Received: 1 September 2022 | Revised: 15 February 2023 | Accepted: 12 June 2023

DOI: 10.1002/aqc.3981

RESEARCH ARTICLE

WILEY

Interdisciplinary science and fishers' local ecological knowledge of sawfishes in the Yucatán Peninsula

Nadia T. Rubio-Cisneros[1,2,3] | Ilse A. Martínez-Candelas[3,4] | Diana Ordaz-García[3,5] | Juan C. Pérez-Jiménez[6] | Nayeli G. Jiménez-Cano[7,8] | Jeffrey B. Glover[9] | Brianna K. Montes-Ganzon[3,10] | Gabriel Ruiz-Ayma[1,3] | José I. González-Rojas[1]

[1]Laboratorio de Biología de la Conservación y Desarrollo Sustentable de la Facultad de Ciencias Biológicas, Universidad Autónoma de Nuevo León, Monterrey, Mexico

[2]Center for Marine Biodiversity and Conservation, Scripps Institution of Oceanography, University of California San Diego, San Diego, California, USA

[3]Mar Sustentable Ciencia y Conservación, Monterrey, Mexico

[4]School of Environmental Studies, University of Victoria, Victoria, British Columbia, Canada

[5]Facultad de Ciencias, Universidad Nacional Autónoma de México, Ciudad de México, Mexico

[6]Departamento de Ciencias de la Sustentabilidad, El Colegio de la Frontera Sur, Lerma, Mexico

[7]Facultad de Ciencias Antropológicas, Universidad Autónoma de Yucatán, Mérida, Mexico

[8]UMR 7209 Archéozoologie - Archéobotanique, Sociétés, pratiques et environnements, Muséum national d'Histoire naturelle, Paris, France

[9]Department of Anthropology, Georgia State University, Atlanta, Georgia, USA

[10]College of Science and Engineering, Seattle University, Seattle, Washington, USA

Correspondence
Nadia T. Rubio-Cisneros, Miguel Hidalgo #920, Cozumel, Quintana Roo, Mexico. C.P. 77667.
Email: nadia@marsustentable.org

Funding information
Save Our Seas Foundation; The Rufford Foundation

Abstract

1. Our knowledge of sawfishes remains scant for Latin America. *Pristis pristis* (largetooth sawfish) and *Pristis pectinata* (smalltooth sawfish) are critically endangered. In the Yucatán Peninsula (YP), *P. pristis* and *P. pectinata* inhabit coastal landscapes.
2. A total of 290 surveys of fishers' local ecological knowledge (LEK), including a geospatial component, were collected; 74 literature sources and available archaeological data for the region were reviewed.
3. Interdisciplinary results show the following: the common past presence of sawfishes, their cultural significance for coastal societies, and the contemporary absence of sawfishes in coastal areas where they existed historically; sightings of juveniles were only documented by elder fishers, and only two recent narratives mention sawfishes caught incidentally 5 years ago.
4. Geospatial results provide evidence for 52 geographic sites where sawfishes were common in the YP.
5. Results support the development of research methodologies to study human–nature interactions integrating LEK. This matters in the YP, where sociocultural values and landscapes have changed rapidly through increasing tourism development and human overcrowding.
6. The results can help conservation managers understand the past presence and contemporary loss of sawfishes, and their habitat, and contribute to understanding the defaunation of megafauna in the YP through time. This is critical for tourism and fishery ecosystem services on which communities of the YP rely for their economies.

KEYWORDS
megafauna, rays, sawfishes, small-scale fisheries, traditional knowledge, Yucatán Peninsula

1 | INTRODUCTION

Sawfishes (family Pristidae) have an elongated rostrum with side teeth, resembling a saw (Bonfil & Abdallah, 2004). The peculiar form and large size of sawfishes has granted them sociocultural significance in the Maya area since pre-contact times. They have been an important fisheries resource as well as having culinary and medicinal uses, along with use as cultural trophies and in ritual practices (Gonzalez, 2005; Bonfil et al., 2017; Bonfil et al., 2018). Historically, sawfishes were common in food webs of estuarine, lagoonal, and coastal habitats spanning tropical and subtropical latitudes across the globe (French & Naylor, 2018; López et al., 2021). Today, however, sawfishes (*Pristis* spp.) are among the most threatened ray families (Gómez et al., 2014; Dulvy et al., 2014a; Dulvy et al., 2014b).

Anthropogenic threats affect sawfishes globally because their life cycle is associated with coastal habitats, which have faced extensive human exploitation in recent human history (Simpfendorfer, 2001; Lotze et al., 2006; Carlson, Wiley & Smith, 2013; Dulvy et al., 2014a; Bonfil et al., 2018; Koubrak, 2018). As a result, existent sawfish populations are small, isolated, and fragmented (French & Naylor, 2018).

Today, our knowledge of sawfishes remains scant for many regions of Latin America (Fernández, 2017). Here, sawfishes (e.g. the largetooth sawfish *Pristis pristis* and the smalltooth sawfish *Pristis pectinata*) face extirpations in coastal habitats, mainly through overfishing. In Mexico, sawfishes were once abundant in bays, estuaries, river mouths, and islands of the Pacific, the Gulf of Mexico, and the Caribbean coasts of the Yucatán Peninsula (YP). Two species are reported for Mexico: *P. pristis* in the Pacific and Atlantic coasts (common in the states of Colima, Chiapas, Campeche, and Quintana Roo) and *P. pectinata* in the Atlantic coast (common in the states of Campeche, Quintana Roo, and Tabasco) (Bonfil et al., 2018).

