) and values of coefficient of determination were compared to assess the quality of the regression fit to data distribution.

To analyze changes in spatial distribution of best day catches we use a nautical chart (Fig. **S3**) of the region. Interviewees were asked to mark in the chart the sites where they caught shark species (Fig. **S3**). To compare past and present periods, we grouped fisher's reports in two different periods: before 2006 and after 2006. We established this division because in 2006, Alkalis Company, an important local producer of calcium carbonate, closed. After this event, the municipality's economy experienced an exponential increase in fishing, once again making it the predominant activity in the primary sector (Carneiro *et al*., 2012). As a result, many people began relying on fishing as their main source of income, increasing the exploitation of marine resources throughout the region (Carneiro *et al*., 2012).

Maps of spatial distributions of best day catches were built using the Quantum GIS software (QGis, 2019). To verify temporal changes in spatial distribution, the catches in number of individuals were compared by fishing site/ground and period (before 2006 and after 2006). Statistical analyzes were performed using R software v. 3.6.1 (R Development Core Team, 2019).

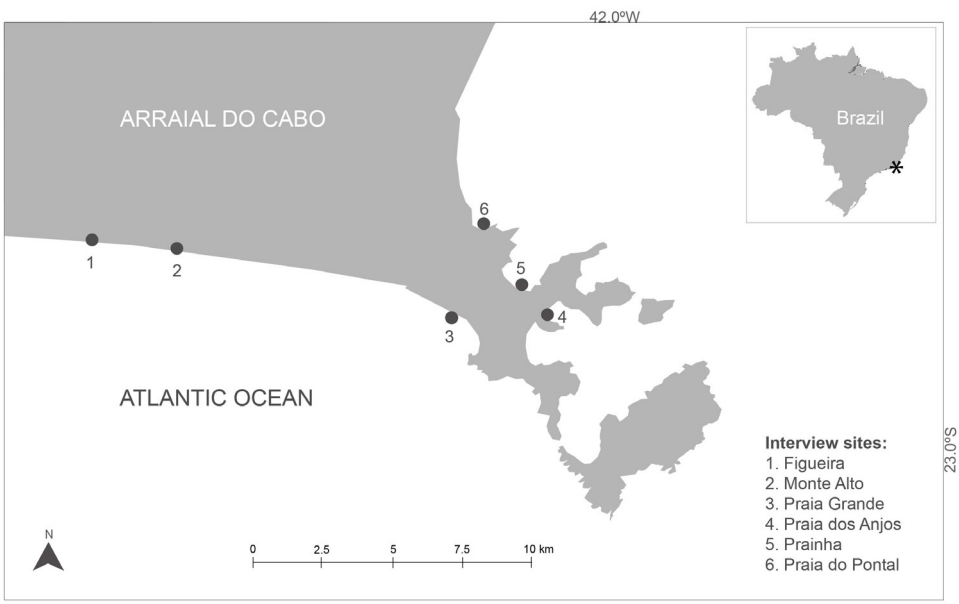


**FIGURE 1** | Map of Arraial do Cabo region, Rio de Janeiro, Brazil, and study sites.

## RESULTS

We interviewed 155 small-scale fishers, of which their age ranged 17 to 82 years old, (average = 50 ±12 years) (±s.d.) and their experience ranged three to 64 years (average = 31 ±13 years). Fishers identified six shark species (one genus) which are considered at risk of extinction (Tab. 1). The most frequently caught sharks were spinner shark (*Carcharhinus brevipinna*), the sandbar shark (*Carcharhinus plumbeus*), and the shortfin mako shark (*Isurus oxyrinchus*). Of these sharks, there were no significant declines in C. *brevipinna* caught with beach seine (Fig. 2) and there were no significant differences over time for both *C. brevipinna* and *I. oxyrinchus* caught with hook and line (Figs. 3A, B). By contrast, the number of *C. plumbeus* individuals was significantly reduced over the last 50 years from an average of 9.56 ±5.13 individuals in 1968 to 2.82 ±1.7 individuals in 2019 (Fig. 3C).

