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Unseen Experts of the Sea: Fishers' Local Ecological Knowledge Reveals Elasmobranch Hotspot Decline Around Curaçao, Dutch Caribbean

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ABSTRACT

Fishing pressure is the primary threat to coastal elasmobranch populations, and understanding its impact requires long-term regional data—often lacking in complex, small-scale fishery settings. This is the case for Curaçao, a southern Dutch Caribbean island with an unmonitored artisanal fishery where, according to anecdotes, elasmobranchs have severely declined but continue to be landed. In such data-limited regions, fishers' local ecological knowledge (FLEK) is a valuable tool for reconstructing historical baselines. Using FLEK from 21 surveys, we quantified historical and current elasmobranch diversity around Curaçao. Participatory mapping identified spatial distributional changes of 14 elasmobranch species, comparing the time of the surveys with fishers' career beginnings. Temporal trends were analysed alongside shifts in fishing efforts, socioeconomic contexts and perceptions of fishery management. Between 1957 and 2009, we identified 36 spatial hotspots of elasmobranch richness, which declined to 14 hotspots from 2010 to 2022, with a 4.3-fold greater likelihood of hotspots occurring in the past. Species richness in these areas significantly decreased from 7.44 ± 1.00 (mean $\pm$ s.e.) to 3.00 ± 1.18 species, while the number of fishers increased from 2.86 ± 0.23 fishers to 5.14 ± 0.49 per hotspot. Although not targeted, incidental elasmobranch catches are commonly retained. Most fishers expressed a desire for increased inclusion in fishery management but viewed elasmobranch-specific measures as unnecessary, perceiving local populations as healthy. We thus provide critical spatial baseline data for evidence-based conservation of elasmobranchs around Curaçao while emphasising the benefits and importance of engaging small-scale fishers in managing elasmobranch populations.

1 | Introduction

The growing human population, technological advancements and an increased demand for marine resources have led to the depletion and collapse of fish stocks worldwide (Pauly et al. 2005; Murawski 2010). Overfishing is particularly threatening to large, long-lived and late-maturing species, such as many elasmobranchs (i.e., sharks and rays, herein collectively referred to as 'sharks'), as their limited reproductive output restricts their recovery potential even at low exploitation rates (Smith et al. 1998; Stevens et al. 2000; García et al. 2007). Sharks are targeted to fuel the consumption and trade of shark meat and other body parts (e.g., fins, liver, skin; Dent and Clarke 2015) or are caught incidentally as they entangle in fishing gear intended for other catch species (Oliver et al. 2015). In 2019, fishing-induced mortality was estimated at 80 to 101 million sharks annually—levels that exceed the rebound potential of most species—with approximately 95% of these deaths occurring in coastal fisheries (Worm et al. 2024). Overfishing currently puts one-third of all elasmobranch species at risk of extinction (Dulvy et al. 2021). Reef-associated sharks have almost completely vanished from around 20% of the world's coral reefs (MacNeil et al. 2020), and oceanic shark abundance has declined by 70% (Pacoureau et al. 2021). In the Greater Caribbean, where sharks were once described as one of the most common groups of species (Watkins 1924), anthropogenic pressures have led to the large-scale absence of sharks on coral reefs (Ward-Paige et al. 2010). This is of ecological concern as sharks occupy diverse ecological roles in marine ecosystems, including regulating abundance, traits and behaviour of prey populations and contributing to nutrient cycling, and their removal can disrupt these processes and lead to imbalances in ecosystem functioning (Heithaus et al. 2010; Dedman et al. 2024).

A substantial proportion of shark catches occurs in small-scale fisheries in lower-resource countries (Dulvy et al. 2017; Dulvy et al. 2021), where they contribute to sustaining livelihoods (Jaiteh et al. 2016; Seidu et al. 2022). Although lacking a universal definition, small-scale fisheries often operate with smaller boats, simpler gears, less investment and technology and are usually more closely associated with coastal zones than industrial vessels (FAO 2015). Despite accounting for 40% of global fish catches (Alfaro-Shigueto et al. 2010; FAO 2022; FAO 2024a), their often complex socioecological dynamics leave small-scale fisheries frequently unmonitored (McClanahan et al. 2009; Saunders et al. 2016; Kalidin et al. 2020). In Latin America and the Caribbean, where small-scale fisheries provide income and nutritional value to approximately two million people, their mixed-species nature deems catch data frequently unreliable and incomplete (Salas et al. 2007; de Oliveira Leis et al. 2019). Accurate data are vital for the assessment of fish stocks and thus the ability to set management priorities (Momigliano and Harcourt 2014; Pita et al. 2019). Especially valuable are long-term monitoring data, as they allow for setting historical baselines, which provide key insights into species trends over time and thus serve as critical reference points for decision-makers (McClenachan et al. 2012; Friedlander et al. 2014; Ferretti et al. 2018).

In data-limited fisheries, the use of nontraditional research approaches, such as fishers' local ecological knowledge (FLEK), can aid in evaluating long-term changes in vulnerable catch species to support fishery management (Beaudreau and Levin 2014; McClenachan et al. 2024). Fishers' daily interactions with marine resources offer important ecological information on species' spatial distributions and abundances and temporal changes in those (Lopes et al. 2018; Leduc et al. 2021). Previous studies have demonstrated the value of FLEK to reconstruct historical trends of shark populations in data-scarce regions (Colloca et al. 2020; Almojil 2021; Shaff et al. 2023; Rubio-Cisneros et al. 2023). Engaging with local fishers simultaneously sheds light on socioeconomic perspectives (Cinner et al. 2010; Booth et al. 2019), fosters mutual understanding between researchers and fishers and strengthens fishers' involvement and responsibility in resource management (Obura et al. 2002; d'Armengol et al. 2018).