More recent interdisciplinary research on coastal fishery exploitation and the collection of fishers' local ecological knowledge (LEK) in Campeche and Quintana Roo (Atlantic coast) and archaeological records show the historical presence of sawfishes on this coast (Jiménez & Götz, 2011; Glover, Rissolo & Mathews, 2013; Glover et al., 2014; Jiménez, 2017; Jiménez & Sierra, 2018; Rubio et al., 2019; Martínez et al., 2020; Ojeda, 2020) (Figure 1a). However, in the last 60 years, coastal towns in Quintana Roo and Campeche have faced increasing ecological challenges associated with increased fishing efforts, oil exploitation, unplanned tourism development, and human overcrowding. These interconnected factors have led to biodiversity and habitat loss in the region (Wiese, 2000; Juárez, 2002; Varns et al., 2018; Rubio et al., 2018; Rubio et al., 2019; Bravo et al., 2021; Appendix S1).

As in other countries, in Mexico sawfishes are part of a sociocultural heritage that is fading in human memory because of their absence in coastal landscapes. In an effort to combat this, contemporary environmental education efforts are underway to promote people's knowledge of sawfishes (Rubio et al., 2021; Martínez, 2022; Appendix S2). This article combines fishers' LEK (as defined by Charnley, Fischer & Jones, 2007) with literature and archaeozoological data analyses to document the historical presence of sawfishes in the YP. The LEK of fishers is a powerful and informative tool that provides historical data on species for which the biological or ecological record is scant (Turvey et al., 2010; Leeney & Poncelet, 2013; Leeney, 2017; Rubio et al., 2017; Leeney, Mana & Dulvy, 2018; Rubio et al., 2019; Martínez-Candelas et al., 2020). It is a key part of an interdisciplinary approach that addresses the problem of coastal exploitation and has proven successful in understanding changes in biodiversity (e.g. McClenachan & Cooper, 2008; Rubio et al., 2017; Rubio et al., 2019). This approach gained momentum with Pauly (1995) and with Jackson (1997). These studies provided a long-term perspective on the impacts that fishing and human disturbances have had on coastal ecosystems and argued for 'shifted baselines' related to the spatiotemporal availability and abundance of species.

This article documents the spatiotemporal presence of the family Pristidae on the YP by employing interdisciplinary methodologies to study long-term human–nature interactions. In particular, the collection of LEK is carried out in towns where sociocultural values are swiftly changing because of increasing fishing and tourism development (García et al., 2004). This is knowledge that will soon be lost as younger fishers and coastal inhabitants live in a world where these once common and majestic fishes are largely gone.

2 | STUDY AREA

The YP faces increasing tourism-based economic development, and in the case of coastal Campeche there is the added threat from oil exploitation. These factors have triggered socio-environmental issues related to the availability of water, living space, biodiversity loss, pollution, and overfishing (Wiese, 2000; Herrera et al., 2004; Carte et al., 2010; Leatherman, Goodman & Stillman, 2010; Rubio, Murad & Rovira, 2010; Leal et al., 2013; Hernández et al., 2015; López, 2015; Rubio et al., 2018; Suchley & Alvarez, 2018). As a result, mangroves, reefs, and coastal lagoons of the YP face threats to their ecological functions, limiting the delivery of critical ecosystem services, e.g. fisheries, protection from storm surges, and biodiversity (Figure 1a) (Rubio et al., 2019). This study focuses on four research areas: Holbox, on the north coast of the YP; Isla Mujeres and Cozumel, on the east coast of the YP; and the Laguna de Términos area of southern Campeche, on the west coast of the YP.

Holbox is an island of 42 km in length and 2 km in width on the north coast of the modern state of Quintana Roo that forms the northern portion of Laguna de Yalahau (275 km^2). The lagoon, part of the Yum Balam Natural Protected Area, is surrounded by mangroves and is a breeding ground for elasmobranchs (Hueter et al., 2007; Herrera & Morales, 2010). Holbox has recently transformed into a tourist hotspot that faces anthropogenic threats related to illegal fishing, excessive refuse, human migration, habitat fragmentation, and water pollution (Rubio et al., 2019) (Figure 1a).