**TABLE 1** | Shark species reported by fishers as most captured during their careers. Conservation status according to the global (IUCN, 2023) and national (MMA 2018, 2022, 2023) red lists of threatened species. Conservation status: CR = Critically Endangered; VU = Vulnerable; EN = Endangered; NT = Near Threatened.

| Species | Common name | Fishing gear | Habitat type | Global status | National status |
|---|---|---|---|---|---|
| *Sphyrna* sp. | Hammerhead shark | Gillnet | Neritic, Oceanic | - | CR |
| *Carcharias taurus* | Sand tiger shark | Longline | Neritic, Oceanic, Coastal/Supratidal | VU | CR |
| *Carcharhinus brevipinna* | Spinner shark | Beach seine, longline | Neritic | VU | VU |
| *Carcharhinus plumbeus* | Sandbar shark | Beach seine, longline | Neritic | VU | CR |
| *Isurus oxyrinchus* | Shortfin mako shark | Longline | Oceanic | EN | CR |
| *Galeocerdo cuvier* | Tiger shark | Longline | Neritic, Oceanic | NT | CR |
| *Prionace glauca* | Blue shark | Line and hook | Neritic, Oceanic | NT | NT |

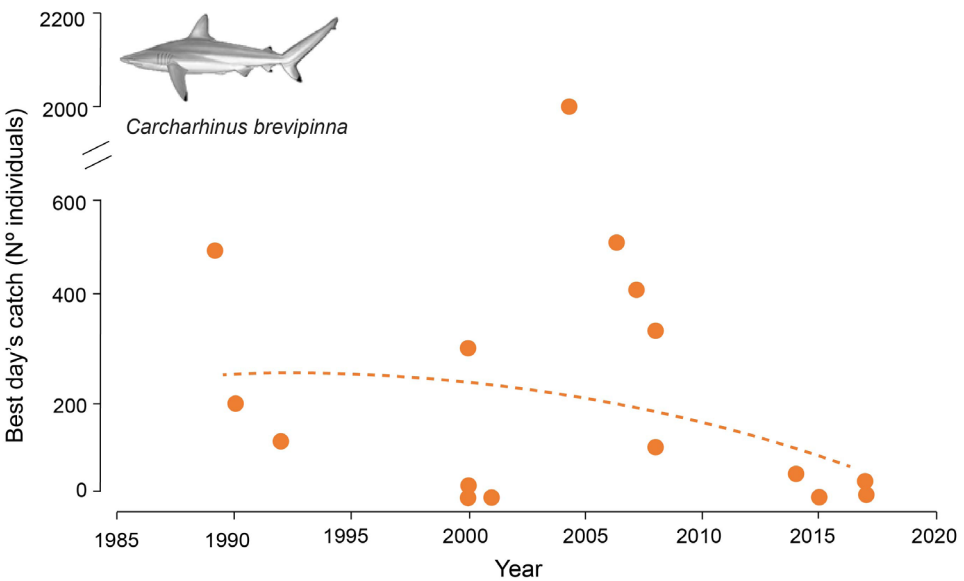


**FIGURE 2** | Spinner shark, *Carcharhinus brevipinna*, catches according to beach seine fishers in Arraial do Cabo (with second order polynomial regression line shown $r^2 = 0.09$, $p = 0.5$).