The success of common shark conservation tools, such as seasonal and spatial fishing closures (White et al. 2015; Graham et al. 2016; MacKeracher et al. 2019), relies heavily on both ecological and socioeconomic insights (Christie 2004; Edgar et al. 2014; Giakoumi et al. 2018). Ecological data on shark distribution is crucial for setting regional conservation focuses (Costello et al. 2010). Meanwhile, understanding the resource dependence of local fishing communities provides context for how species declines have been influenced and how perceptions of fishery management shape conservation outcomes (Eriksson 2016; Booth et al. 2019; Mason et al. 2020). Failing to incorporate local perspectives and account for the vulnerabilities of fishing communities to policy changes has undermined shark conservation efforts in the past (Jaiteh et al. 2016; Guirkinger et al. 2021).

A notable regional example of shark conservation is the *Yarari Shark and Marine Mammal Sanctuary*, which was established in 2015 to protect sharks across the exclusive economic zones (EEZs) of the Dutch Caribbean islands of Bonaire, Saba and St. Eustatius (Dutch Caribbean Nature Alliance 2019). While sharks are not directly targeted in this region, incidental catches are common, with sharks frequently consumed, sold, used as bait or killed and discarded (Van Beek et al. 2012). On the Dutch Caribbean island of Curaçao, where artisanal small-scale fleets operate unmonitored, ongoing shark landings and a severe decline in shark populations have been anecdotally documented (Van Beek et al. 2012). Efforts to quantify and reconstruct historical shark landings have been inconsistent or lack species-specific detail (Vermeij et al. 2019; Zaneveld 1962), creating challenges for extending conservation initiatives to Curaçaoan waters (Dutch Caribbean Nature Alliance 2019). Similarly, the current status of sharks around Curaçao is poorly understood, with existing data limited to a single, spatially restricted snapshot study (Winter and de Graaf 2019).

In this study, we leveraged the local ecological knowledge of artisanal fishers from Curaçao to map and compare the spatial distribution of historical and current shark diversity around the island. Additionally, we explored changes in fishing practices, socioeconomic perspectives and fishers' views on management, contextualising these insights alongside the observed decline in shark diversity. We provide novel findings that contribute to the historical understanding of shark populations around Curaçao and may help inform regional management efforts. Furthermore, our study highlights the importance of community engagement in advancing shark conservation, particularly in unmonitored nontarget fisheries.

2 | Methods

2.1 | Study Area

The study was conducted on Curaçao (12.1696° N, 68.9900° W), an island in the southern Caribbean Sea, situated about 65 km north of Venezuela (Figure 1a). Curaçao is a constituent country within the Kingdom of the Netherlands and part of the Lesser Antilles island group, comprising the main island (444 km^2) and the smaller, uninhabited Klein Curaçao (1.7 km^2). The island's fishery primarily involves artisanal small-scale fishing and recreational fisheries catering to tourists. Local artisanal fishers typically use small, motorised wooden boats, often locally manufactured, with lengths of up to 12 m (Dilrosun 2022). These fishers land their catches at 13 harbours and landing beaches, of which nine were sampled for this study (Figure 1b). The exact number of professional fishers on Curaçao is not officially monitored, and various estimates exist. According to the FAO (2024b), there were approximately 15 full-time and 229 part-time fishers in 2018. However, the definition of 'part-time' is not clearly specified. Dilrosun (2022) estimates that 10–15 artisanal fishing boats operate regularly, and given that each boat typically has two fishers onboard, this would suggest a range of 20–30 fishers who fish on a regular basis. Vermeij et al. (2019) reported that 183 fishers were operating on the island in 2016 and estimated that 57 fishers considered fishing their main source of income. Additionally, they noted that the number of functional fishing boats is likely half of the number of registered fishing boats, indicating that not all boats are actively used for fishing. Moreover, Vermeij et al. (2019) noted a steady decrease in numbers of fishers since 1905, declining from 1118 fishers in 1905 to 183 in 2016. Wahoo (*Acanthocybium solandri*), mahi-mahi (*Coryphaena hippurus*), red snapper (*Lutjanus campechanus*) and grouper (*Epinephelus striatus*) yield the highest economic value (FAO 2024b). However, there is no clear distinction between target and by-catch species in this fishery and less desirable (by-catch) species, including sharks, are reportedly sold at relatively high prices (FAO 2024b).

2.2 | Collection of FLEK

Between July and October 2022, we conducted face-to-face interviews with local artisanal fishers. Additionally, we handed out questionnaires which were completed independently by fishers. Given the exploratory nature of our study, we did not predetermine a sample size but instead sought to engage with as many fishers as possible within the study period. However, we restricted the participation to fishers who engaged in fishing professionally to some extent, which we defined as earning income from their fishing activities. A local guide initially identified potential interviewees through personal contacts. Additionally, we employed a snowball sampling approach (Goodman 1961), where each interviewed fisher was encouraged to recommend other participants. We also approached fishers directly at popular landing sites around the island (Figure 1b). Sampling sites were selected based on the knowledge of a local expert and the available time and opportunities in the field. Similarly, questionnaires were distributed in multiple ways: by previously interviewed fishers, directly by us at landing sites and through local restaurants that regularly purchase catches from local fishers. Both interviews (Appendix S1) and questionnaires (Appendix S4) comprised the same set of questions with a