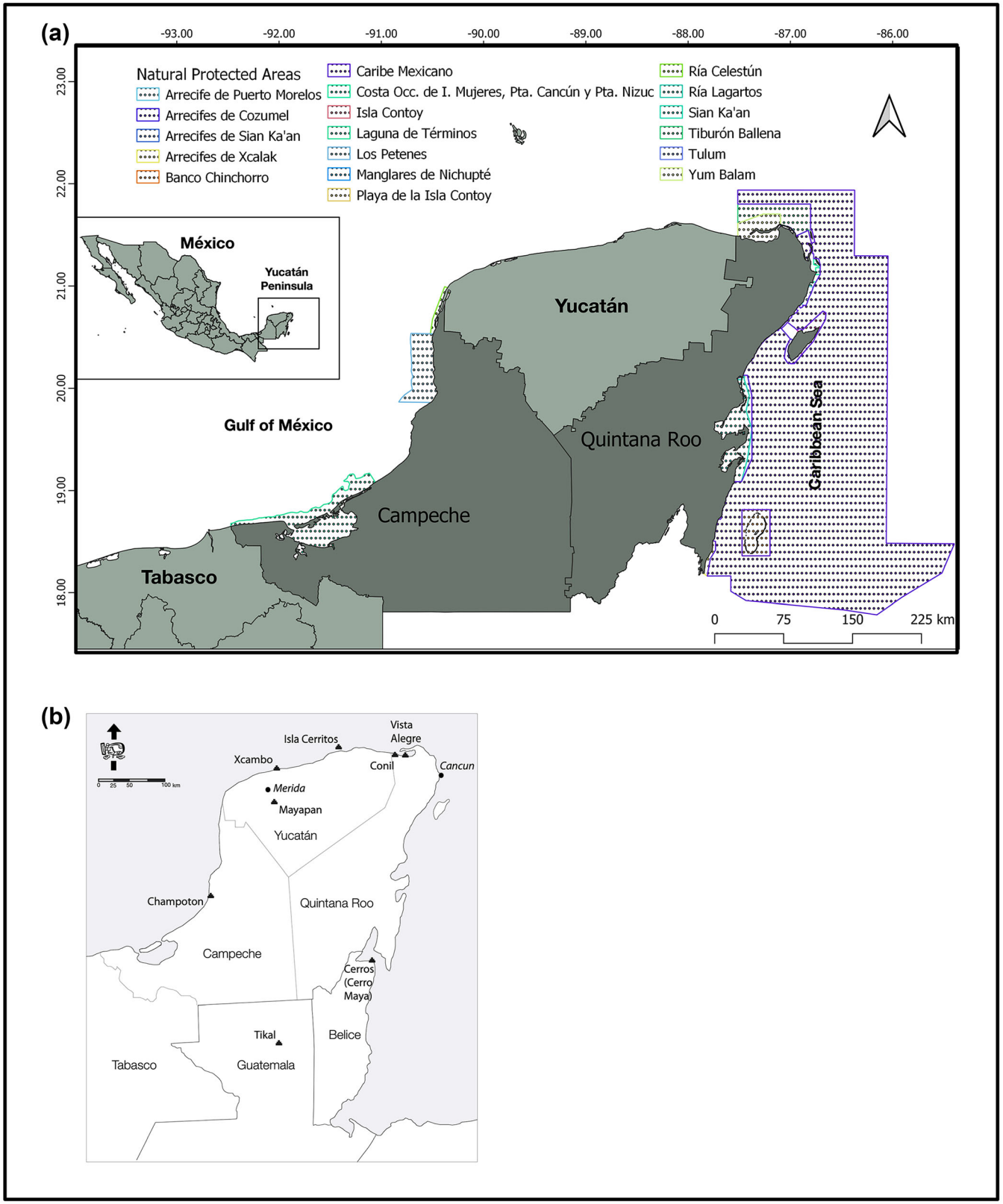

FIGURE 1 (a) Study area. The figure shows the states of Campeche and Quintana Roo, where our study took place, in the Yucatan Peninsula. The polygons represent the different natural protected areas in the region. (b) Archaeological sites of this study.

Isla Mujeres is approximately 7 km in length and 650 m in width, and lies just east of Cancun. The reefs between Isla Mujeres and Cancun have been a flora and fauna reserve since 1973 and became the national park 'Parque Nacional Costa Occidental de Isla Mujeres, Punta Cancún y Punta Nizuc' in 1996 (CONANP, 2019). Multi-specific, small-scale fisheries occur here, and the proximity of the island to Cancun has made it a target for tourism, with about 944,477 tourists visiting in 2019 (SEDETUR, 2019). The site is renowned for its recreational fishing of bill fishes and whale shark ecotourism.

The large island of Cozumel is 48 km in length and lies 17 km offshore from Playa del Carmen. Cozumel's reefs belong to the Mesoamerican Barrier Reef System, which is considered Critically Endangered by the International Union for Conservation of Nature (IUCN) Red List of Ecosystems (Kramer, Richards & McField, 2002). The island has the Arrecifes de Cozumel National Park (home to approximately 85% of Cozumel's dive sites) and the Flora and Fauna Protection Area of Cozumel Island in the north. A strong diving industry has existed on the island since the 1970s, and Cozumel is a hub for the cruise industry, with approximately 4.5 million cruise ship tourists in 2019.

Campeche state has a continental and a broad carbonate platform belonging to the Campeche Bank, an area of high primary productivity that supports diverse marine fauna. Campeche has a long history of fishing, and the shark and ray fisheries are still active today (Pérez & Méndez, 2015; Newman, 2016; Jiménez, 2019) (Figure 1; see Appendix S3). In addition, oil exploitation has taken place in the state since the 1970s. Laguna de Términos is a natural protected area in the south-west portion of the state, and the largest coastal lagoon in south-east Mexico. Like Laguna de Yalahau, it also serves as a nursery area for elasmobranchs (Bonfil, 1997; Kemp et al., 2016).

3 | METHODS

3.1 | Semi-structured fisher surveys with a geospatial component and open interviews

Semi-structured fisher surveys with a geospatial component and open interviews were collected on Holbox, Isla Mujeres, and Cozumel, along with open interviews with key community members (e.g. native residents, community leaders, and people involved in conservation) (Figure 2). A snowball sampling approach was used to identify people to interview on all study sites (Goodman, 1961). On Holbox Island, pilot interviews with fishers occurred early in our study in 2015. This allowed us to tailor the semi-structured fisher surveys with a geospatial component used to gather LEK related to historical and current small-scale fisheries, fishing grounds, species caught, changes