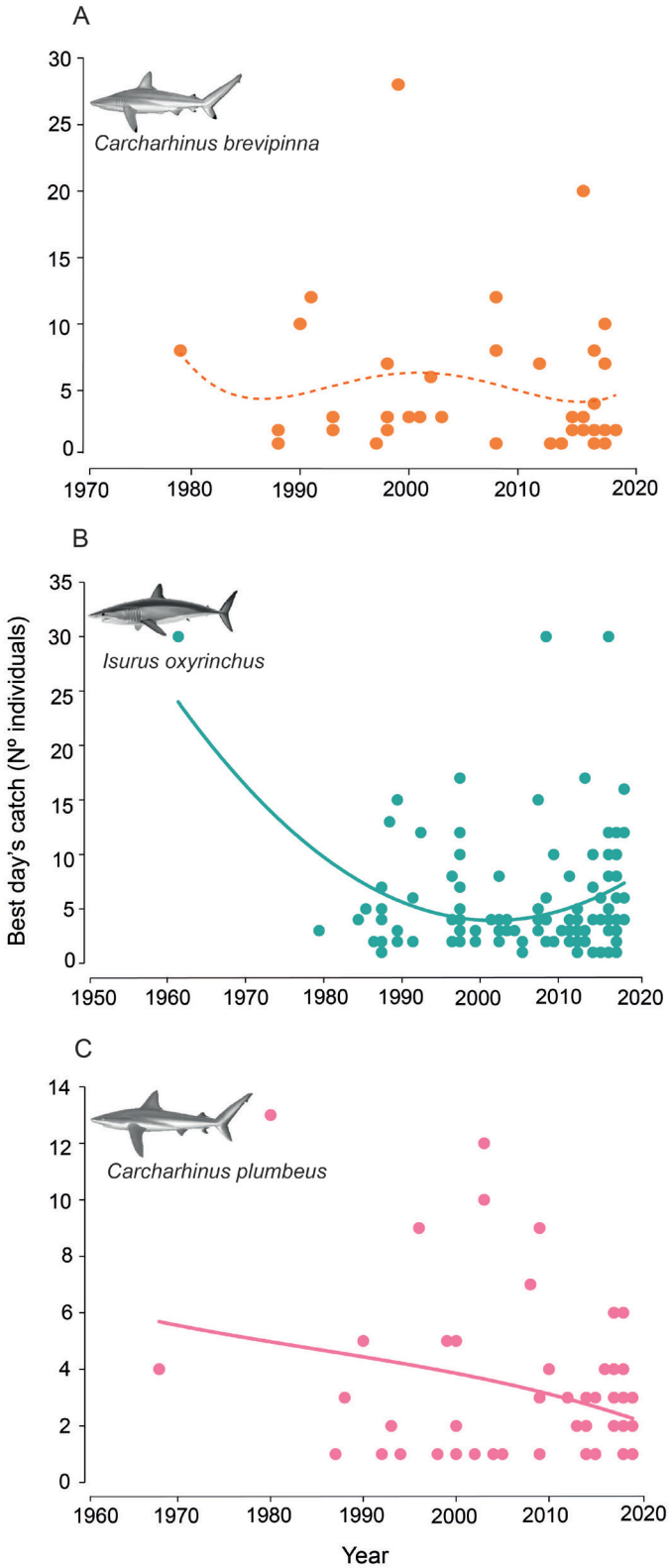


**FIGURE 3** | Best day's catches (number of individuals caught) according to hook and line fishers of Arraial do Cabo. **A.** Spinner shark, *Carcharhinus brevipinna*, with fourth order polynomial regression ($r^2$ = 0.02, p = 0.8); **B.** Shortfin mako shark, *Isurus oxyrinchus*, with second order polynomial regression ($r^2$ = 0.14, p = 0.46); **C.** Sandbar shark, *Carcharhinus plumbeus*, with third order polynomial regression ($r^2$ = 0.08, p = 0.02).