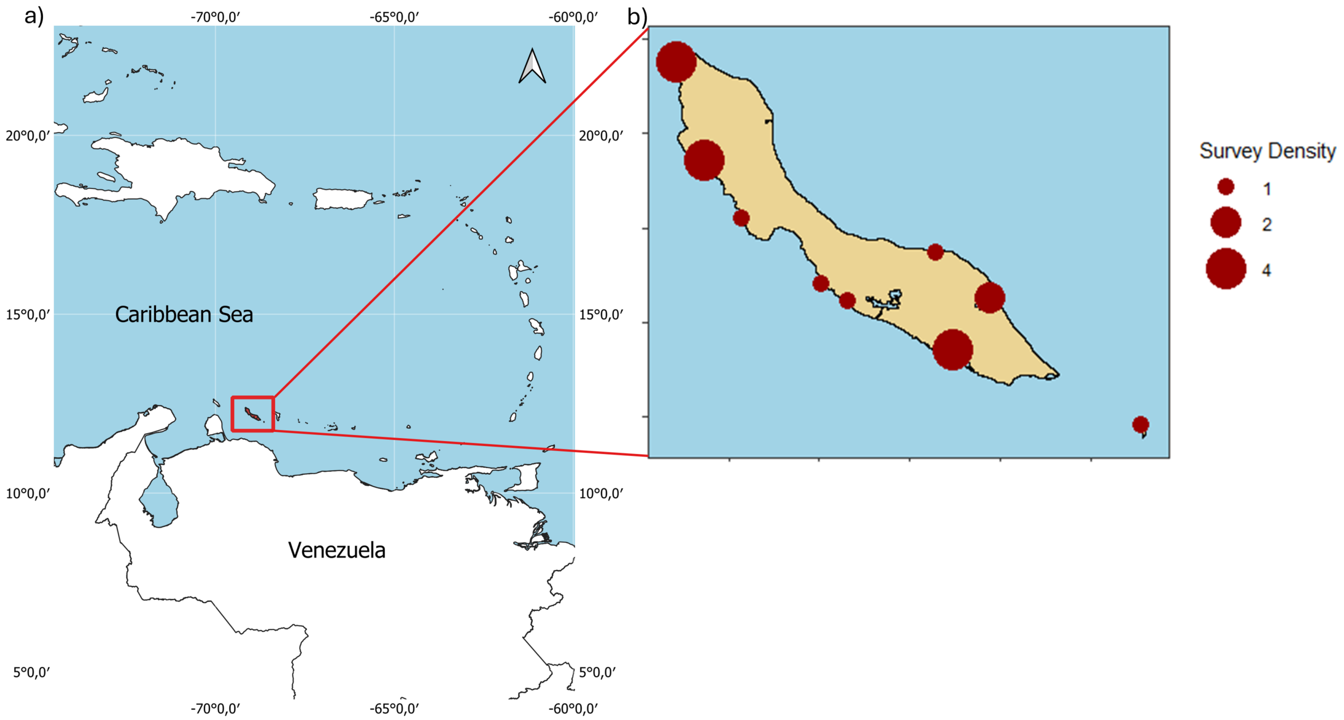

FIGURE 1 | Study area: (a) Curaçao in a regional context and (b) the distribution of landing sites sampled in this study, where circle sizes indicate the number of conducted surveys at a site.

focal point on elasmobranch observations of 14 species (Table 1). Interviews were conducted in either English or Papiamentu, based on the fisher's preference. When conducted in Papiamentu, a local translator facilitated the interview, translating each response for the researcher in real time. Photographs of landed sharks (Appendix S5) were shown to fishers to assist in species-level identification and to ensure mutual understanding of the species being discussed, as artisanal fishers may use local names or species characteristics, such as size, to distinguish between shark species. Hammerhead sharks were grouped under the family Sphyrnidae, as fishers indicated that distinguishing between species within this family was challenging. Once a shark was identified, fishers were asked if they typically observed that species during an average fishing trip. A shark observation was defined as either the capture of a shark and/or the sighting of a shark from the fisher's boat. The observation frequency (e.g., every trip, monthly, yearly) and the observation location were documented. The latter was specified for every positively identified species through drawings on a laminated 3×3 km grid map by the fisher (Appendix S2). To capture changes over time, fishers were asked to provide information on shark observations from the year in which they started fishing professionally and from the 'current' year when the interview was conducted (2022) or, in the case of retired fishers, the year in which they stopped fishing professionally. This approach was based on the findings of Tesfamichael et al. (2014), who showed that questioning interviewees about profound moments in time (i.e., the start of their career and 'now') allows them to recall memories more easily and, therefore, leads to more accurate results. We marked the professional career start of fishers as the year in which they acquired their own fishing boat or in which they actively fished to make a living. Moreover, fishers' demographics, fishing grounds, fishing gear and perceptions of current fishery management and marine conservation efforts were documented.

TABLE 1 | Shark and ray species included in each survey.

Scientific name	Common name	Global IUCN Red List status[a]
Carcharhinus perezii	Caribbean reef shark	EN
Carcharhinus limbatus	Blacktip shark	VU
Carcharhinus longimanus	Oceanic whitetip shark	CR
Carcharhinus leucas	Bull shark	VU
Galeocerdo cuvier	Tiger shark	NT
Negaprion brevirostris	Lemon shark	VU
Rhincodon typus	Whale shark	EN
Ginglymostoma cirratum	Atlantic nurse shark	VU
Prionace glauca	Blue shark	NT
Isurus oxyrinchus	Shortfin mako shark	EN
Sphyrnidae	Hammerhead shark ssp.	EN/CR[b]
Aetobatus narinari	Spotted eagle ray	EN
Hypanus americanus	Southern stingray	NT
Mobula birostris	Giant oceanic manta ray	EN

[a]Global IUCN (International Union for Conservation of Nature) Red List status from least to most threatened: DD = data deficient, NT = near threatened, VU = vulnerable, EN = endangered, CR = critically endangered.
[b]Based on bonnethead shark (*Sphyrna tiburo*) and scalloped hammerhead shark (*Sphyrna lewini*) as found around Curaçao according to Van Beek et al. (2012).