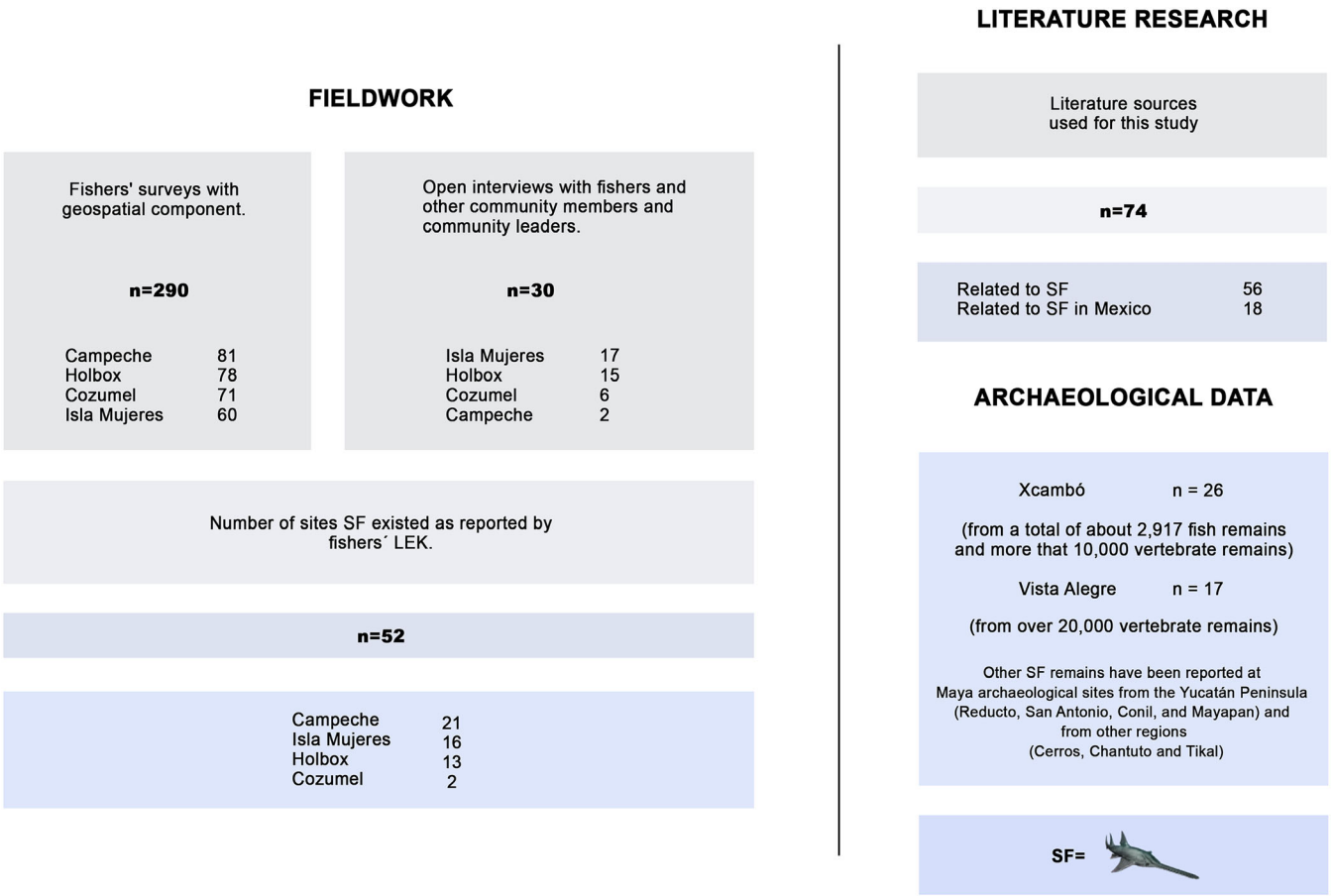

FIGURE 2 The figure shows the different data types collected at the study sites for this study.

in fishing technology, and perceptions of the future of fisheries (for the results of this semi-structured survey, see Rubio et al., 2019). Focus groups were held with Holbox fishers (2015–2018) and the results were used as a tool to account for biases in the results of later surveys (Grant & Berkes, 2007).

On Isla Mujeres and Cozumel, pilot interviews were conducted in 2021. During the pilot interview process, we used field guides with photographs to help clarify the species that the fishers were mentioning. Semi-structured fisher surveys with a geospatial component and open interviews acknowledged local customs (Bunce et al., 2000; Moreno et al., 2010; Rubio et al., 2017; Rubio et al., 2019). Focus groups were also conducted on Isla Mujeres and Cozumel, but only three meetings were held with small focus groups of fewer than five fishers because of the COVID-19 pandemic.

In Campeche, pilot interviews occurred in four communities in 2018. Interviewees were asked to identify different elasmobranch species by their common Spanish or Mayan names from unlabeled photographs, based on the method of Jabado et al. (2015). The two *Pristis* spp. were grouped together, and a single photograph was used in the following interviews because few fishers were able to differentiate between images of these two species. The information collected included historical distribution, fishing gear from different time periods, and the last year and area where *Pristis* spp. were sighted or captured.

Despite some differences in the structure of the interviews among study sites, there were overlaps in the questions used, such as information on historical sawfish distribution and species caught through time. This allows for fruitful comparisons of the results from the different sites. Our field studies were approved by the Comité de Ética e Investigación (Ethics and Research Committee) from the Health Services in the state of Colima (CONBIOÉTICA-06-CEI-001-20200721).

3.2 | Documentation of species fished

Data on the species fished on Holbox, Isla Mujeres, Cozumel, and Campeche were gathered through the semi-structured fisher surveys with a geospatial component and were described to the lowest taxon possible (e.g. genus or family), based on Gallardo et al. (2014) and Humann & DeLoach (2014). For each of the study sites in Quintana Roo, over 40 species of aquatic fauna were obtained, including sharks, rays, bony fish, reptiles (sea turtles and crocodiles), crustaceans, bivalves, and marine mammals (dolphins and manatees). For Holbox, the species list was published by Rubio et al. (2019), and for Isla Mujeres and Cozumel, the authors are now working on publishing the species lists. The data are available upon request.

A fishers' species identification workshop was held on Holbox in December 2015 and July 2016, where fishers associated the common names of species with their scientific name using published fish guides. On Isla Mujeres and Cozumel, given that our fieldwork occurred in 2021 during the COVID-19 global pandemic, species identification questions were addressed with fishers on a one-to-one basis. In addition, books and photographs were used to clarify doubts regarding the species documented in the surveys.

In Campeche, species documentation was obtained with face-to-face interviews followed by two fieldwork seasons, from March to August 2018 and from April to May 2021. During the second fieldwork season, fishers identified the historical distribution of *Pristis* spp. in Laguna de Términos during five participatory mapping workshops. Additionally, in Campeche, fishers identified nine rays and 13 shark species.

3.3 | Literature sources

Literature sources are from online documents collected from: Web of Science; Google scholar; BASE (Bielefeld Academic Search Engine); CrossRef Metadata Search; Semantic Scholar; and WorldWideScience. This part of the research occurred during the COVID-19 pandemic, which limited visiting historical archives in Mexico City in person. DO-G reviewed the Archivo Nacional of the Universidad Nacional Autónoma de México (UNAM) online for historical records of sawfishes and visited the National Collection of Fishes of the Instituto de Biología at UNAM to search for sawfish literature.