Fishers' knowledge revealed temporal changes in the fishing grounds of three investigated shark species (Fig. 4). The spatial distribution of shark catches revealed that new fishing grounds have been exploited over time. For instance, eight new fishing grounds of *C. brevipinna* were reported after 2006 (Figs. 4A, B). In some fishing grounds, such as Praia Grande, the number of individuals caught decreased over time (Fig. 4B). Between 1979 and 2005, beach seine fishers caught around 2000 individuals. After this period (2006–2019), the number of individuals declined to a maximum of 500 individuals caught on the best day's catch (Figs. 4A, B). The number of fishing grounds where the interviewees reported catches of *I. oxyrinchus* also increased; six new sites appeared from 1962 to 2019 (Figs. 4C, D). Finally, for *C. plumbeus*, four new fishing grounds were reported after 2006. In Praia Grande, where 11–12 individuals were caught between 1968 and 2005, no *C. plumbeus* individuals were captured between 2006 and 2019 (Fig. 4F).

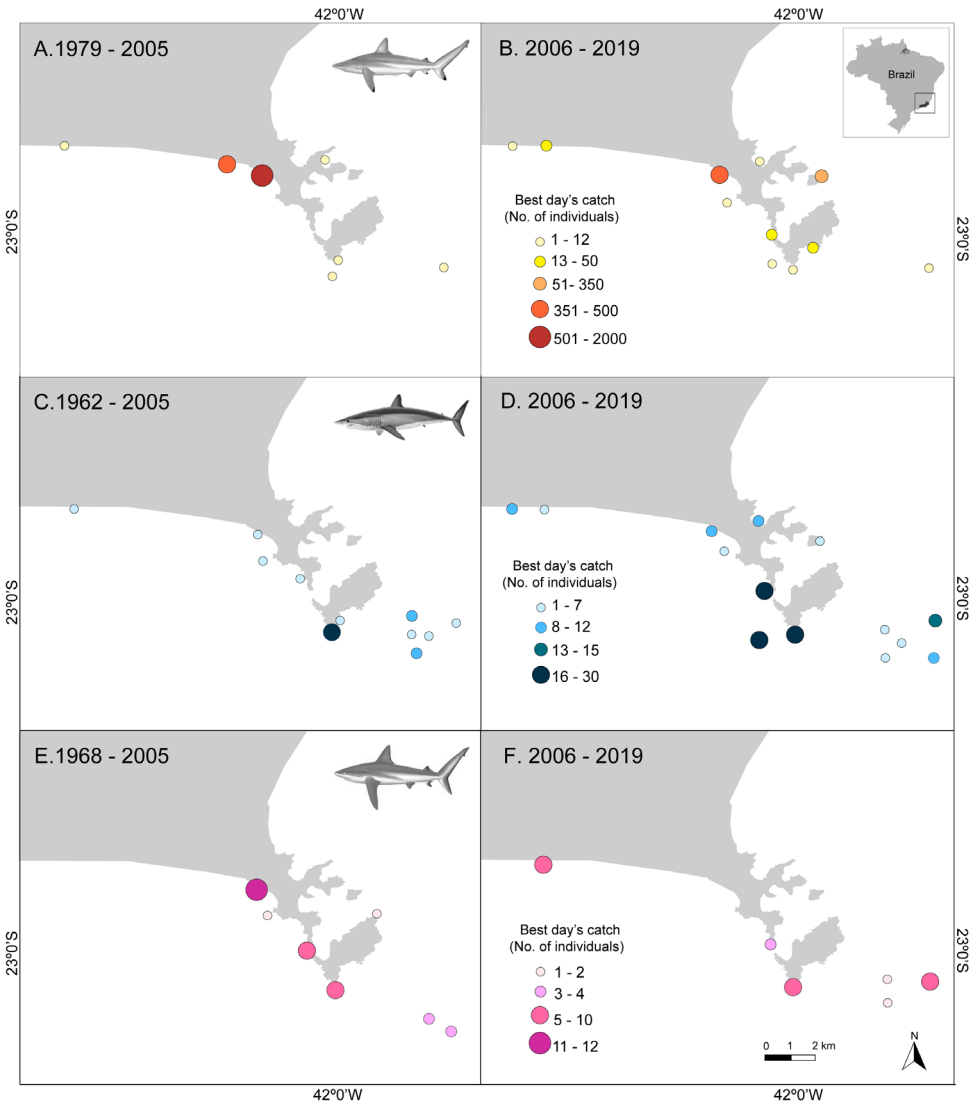


**FIGURE 4** | Spatial distribution of fishing grounds of best day's shark catches in Arraial do Cabo (number of individuals caught). **A.** Spinner shark, *Carcharhinus brevipinna*, catches from 1979 to 2005 and **B.** 2006 to 2019; **C.** Shortfin mako shark, *Isurus oxyrinchus*, catches from 1962 to 2005 and **D.** 2006 to 2019; **E.** Sandbar shark, *Carcharhinus plumbeus*, catches from 1968 to 2005 and **F.** 2008 to 2019.

## DISCUSSION

During the last 60 years in Arraial do Cabo, shark catches and fishing grounds have changed. Fish stocks have experienced changes in this region (Fogliarini *et al*., 2021), where target top and mesopredators, such as sharks, groupers, and tunas, have declined and fishers have concentrated on new ones (Bender *et al*., 2014; Fogliarini *et al*., 2021). In general, shark fisheries have changed over time. A small portion of the fleet currently focuses on shark fishing seasonally, operating fishing grounds located farther away from the coast to maintain profitability. However, despite the increased effort, this has not resulted in a corresponding increase in catches. Our research, in fact, has revealed a decline in the number of sharks caught in some fishing grounds closer to the coast. Fishers reported the best day catch of over 2,000 sharks using beach seine at Praia Grande beach. Due to unsustainable captures, catch events with hundreds of individuals have become increasingly rare (Fig. 5).