We shared the study's main findings with all participating fishers through our local guide, who distributed flyers (Appendix 3) and displayed posters at landing sites (Figure 1b) prior to scientific publication. The flyers and posters included a QR code linking to a designated website (www.guidoleurs.org/sharks-of-curacao/) showcasing all relevant information and through which fishers could contact us directly with any questions, feedback or concerns.

2.3 | Data Analyses

Data analyses were conducted using R Version 4.3.1 (R Core Team 2023). Changes in shark observations over time were revealed by comparing shark species richness hotspots in two time periods: 1957–2009, reflecting the experiences of participating fishers at the beginning of their careers, and 2010–2022, corresponding to the most recent decade during which the survey was conducted. For the latter period, we assumed that shark demand and catches remained relatively constant. Fishers provided specific locations for shark observations on a gridded map (Appendix S2), yielding species richness for each map cell. Although our questionnaire included prompts for estimating species abundance, we found that fishers reported high variability in shark encounters over time, making average abundance estimates unreliable. Consequently, we focused our analysis on species richness based on recurring interactions reported to occur at least once per year (i.e., on every trip, weekly, monthly or annually). A Moran's I test with queen contiguity ('spdep' package, Pebesma and Bivand 2023) confirmed spatial autocorrelation of the data (2010–2022: $I = 0.180$, $p < 0.001$; 1957–2022: $I = 0.407$, $p < 0.001$). Subsequently, a hotspot analysis using Getis-Ord Gi* statistic was performed ('sfdep' package, Parry 2023) to identify significant, nonrandom clusters of high values of species richness. A neighbourhood matrix using queen contiguity and a spatial weight matrix with basic binary coding was computed ('spdep' package, Pebesma and Bivand 2023). Grid cells were identified as shark species richness hotspots when associated data scored a positive Z-score in combination with a p value of ≤ 0.1. Hotspots were further divided into 99% confidence ($p < 0.01$), 95% confidence ($p < 0.05$) and 90% confidence ($p < 0.1$) hotspots. Additionally, fishers provided geographical information about their fishing grounds on the same gridded map. Thus, an identical hotspot analysis was repeated for fishing grounds in both time periods. If two neighbouring grid cells were identified as hotspots, they were treated as separate hotspots rather than being combined into a single clustered hotspot. To test whether the occurrence likelihood of shark species richness/fishing area hotspots differed among time periods, we constructed generalised linear mixed models with binomial distributions (1 = hotspot, 0 = no hotspot) ('lme4' package, Douglas et al. 2015). We included *interviewee* as a random effect and *distance to the coast (kilometre)* and *fishing trip duration (hour)* as fixed effects in the model selection processes. Distance to the coast was calculated from each grid cell's centroid to the closest point to the coast using QGIS V. 3.32.2 (QGIS.org 2023). The goodness of fit was tested using the 'r.squaredGLMM' function ('MuMIn' package, Bartón 2023). Further, we performed a Wilcoxon rank-sum test to test whether the mean shark species richness within identified shark richness hotspots differed among the two time periods. Similarly, we used a Wilcoxon rank-sum test to test for differences in mean numbers of fishers fishing within fishing area hotspots over time. In addition, we determined active fishers within shark richness hotspots, fishing trip duration (hour), the frequency of fishing trips per month (in days) and the utilisation of fishing gear. Temporal changes in the latter were assessed using generalised linear mixed models with a binomial distribution (1 = gear used, 0 = gear not used) for both handlines and electric reels ('lme4' package, Douglas et al. 2015). Finally, we performed Wilcoxon signed-rank tests to test whether the mean number of active fishers within shark richness hotspots, trip duration and monthly sea days changed throughout the two examined time periods. Additionally, we employed descriptive statistics to outline potential socioeconomic drivers contributing to a change in shark observations and fishers' perceptions of management.

3 | Results

In total, we conducted 24 surveys with local artisanal fishers. Of these, 17 were face-to-face interviews and seven were independently completed questionnaires. Three surveys were excluded from further statistical analyses due to incomplete data, species misidentification or interruptions by others, possibly causing biased results. This resulted in a total sample size of 21 surveys used for all statistical analyses including descriptives.

3.1 | Fishers' Demographics

The study included 20 male fishers and one female fisher. Participants began their fishing careers as early as 1957 and as recently as 2017 (Figure 2a), with an average of 33.7 ± 3.4 years (mean ± s.e.) of professional fishing experience (Figure 2b). The average age of fishers was 55 ± 3.4 years, ranging from 27 to 82 years (Figure 2c). In 2022, when the survey was conducted, 16 fishers reported fishing part-time, while five engaged in full-time fishing.

3.2 | Hotspot Analyses

Fishers marked a total of 251 grid cells for the period 1957–2009 and 221 grid cells for 2010–2022. This corresponds to fishing efforts distributed across 2259 and 1989 km^2, respectively, as each grid cell (3 × 3 km) covers an area of 9 km^2. Within these broader regions, we identified 34 fishing area hotspots for 1957–2009 and 33 fishing area hotspots for 2010–2022 (Figure 3c,d). The likelihood of a fishing area hotspot occurring increased significantly with decreasing distance from the coast (kilometre) ($p = 0.005$) but did not differ significantly among time periods ($p = 0.35$). Similarly, the difference in the mean number of fishers within fishing area hotspots was not significant among time periods ($Z = 628.5$, $p = 0.07$).