3.4 | Collection of archaeozoological data

The archaeozoological data of marine faunal remains reported in this article came from excavations at Maya archaeological sites in the YP (Figure 1b). These include Conil and Vista Alegre (Quintana Roo), Xcambo, Isla Cerritos, and the interior sites of Mayapan (Yucatan) and Champoton (Campeche) (Götz, 2008; Jiménez & Götz, 2011; García & Götz, 2013; Jiménez, 2017; Jiménez & Sierra, 2018; Jiménez & Cobos, 2019; Ojeda, 2020; Jiménez, 2022). Other Maya sites where sawfish remains have been reported in the literature are Chantuto (Chiapas), Cerros/Cerro Maya (Belize), and Tikal (Guatemala) (Voorhies, 1976; Carr, 1986; Moholy, 2004).

The authors' own ichthyoarchaeological results and site information included in this article come from research conducted as part of the Costa Escondida Project (Glover et al., 2022) at Vista Alegre and Conil, the Xcambo Archaeological Project (Sierra, 1996; Sierra, 1997; Sierra, 1998), and investigations carried out at Reducto de San Antonio in Campeche (Jiménez, 2022). For identifications of archaeozoological remains, see Jiménez & Götz (2011), Götz (2008), Jiménez (2017, 2022), Jiménez & Sierra (2018), and Ojeda (2020). For this article, authors extracted sawfish information from the general databases of the different excavation sites and used geospatial tools to plot the historical occurrence of sawfish remains throughout the YP. The archaeological research was conducted with the permission of the Consejo de Arqueologia of Mexico's National Institute of Anthropology and History (INAH) (401.B(4)19.2015/36/2792, 401.1S.3–2017/670, and 401.15.3–2017/670).

3.5 | Spatial data collection on fishing grounds, assembly, and analysis

Data on sawfishes obtained from fisher surveys conducted at the different study sites were extracted from the fishers database, which included information on the taxonomic richness of sharks, rays, bony fishes, and sea turtles. Spatial data on the distribution of sawfishes were collected through semi-structured fisher surveys (Figure 3) and participatory mapping (Rubio et al., 2019). During the map test period, fishers identified the location and drew fishing grounds for several species exploited in their respective region (Eghenter, 2000; Moreno et al., 2010; Rubio et al., 2019). Once tested, printed maps were included in the fisher surveys to allow interviewees to draw fishing grounds. Fishers were asked about the historical distribution of sawfishes in individual interviews or during the participatory mapping exercises. The specific locations mentioned or marked by fishers were digitized and georeferenced for Campeche and Quintana Roo using QGIS 3.16 (https://qgis.org/en/site/). The minimum distance that most fishers travel to get to their fishing grounds was used as a reference to build an 8 km × 8 km grid, which enabled the quantification of sawfishes for each grid unit (Appendix S4).

4 | RESULTS

4.1 | Fishers' LEK

The number of interviews varied from 60 at Isla Mujeres to 81 in Campeche. Among study sites (Figure 3), Cozumel has the highest percentage of young fishers (37%), Holbox has the highest percentage of middle-aged fishers (49%), and Campeche has the highest percentage of elder fishers (69.1%). In addition, all study sites have 75% of fishers with more than 30 years dedicated to fishing, except Cozumel, with only 35%, and all the study sites have at least 50% native fishers. Finally, Campeche has the highest percentage of fishers who mentioned knowing, having seen, or fished sawfish (64%), and Cozumel has the lowest percentage (8%) (Table 1).

A total of 32 (41%) Holbox fishers mentioned knowing, having seen, or fished *Pristis* spp., and could identify the two sawfish species according to size (small and large) and coloration (light and dark). Fishers were asked if they had any rostrums at home to confirm the species, but no rostrums were documented. One of the main reasons cited by the elder fishers interviewed was the impact that Hurricane Gilbert had on the island in 1988. Many personal items related to the history of the island were lost, including sawfish rostrums. When elder fishers were asked to recall the number of teeth that these rays had, only one fisher who remembered an exceptional catch in the early 1980s answered. He recalls the sawfish had 32 teeth on each side of its rostrum, suggesting that it could be a smalltooth sawfish. This was a very relevant event in the fisher's life. He recalls that they were fishing for rays at Punta Mosquito, and the sawfish was entangled unexpectedly in the net. This was unexpected for him because of the rareness of sawfishes. It was a great catch as the fisher received a good payment for it (for further quotes see Table 2).

The results from Holbox reveal that sawfishes were a target or were caught incidentally (Table 3). Elder fishers mention that the white meat of the sawfishes was dried and salted and sold in Mexico