Off the Brazilian coast, catches on pregnant sharks, including juveniles and immature individuals using beach seine and other gill nets are common (Vooren, Klippel, 2005; Yokota, Lessa, 2006; Bornatowski *et al*., 2014a). We verified that pregnant individuals of *C. brevipinna* and *I. oxyrinchus* were frequently captured between June and July (Tab. **S2**). Patterns of reproduction, migration, and feeding habitats of these shark species are poorly known for the Brazilian Province. In South Africa, the capture of pregnant *C. brevipinna* was confirmed in beach nets between March and August (Allen, Gliff, 2000). In our study, fishers also reported large catches of this species during upwelling events and following large mullet shoals (*Mugil* sp.) (Tab. **S2**). According to reports, sharks are attracted to the coastline to feed on mullets, typically occurring between April and August. Along the African coast, spinner sharks were captured during feeding aggregations, especially in austral winter months, also coinciding with the abundance of sardines (*Sardinops sagax*) in coastal waters (Allen, Gliff, 2000). This feeding aggregation behavior has also been observed in Florida, where *C. brevipinna* formed "packs" behind shrimp boats (Dodrill, 1977).

Shark fishing in Arraial do Cabo sustained an international shark finning market until the 1990s, when this market was banned in Brazil (Amorim *et al*., 1998; Hazin *et al*., 2008). As in other countries, management of shark fishing in Brazil has not prevented population declines (Bornatowski *et al*., 2014a,b). By 2018, the National Red List of Threatened species included 30 shark species (MMA, 2018). In 2023, five other species were added to this list. Among these, the spinner shark, *C. brevipinna,* categorized as Vulnerable (VU), and the shortfin mako *I. oxyrinchus*, listed as Critically Endangered (CR) (MMA, 2023). The spinner shark is a common coastal-pelagic species that occurs in warm-temperate and tropical areas of the Western and Eastern Atlantic and the Western Indo-Pacific (IUCN, 2023). This species is highly susceptible to fisheries due to its low biological productivity, and its breeding area which overlaps with areas of intensive and unregulated fisheries (Diop, Dossa, 2011; Doumbouya *et al*., 2017). A global estimate suggests that spinner shark populations have suffered reductions of 30–49% in the recent decades (IUCN, 2023). Similarly, studies have indicated the depletion of shortfin mako stocks in various marine regions, including the South Atlantic (Ferretti *et al*., 2008; Barreto *et al*., 2016; ICCAT, 2017; Brunel *et al*., 2018). An assessment has revealed a 99% decline in the average CPUE (Catch per unit effort) of shortfin mako caught in longline fisheries over the last 30 years (Barreto *et al*., 2016).