We identified 36 shark species richness hotspots in the past (1957–2009) and 14 in the present (2010–2022) (Figure 3a,b). Both time period ($p < 0.001$) and distance from the coast (kilometre) ($p = 0.004$) were significant predictors of the likelihood of shark species richness hotspot occurrence ($R^2 = 0.65$). The likelihood of these hotspots decreased with increasing distance from the coast. The maximum distance from the coast at which

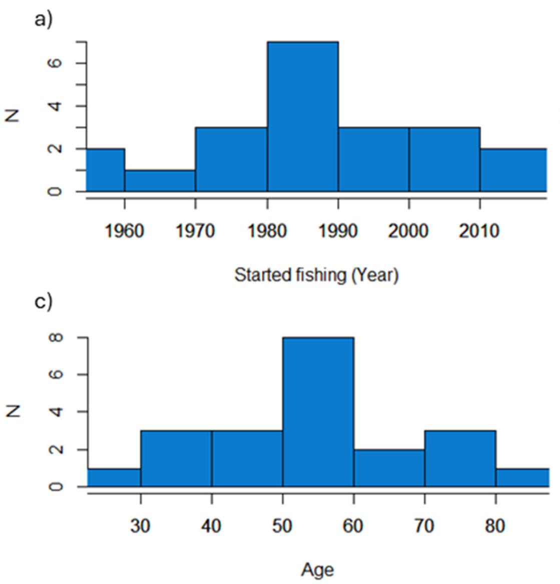

FIGURE 2 | Demographic overview of (a) the years in which surveyed fishers started fishing, (b) their professional fishing experience in years and (c) their age at the time of the survey.

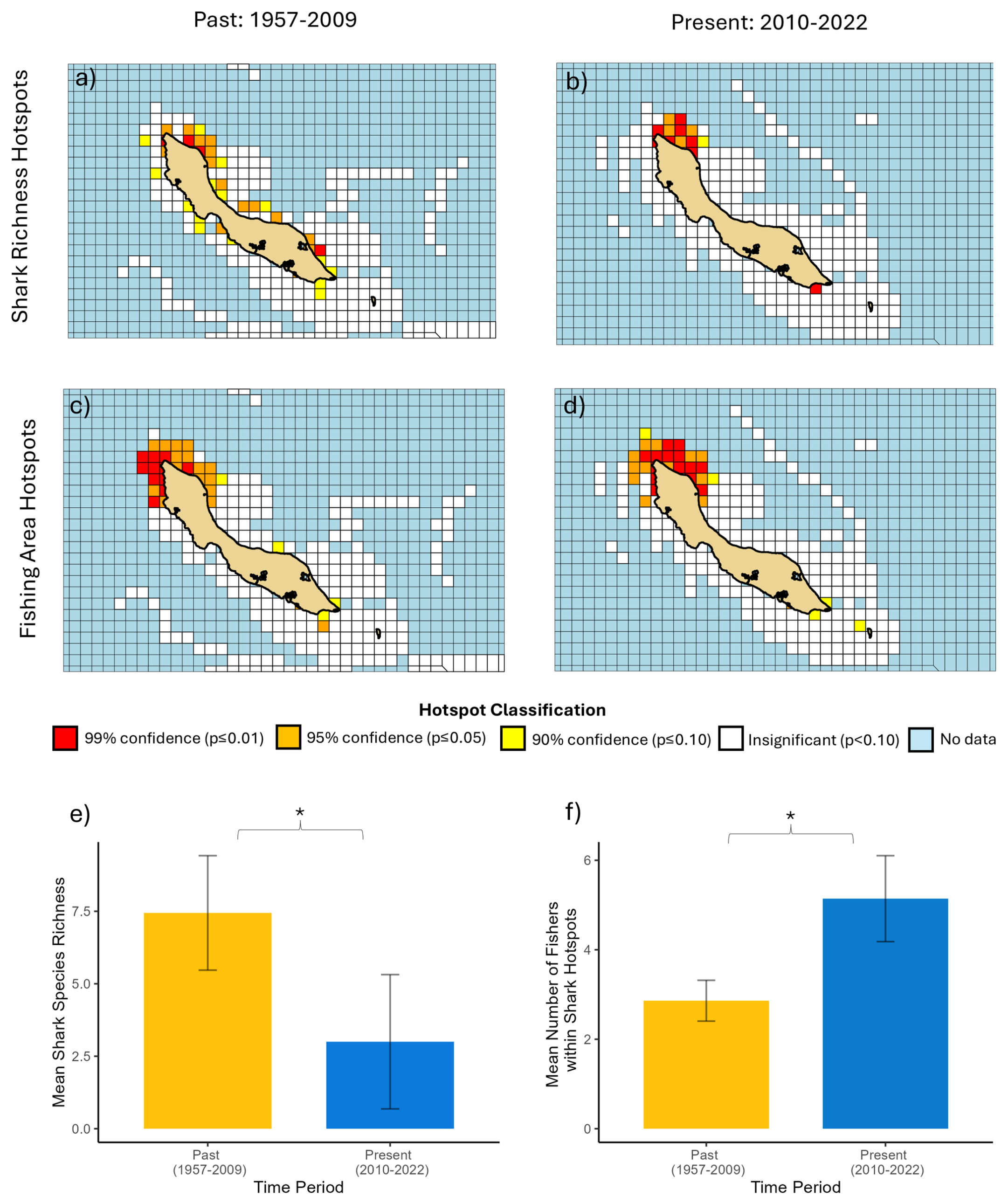

FIGURE 3 | Spatiotemporal changes in shark species richness and fishing area hotspots around Curaçao. Shark species richness hotspots around Curaçao for two time periods: (a) 1957–2009 and (b) 2010–2022. Fishing area hotspots around Curaçao for two time periods: (c) 1957–2009 and (d) 2010–2022. (e) Within-hotspot mean (±SE) shark species richness for both time periods (present 2010–2022, past 1957–2009), $*p<0.05$. (f) Mean number (±SE) of fishers fishing within shark species richness hotspots for both time periods (present 2010–2022, past 1957–2009), $*p<0.05$.