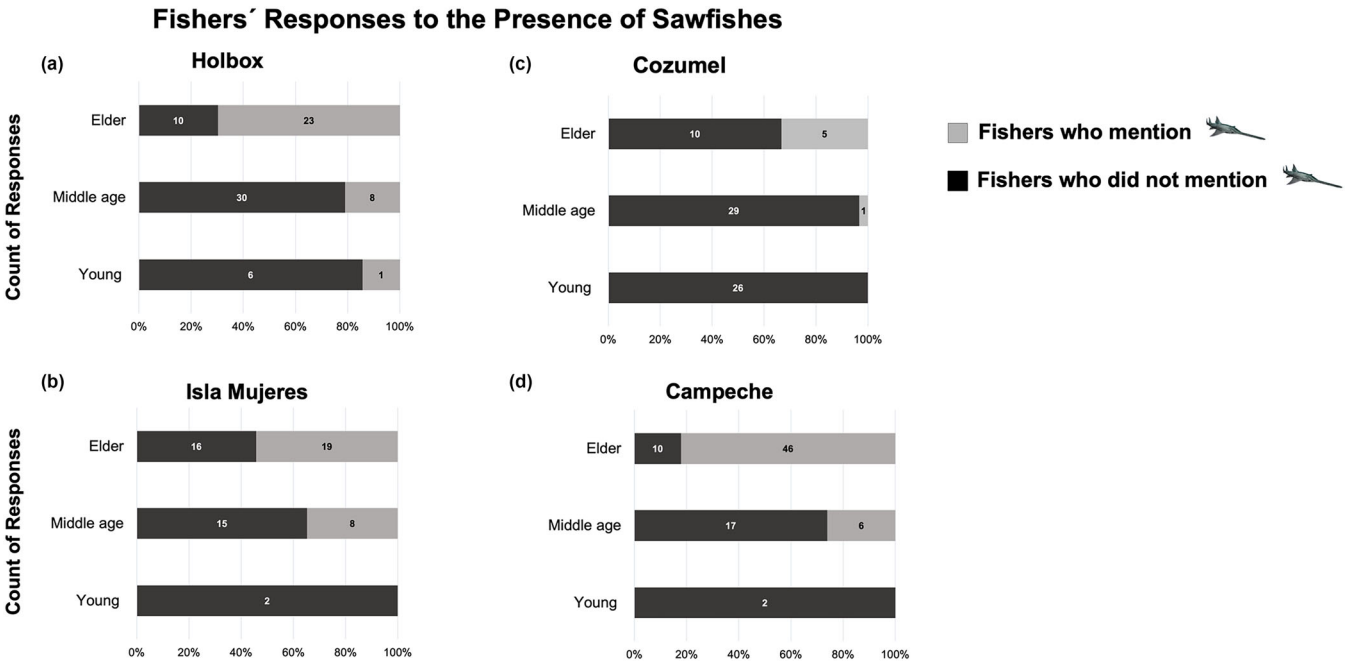

FIGURE 3 The figure shows fishers´ responses about the presence of sawfishes in the different study sites.

TABLE 1 Number of fishers interviewed by sampling sites and percentages of fishers by age class, fishers with >30 years of fishing at the study sites, fishers who were native to the study site, and fishers who mentioned sawfishes.

Study sites	Number of fishers	Percentage of fishers					
		Young (21–35 years)	Middle aged (36–59 years)	Elder (≥60 years)	≥30 years fishing at the study site	Native	Reported knowing, having seen, or having fished sawfishes
Holbox	78	9%($n = 7$)	49%($n = 38$)	42%($n = 33$)	86%	65%	41%($n = 32$)
Isla Mujeres	60	3%($n = 2$)	38%($n = 23$)	58%($n = 35$)	95%	50%	45%($n = 27$)
Cozumel	75	37%($n = 28$)	42%($n = 31$)	21%($n = 16$)	35%	72%	8%($n = 6$)
Campeche	81	2.5%($n = 2$)	28.4%($n = 23$)	69.1%($n = 56$)	75%	59%	64%($n = 52$)

Note: Native fishers are defined as people who were born at the site at which they were interviewed. This distinction helped provide a reference when observing and analysing how long non-native fishers have been living and fishing in the study sites. The non-native fishers have been fishing in the study sites for at least two decades.

TABLE 2 Fishers' quotes related to sawfishes on Holbox.

Year born	Age class	Fisher quote
1932	E	The sawfishes could be found in the sandy bottoms. We would use harpoons to catch them. They defended themselves with their saw. They also used their saw for feeding by shaking it in the water column to chop small sardines
1936	E	There were many types of sharks at Laguna de Yalahau (e.g. large sawfishes, the white ones, and the brown ones that are currently inexistent). Today there are no sharks either at the lagoon or offshore. Hammerheads were not so prevalent in the lagoon, but blacktip sharks and sawfish were prevalent
1936	E	In Laguna de Yalahau, we found two kinds of sawfish, medium and large. About 60 years ago, I saw huge ones ranging between 500 and 800 kg
1941	E	When I was 30 years old, I remember sawfishes in the river. We could catch three or four per week. Some extremely big were rare but existed as large as 4.5 m
1943	E	Laguna de Yalahau was like a 'nursery'. Lots of hammerhead sharks, bull sharks, blacktip sharks, and sawfish existed, but not anymore. The *cazon* (small shark species) were very abundant, and we could catch up to 500–700 kg per night. However, at that time, we were only about 12 boats fishing at Holbox
1943	E	We could find both kinds of sawfish, the light-coloured one and the darker one. Their saws and sizes were different
1943	E	The sawfish was caught using a harpoon. We could find them in the schools of sardines. It would move up and down throughout the water
1945	E	The river (referring to Laguna de Yalahau) used to have many bonnethead sharks. We could see schools of these but not anymore. We would also catch nurse sharks and sawfish with a harpoon. I have not seen a sawfish in the last 30 years. The quantity of the many small sharks that populated the river is not seen anymore
1946	E	For over 40 years, I have not seen sawfishes in the lagoon. There used to be large ones, almost one ton. We could see them moving through the bottom in groups of 10–15 animals
1949	E	There were sawfishes in the river: one had a small saw or spade; the other one had a larger spade
1950	E	There were lots of sawfish in the river. We catch them with a harpoon and put a bag on its saw to avoid being injured. Its meat was salted and sold in Mexico City and the USA.
1969	M	I caught sharks near Cabo Catoche when I was 15 years old. However, I never saw the big sawfishes

Note: E, elder fishers; M, middle-aged fishers.

City's markets as bacalao. In Mexico, bacalao is supposed to be made from imported Atlantic cod that is dried and salted and used to prepare a traditional Spanish dish. On Holbox, young fishers commented that they had not seen sawfishes swimming freely in the island's shallow waters and nearby places, where older fishers reported seeing them (Figure 4a,b). The main sites where elder and middle-aged fishers mentioned having seen, captured, or knew where sawfish existed were: the entrance to Laguna de Yalahau; Manchones de la Bocana; Punta Caracol; Punta Mosquito; La Ensenada; Laguna de Yalahau; Cabo Catoche; in front of the Holbox coast; and Isla Contoy.

On Isla Mujeres, 22% ($n = 6$) of the 27 fishers who mentioned *Pristis* spp. described the existence of two different sawfish species (Table 1). All responses came from elder fishers who identified more specific characteristics between the two types of sawfishes. For example, 'There are two types of sawfishes: the short-billed whitefish and the long-billed swordfish'; 'There was the white fish with the short and broad sword [referring to the rostrum] and the black

TABLE 3 Cultural use of sawfishes in the study sites based on the fisher surveys.