**FIGURE 5** | Photographs showing past and present of beach seine catches of spinner shark, *Carcharhinus brevipinna*, caught in Arraial do Cabo, Brazil. **A.** Individuals caught in 1979; **B.** In 1996; **C.** In 2005; and **D.** In 2014. Images were kindly provided by interviewed fishers of Arraial do Cabo.

In conclusion, we observed a shift in shark fishing practices in Arraial do Cabo over the past 60 years. The shark fleet has moved further away from the coast due to overexploitation. However, this change has not been accompanied by an increase in catches. A fundamental step in managing the cross-scale overfishing scenario for sharks in Brazil is the establishment of protected areas in nursery and breeding sites. However, given that most of these sharks exhibit high mobility, migrating through long distances during their life cycle, which includes feeding and breeding areas (Capapé *et al*., 2003; Stevens, 2008; Letessier *et al*., 2017), effective protection for these species will solely be effective though a network of protected areas and shark fishing bans, coupled with effective monitoring and education initiatives. Since 2007, Brazil has lacked a systematic nationwide fishing monitoring program (IBAMA, 2007), lacking basic data to support fisheries management. We strongly recommend that the Brazilian government accelerates the establishment of monitoring programs, integrating scientific guidance, stakeholders' knowledge, and leadership. Alarmingly, increasing evidence indicates a decline in fish stocks targeted by both industrial and small-scale fisheries along the Brazilian coast (Freire *et al*., 2021). Additionally, shark species and other targeted fisheries such as groupers possess life history traits that render them even more susceptible to fishing impacts (Bender *et al*., 2013; Ceretta *et al*., 2020). Fisheries landing data across long time-series also remain scarce for sharks in Brazil. However, through fishers' LEK, we may fill in gaps in fisheries landing data for some species. Combining different data sources can help us improve our understanding of shark population trends in complex

and multi-specific fisheries. This approach can provide insight into data-poor sites where information is absent or fragmented over time. Biological and social approaches are complementary, and their integration has gained increased recognition, providing relevant information for fisheries management and the conservation of threatened species. The public in general is unaware about the key role of top predators like sharks. This fact reinforces the constant need for public awareness to value sharks alive, considering the multiple examples of revenues where sharks are protected (Vianna *et al*., 2018; Gonzáles-Mantilla *et al*., 2022). These recommendations collectively underscore the need for a holistic approach that integrates various strategies and stakeholders to ensure the sustainability and conservation of Brazil's shark populations.

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## AUTHORS' CONTRIBUTION

**Carine O. Fogliarini:** Conceptualization, Formal analysis, Investigation, Methodology, Software, Visualization, Writing-original draft, Writing-review and editing.

**Vinicius J. Giglio:** Conceptualization, Methodology, Visualization, Writing-original draft, Writing-review and editing.

**Mariana G. Bender:** Conceptualization, Methodology, Supervision, Visualization, Writing-original draft, Writing-review and editing.

**Carlos E. L. Ferreira:** Conceptualization, Funding acquisition, Supervision, Visualization, Writing-original draft, Writing-review and editing.

## ETHICAL STATEMENT

The interviews were approved by the Ethics Committee of Universidade Federal de Santa Maria, Brazil (CAAAE 29157919.6.0000.5346) and by Sistema de Autorização e Informação em Biodiversidade (SISBIO-ICMBio/IBAMA/Brazil #55911–6).

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The author declares no competing interests.

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