a shark species richness hotspot was identified was 6.40 km in 2010–2022, compared to a slightly shorter maximum distance of 4.95 km in 1957–2009. The likelihood of a hotspot occurring was 4.3 times higher during 1957–2009 compared to 2010–2022. This pattern is supported by a significant decrease in mean shark species richness within hotspots between the two time periods ($Z=160$, $p=0.03$). During 1957–2009, the mean number of shark species within a hotspot was 7.44 ± 1.00 (mean ± s.e.), which decreased to 3.00 ± 1.18 species during 2010–2022 (Figure 3e). Despite this overall decline, all shark species, except the blue shark (*Prionace glauca*), were observed in both time periods. However, while 19 hotspots scored a shark species richness of 13 between 1957 and 2009, only two hotspots reached this level of richness between 2010 and 2022, marking a decrease of over 90%. Noteworthily, mean species richness may be slightly underestimated, as hammerhead sharks were grouped rather than considered individual species.

Within shark species richness hotspots, the mean number of active fishers increased significantly over time ($Z=417$, $p<0.001$). While between 1957 and 2009, a mean of 2.86 ± 0.23 fishers fished within shark richness hotspots; this number increased to 5.14 ± 0.49 fishers between 2010 and 2022 (Figure 3f). Further, we observed a noteworthy change in the use of electric reels ($p<0.001$, $n=19$). While only 11% ($n=2$) of surveyed fishers reported using electric reels in the past, 58% ($n=11$) of surveyed fishers use electric reels in the present. Conversely, the traditional use of handlines remained consistent over time, with 18 out of 19 fishers (95%) reporting using it in both periods. Moreover, the mean duration of fishing trips in hours did not significantly change over time ($V=88.5$, $p=0.81$, $n=19$). Fishing trips lasted 8.61 ± 0.85 h on average in 1957–2009 and 8.40 ± 0.79 h in 2010–2022. Similarly, the monthly days at sea did not differ significantly between time periods ($V=29$, $p=0.14$, $n=17$). On average, fishers spent 15.0 ± 2.48 days at sea each month in 1957–2009 compared to 11.67 ± 1.93 days between 2010 and 2022.

3.3 | Socioeconomic Perspectives

Of the 21 surveyed fishers, 12 reported catching sharks during their careers. Among these, most indicated that they sell shark catches and meat and/or liver oil (1957–2009: 57%, 2010–2022: 64%) or use them for personal consumption (1957–2009: 64%, 2010–2022: 43%). A smaller proportion of fishers reported releasing sharks after capture, both in 2010–2022 (28%) and in 1957–2009 (36%). Even fewer fishers shared their catches with the community or relatives, with 14% of fishers doing so in 2010–2022 and 21% in 1957–2009. Notably, fishers were allowed to select multiple outcomes for their catches. Except for one surveyed fisher who admitted catching sharks 'for the thrill of it', the majority of fishers stated that they do not intentionally target sharks. Most described sharks as a nuisance, noting that catching them is exhausting and often results in broken or damaged fishing gear. Many fishers explained that they typically land a shark to avoid gear loss, rather than cutting the fishing line. In the past, shark meat was commonly used in a traditional dish called *Kari Kari*. However, according to surveyed fishers, this dish has lost popularity among younger generations, leading to decreased demand for shark meat. Despite this, some fishers expressed a preference for selling mako shark (*Isurus oxyrinchus*) meat, which resembles wahoo (*A. solandri*) and fetches higher prices. Fishers also admitted to selling shark meat disguised as other types of fish, such as grouper. They also voiced a particular dislike for Atlantic nurse sharks (*Ginglymostoma cirratum*), stating that there is no consumer demand for their meat and thus they are difficult to sell. While most fishers primarily sell shark meat, there has been a recent rise in demand for shark liver oil, which is believed by some to have medicinal properties, including the ability to cure diseases like cancer. Only one fisher mentioned selling shark fins to restaurants, emphasising that this practice is relatively rare on the island.

3.4 | Management Perceptions

Of the 19 fishers who responded to whether protecting the ocean and its species is important, the majority (90%, $n=17$) agreed (Figure 4a). Contrarily, 57% ($n=11$) of those fishers did not support the idea that sharks need protection in Curaçao (Figure 4b). Among those, most fishers stated that they perceive Curaçao's shark population as healthy and that sharks are not targeted by Curaçaoan fishers. The 43% of fishers ($n=8$) who endorsed shark protection acknowledged their ecological importance and expressed concerns about their disappearance. Of the 19 surveyed fishers, 84% ($n=16$) did not feel included in current fishery management decisions (Figure 4c). In comparison, out of 14 fishers who responded to the question of whether they would like to be more involved in management decisions, 86% ($n=12$) expressed their desire for inclusion. All surveyed fishers ($n=24$) expressed interest in learning about the results of the study. This request was followed up on as described under Section 2.2.

4 | Discussion

Using FLEK, we demonstrated a significant decline in shark species richness hotspots around the island of Curaçao, Dutch Caribbean, over two time periods: 1957–2009 and 2010–2022. These hotspots exhibited a sharp reduction in the average number of shark species, alongside a significant rise in the number of active fishers and increased use of electric reels. The most species-rich hotspots declined by 90%. Most fishers perceive the local shark population as healthy and not requiring protection. Shark catches are reportedly mainly incidental, but landings are frequently sold or consumed. Moreover, local fishers feel largely excluded from fishery management and expressed a strong desire for greater inclusion in the future.