	Type of catch		Fishing gear				Types of use				
Cultural use of sawfishes	A Incidental or by-catch	B Target catch	C Harpoon	D Bows and arrows	E Specific nets for the species	F Nets for catching other species (incidental catch)	G Food	H Tool (raw for cleaning the floor)	I Ornament	J Trophy fish	K Relevant for cultural traditions, *c.*1900
Campeche	✓	✓	✓	✓	X	✓	✓	?	✓	✓	✓
Quintana Roo											
Holbox	✓	✓	✓	?	X	✓	✓	?	?	?	?
Isla Mujeres	✓	✓	✓	?	X	✓	✓	✓	?	?	?
Conil (?)											
Baluarte de San Antonio (?)							?	?	?		
Isla Cerritos (AD 800–1000)							✓				
Mayapán (AD 1050–1500)							✓				
Vista Alegre (?)											
Xcambó (AD 250–750)							✓		✓		✓

Note: ?, period unknown.

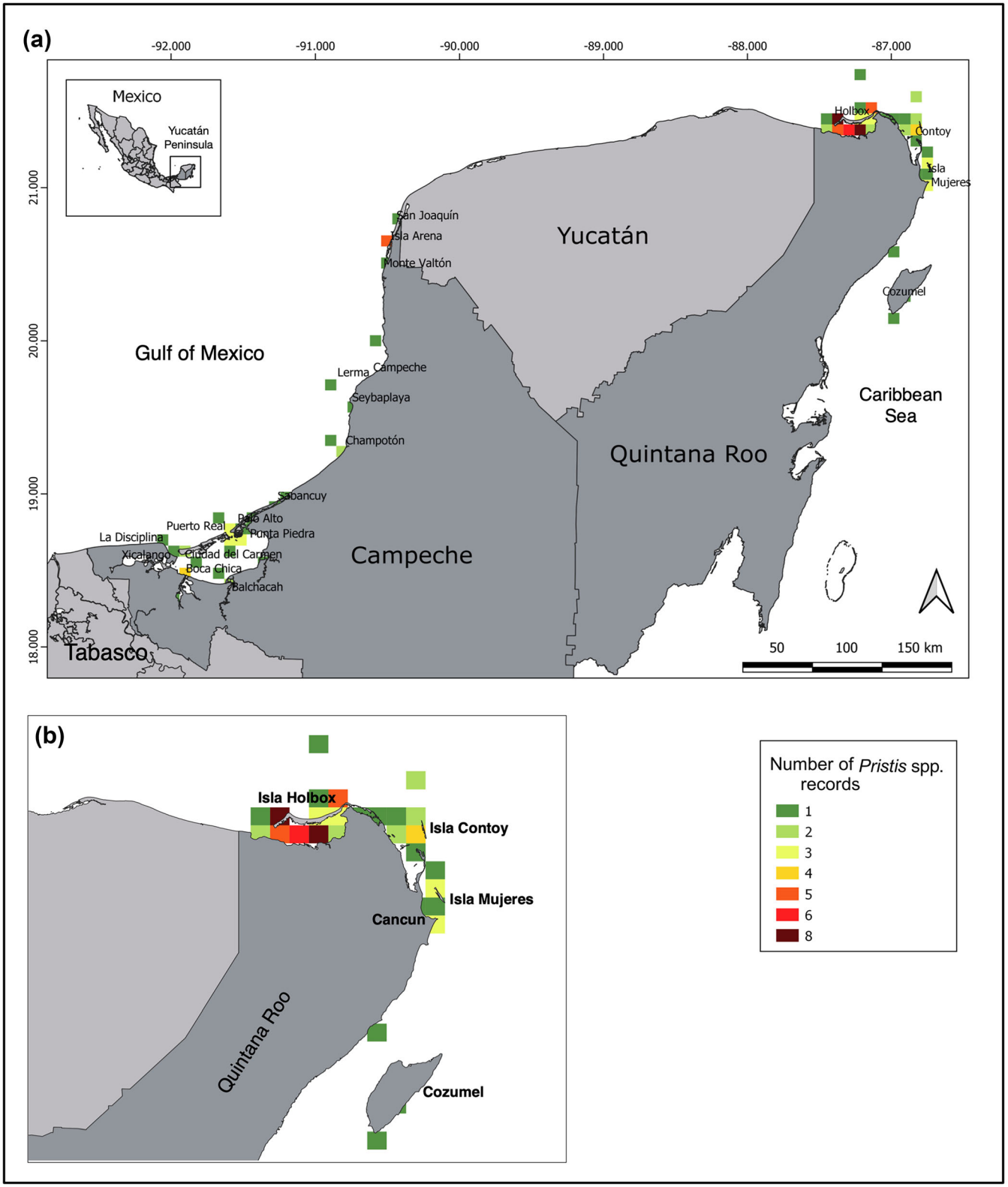

FIGURE 4 The figure shows the local ecological knowledge (LEK) responses from fishers throughout our study sites. (a) Responses for all study sites at Campeche and Quintana Roo. (b) Detail of the study locations of Quintana Roo, which are the islands of the Mexican Caribbean. The colours in the legend show the number of sawfishes documented.

sawfish with the long and narrow sword'. At Isla Mujeres, no rostrums were found, and the elder fishers did not recall the number of teeth that these rays had.

Two fishers from Isla Mujeres mentioned that 'Less than a year ago [meaning the year 2020], a fisher saw a sawfish between Cabo Catoche and Isla Contoy' and another fisher said that 'approximately five years ago, one sawfish was caught in a longline'(Figure 4; Table 4). An elder fisher, born in 1936, mentioned that they used the sawfish rostrums as a broom to sweep leaves (Table 3).