4.1 | Temporal Decline of Shark Hotspots

The decline in shark distribution and species richness presented in our study confirms existing anecdotal evidence (Van Beek et al. 2012). Personal and incidental observations suggest a drastic

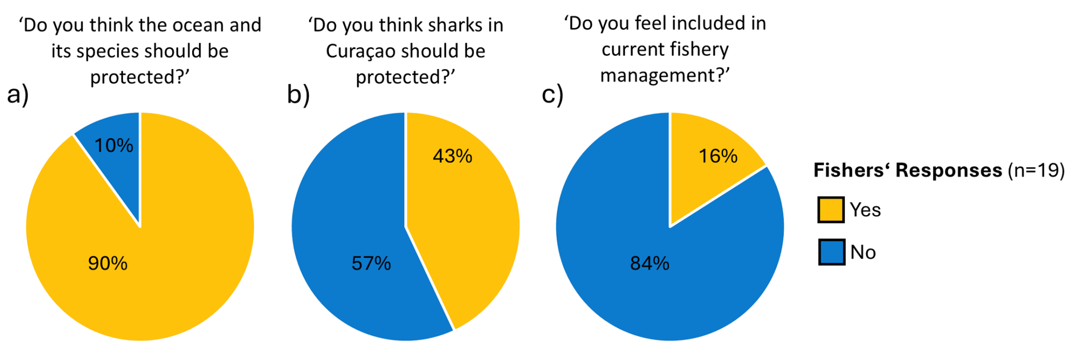

FIGURE 4 | Overview of fishers' responses ($n=19$) to the question (a) whether the ocean and its species should be protected, (b) whether sharks should be protected in Curaçao and (c) whether they feel included in current fishery management.

decline in sharks in the Dutch Caribbean since the 1940s (Van Beek et al. 2012). In line with our results, a previous compilation of catch data showed reductions in shark landings from handline fishing between 1905 and 2016 and spearfishing between 1950 and 1990 (Vermeij et al. 2019). Moreover, Zaneveld (1962) noted increased shark landings in Curaçao between 1908 and 1957 and Paddack et al. (2009) reported declines in Caribbean reef fish since 1955, corresponding with the beginning of our timeline. Within the Greater Caribbean, a broad-scale absence of sharks on reefs has been reported since 1993 (Ward-Paige et al. 2010). Notably, the EEZ of Curaçao borders the EEZ of Venezuela, the second-largest shark fishing nation in the Caribbean (Talwar et al. 2022). The reported peak of shark catches in Venezuela's EEZ in the early 1990s (Talwar et al. 2022) and the reduced species diversity of Venezuela's shark catches (Tavares and Arocha 2008) expectedly align with our results, given the mobile nature of many shark species (Lascelles et al. 2014; Heupel et al. 2015). Overall, our findings align with the global trend of declining elasmobranch populations (Pacoureau et al. 2021; Dulvy et al. 2021; Simpfendorfer et al. 2023), highlighting its local manifestation in the Dutch Caribbean.

We identified significant shark species richness hotspots around the western and eastern tips, and along the northern coast of Curaçao, with an average of three shark species present since 2010. A 2017 study using Baited Remote Underwater Video (BRUV) systems recorded six shark and ray species, primarily around the eastern tip of Curaçao (Winter and de Graaf 2019), partially validating our findings, as this area also featured shark species richness hotspots. Notably, the northern coast, where most hotspots were identified, was not part of the BRUV sampling area. Additionally, Winter and de Graaf (2019) noted two shark species around the neighbouring island of Bonaire, while other studies reported a complete absence of sharks on the reefs of Curaçao and Bonaire (Sandin et al. 2008). In contrast, Venezuelan catch records from 2003 listed up to 25 shark species (Tavares and Arocha 2008). These studies provide total species counts, whereas we present average richness within specific hotspots. In both time periods (1957–2009 and 2010–2022), hotspots with a maximum species richness of 13 shark species were identified. However, since 2010, these rich hotspots have decreased by over 90%, suggesting a marked spatial and temporal decline in shark diversity. This decline may result from reduced individual shark numbers, leading to fewer observations at particular sites. Species richness and biodiversity are influenced by the relative abundance of shark species over time (Brunnschweiler et al. 2014; Espinoza et al. 2014). As we did not analyse species-specific abundances, it remains unclear to what extent individual species have contributed to this spatial shift.

Since 2010, the average number of fishers operating in designated shark hotspots has increased, yet shark observations have declined. If shark populations had remained stable, an increase in fishers would likely have led to more shark observations. Therefore, the decline in observations suggests an actual decrease in the shark population. Globally, overfishing is the main cause of shark declines (Davidson et al. 2015; Dulvy et al. 2021; Pacoureau et al. 2021). While the spatial distribution and abundance of fishing hotspots around Curaçao stayed consistent, this may not accurately reflect the level of fishing pressure. Qualitative changes, such as the increased use of electric reels, enhance the efficiency and productivity of artisanal fisheries (Johnson 2006). The extent to which this affects the assessed species is likely low, as electric reels enable effortless deep-sea fishing (Dilrosun 2022) and thus may have an increased impact on other shark species such as Cuban dogfish (*Squalus cubensis*). However, the number of fishers in Curaçao has dropped by over 70% since 1959, while the total annual catch has decreased by only 8% (Vermeij et al. 2019), which suggests additional technical evolutions not documented here. Next to local fishing pressure, the connectivity to Venezuela's EEZ, with its significant catch and by-catch reported by Venezuela's longline fishery (Arocha et al. 2002; Arocha et al. 2016; Tagliafico et al. 2021), must be considered in our causality assessment between overfishing and the demonstrated shark diversity decline.

While our approach provides valuable insights, it is important to acknowledge its limitations. FLEK relies on memory, which can introduce recall bias, particularly for older time periods compared to more recent ones (O'Donnell et al. 2010; Damasio et al. 2015). Additionally, FLEK is inherently subjective, influenced by individual experiences and personal perceptions (Carr and Heyman 2012). However, despite these limitations, FLEK has been shown to provide reliable ecological data that aligns with independent scientific assessments (Silvano and Valbo-Jørgensen 2008; Lima et al. 2017). As such, it remains a crucial tool for assessing long-term ecological trends in data-limited regions, offering historical insights that conventional scientific methods cannot capture (Johannes et al. 2008; Damalas et al. 2015).

Similarly, we must include the possible role of other anthropogenic pressures in our interpretation. Across the Caribbean region, rising human population densities have been associated with the disappearance of reef sharks (Stallings 2009; Ward-Paige et al. 2010). Since 1995, Curaçao's population nearly doubled, and its tourism industry has grown significantly (CTB 2024). This has led to poor water and waste management practices, severely polluting local marine ecosystems (Waitt Institute 2018; Mulderij-Jansen 2023; Peterson 2023). Changes in seawater quality and other abiotic factors due to climate change have been shown to influence shark movements and habitat use (Schlaff et al. 2014) and thus possibly affect the occurrence of hotspots. Overall, the extent of anthropogenic pressures, including overfishing, and their contribution to the here demonstrated shark diversity decline remain speculative and await further research.

In addition, we acknowledge the limited sample size of 21 fishers in our study, which may not fully capture the local ecological knowledge across the entire fishing community of Curaçao. While estimates of the fisher population vary (Vermeij et al. 2019; Dilrosun 2022; FAO 2024b), we believe this sample offers valuable insights into a subset of active, income-generating fishers and their interactions with shark species. Further, it is important to note that this study does not aim to assess shark population trends. Rather, we compare species presence across two broad time periods, using fishers' knowledge to explore potential shifts in perceived shark diversity. Given the exploratory nature of this study, we view our findings as indicative rather than definitive. We encourage future research to build on this work by engaging more broadly with the local fishing community and conducting complementary scientific studies to further explore shark diversity and draw more definite conclusions for their future management.

4.2 | Socioeconomic Perspectives and Management Inclusion

Our findings confirm that most Curaçaoan fishers do not actively target sharks but retain incidental catches for sale or personal consumption. This aligns with previous reports (Van Beek et al. 2012), noting that sharks are generally an undesired catch. Instead, fishers often land sharks due to concerns over gear loss and the associated economic impact—a motivation echoed in our study and earlier documentation (Van Beek et al. 2012). However, one fisher reported specifically targeting sharks. While this represents a small minority in our sample, it underscores the importance of considering the diversity of targeted fishing practices, even if uncommon, in future management approaches. Moreover, understanding the drivers of shark mortality is essential for tailoring effective conservation strategies. For instance, while economic hardship is the main driver of illegal shark landings in fisheries in countries like Indonesia or Peru (Eriksson et al. 2019; Booth et al. 2021; Guirkinger et al. 2021), factors such as gear selectivity may dominate in other fisheries (Tolotti et al. 2015). While our study does not include detailed economic figures, such as income from shark landings, the qualitative data provide valuable insights into the presence—or absence—of broader socioeconomic drivers and motivation behind shark fishing in Curaçao. Understanding socioecological complexities and including the perspectives of those groups ultimately affected by fishing restrictions—local fishing communities—is inevitable to conservation success (Giakoumi et al. 2018; Grorud-Colvert et al. 2021). While our study does not provide detailed economic figures, such as income generated by shark landings, the qualitative data collected in our study helps to understand the presence—or absence—of socioeconomic drivers and motivations regarding shark fishing.

In Curaçao, fishers currently feel excluded from fishery management yet express a strong desire to participate in future decision-making processes. This sentiment mirrors findings from a previous study which highlighted environmental awareness and support for management among Curaçaoan fishers (Debrot and Nagelkern 2000). During fieldwork for this study, Curaçaoan fishers demonstrated openness, communicative engagement and cooperation. Including fishers in the design and implementation of management strategies for sharks is particularly crucial given that most fishers do not perceive shark conservation as necessary, which may indicate shifting baselines among fishers (Baum and Myers 2004; Soga and Gaston 2018). Involving fishers as active stakeholders could facilitate mutual understanding while strengthening their sense of responsibility and ownership over conservation efforts (Mikalsen and Jentoft 2001; Berghöfer et al. 2008; Pita et al. 2010). Future research on fishers' responses to FLEK-based studies that contradict their perceptions could provide valuable insights into the behavioural impact of such findings and offer a deeper understanding of alternative explanations for population declines. This study along with others (Colloca et al. 2020; Barbato et al. 2021; Karnad 2022) demonstrates the value of engaging local fishers to gain ecological insights into historical species trends, especially in regions where inconsistent and incomplete landing records have impeded scientific assessments and baseline setting (Lindop et al. 2015). Establishing a strong relationship among fishing communities, researchers and decision-makers benefits all parties by providing novel data, fostering community trust and creating informed, inclusive and thus effective policies.

Data scarcity in complex small-scale fishery settings poses a major challenge to the conservation of endangered species like sharks and rays. By leveraging FLEK in Curaçao's data-limited small-scale fishery, we were able to quantify a significant historical decline in shark diversity and its spatial distribution, providing a valuable foundation for future evidence-based decision-making. While this shows the need for improved management of sharks in the waters of Curaçao, we emphasise that continued collaboration with the local Curaçaoan fishing community and future research is inevitable to ensure the success of future conservation efforts.

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Ethics Statement

Internationally recognised standards to protect the data of participating fishers were followed, conforming to the regulations and guidelines of the ethics committee of the University of Groningen. To ensure the fishers' anonymity, the collection of sensitive personal data was limited as best as possible. Participants were informed about the project's goal, and their voluntary and informed consent was obtained before every interview. Only when consent was given, the interview was audio recorded for subsequent transcription. Before publication, the study's results were communicated to fishers, who had the opportunity to respond to the outcome.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section.