The main sites where fishers from Isla Mujeres mentioned having seen, captured, or known sawfishes lived there were: within 3 miles of Isla Mujeres; Faro Cancun; Laguna Nichupté; Arrecifes Noreste; Pasaje Tiburón; Cancún; Boca del Río Nichupté. The channel to enter Laguna Nichupté, where the hotel zone is, was an important site, as our interviewees mentioned sightings of juvenile sawfish there throughout the 1980s.

Of the 75 fishers interviewed on Cozumel, only 8% ($n = 6$) mentioned *Pristis* spp., and none could differentiate between the two species (Table 1). Of the six fishers who knew of *Pristis* spp., five saw them, and one said he knew about these sawfishes because his grandfather had seen them. Results from fishers' LEK from Cozumel about *Pristis* spp. Are scant. None of the fishers commented on the two types of sawfishes. The fishers who mentioned knowing about the sawfishes said that they had never caught one. The sites where fishers mentioned seeing sawfishes were: Punta Herrero, Punta Celarain (Punta Sur), and Chen Río. Chen Río is a historical fishing site on the south-eastern shore of Cozumel, where abundant lobster and grouper have been recorded previously. Similarly, Punta Celarain (Punta Sur) was quoted as having a rich population of fishes and lobsters as well as extremely clear water.

On Campeche, of the 81 fishers interviewed, 64% ($n = 52$) mentioned *Pristis* spp. Five fishers mentioned that two types of

TABLE 4 Fishers' quotes related to sawfishes on Isla Mujeres.

Year born	Age class	Fisher quote
1936	E	There are two types: the short-billed whitefish and the long-billed swordfish. We salted the meat. We used its saw as a rake for sweeping. There were no saws or spades on the island at that time
1941	E	It is a rare fish. We could see these fish from about 3 miles away. Between three and 10 sawfishes could be caught in the long line. About 5 years ago, one sawfish was caught
1946	E	We could see them in the sandy area of Isla Contoy, about 6 m deep. Commonly they were caught in the longline around the 1970s
1948	E	Those animals became extinct, and we never saw one more. There was the white fish with the short and broad sword and the blackfish with the long and narrow sword. Palo Bravo was a place where there were those animals
1948	E	Below the school of *esmedregal* (a type of fish), there was the whitefish. These animals grow a lot and weigh more than a ton. In Palo Bravo around 1970, we saw one. I was 18 years old. We were about 18 people on the boat, and we could not get the sawfish onto the boat
1949	E	Sawfishes were common in front of Isla Contoy in Bajo Blanco. We salted their meat
1950	E	That fish bury itself in the sand, and we could just see its eyes. I saw a sawfish by the pier by the second lighthouse. The sawfish was dozing. I remember that the sawfish got up and began moving its saw from side to side
1954	E	When I was about eight years old, I caught three small swordfish about 2 miles north east, towards the reefs
1955	E	There are no sawfishes anymore; there were before in the sandy areas
1958	E	I have no longer seen sawfishes for more than 25 years. There were two types, the light and the dark. In the Bay of Contoy, there were sawfishes around 1976 and 1978. They were in Bajo Blanco
1959	E	There were sawfishes to the north of Isla Contoy in the sandy area. There were few, and there were two different types
1961	E	There were indeed big sawfishes, and we could see them. They were brought to the beach because they came out caught in the nets and in the longline
1962	E	Less than a year ago, an acquaintance saw a sawfish between Cabo Catoche and Contoy
1962	E	In Laguna Nichupté, I saw broods of sawfishes along the channel; a bridge is attached to the hotel's zone. There, in the shallow areas of the seagrasses, we could see young sawfishes. Laguna Nichupté was also home to many species
1962	E	On top of the sawfish, there were always schools of jacks and cobias (fish species). That was a way we could locate sawfishes
1962	E	I saw a sawfish when I was 15 years old
1967	M	Sawfishes were known to be seen in a spot known as the 'sawfish spot', about 4 miles from here
1967	M	We captured sawfishes with a fish spear. When I was 18 years old, we caught one of about 200–300 kg
1971	M	An experienced shark fisher commented that he never saw sawfishes but knew some fishers from the island would fish them in the Bajo Blanco
1972	M	I saw a sawfish at the mouth of Laguna Nichupté
1974	M	Many years ago, the sawfish were caught in fishing nets

Note: E, elder fishers; M, middle-aged fishers.

sawfishes existed in the lagoons. For example, 'Peje Espada Chavache' has a narrower and larger sword (smalltooth sawfish) than the 'Peje Blanco' (largetooth sawfish), which has a wider and smaller sword. Table 5 shows some fishers' quotes regarding the two types of sawfishes and describes Campeche fishers' sightings of newborns and young sawfishes. In Campeche, compared with the other study sites, fishers' narratives frequently mentioned the abundance of young sawfishes (Table 6).

New information was recorded regarding the importance of sawfishes for cultural traditions and ornaments in Campeche. For example the rostrum was considered an ornament by locals. During the Holy Week (Easter is an important time for Christians), the people from Campeche ate the white meat of sawfishes. Also, young sawfish rostrums were used to make crosses. Fishers mentioned that wooden bows and arrows were used to catch young sawfishes, a new traditional fishing technique compared with those documented on Isla Mujeres and Holbox (Table 3).

Lastly, most of the fishers interviewed on Holbox (96%), Isla Mujeres (97%), and Cozumel (94%) responded that they know of some abundant species that are no longer so plentiful in the waters that they fish. These species include: coastal sharks, such as *Carcharhinus leucas* (bull shark), *Carcharhinus limbatus* (black tip shark), *Sphyrna tiburo* (bonnethead), and hammerheads (*Sphyrna* spp.); large groupers, such as *Epinephelus itajara* (Atlantic goliath grouper) and *Mycteroperca bonaci* (black grouper); parrot fishes; *Aliger gigas* (Queen conch); and *Panulirus argus* (Caribbean spiny lobster), among others (Rubio et al., 2019; Bravo et al., 2021). Thus, it is possible to affirm that most of the fishers interviewed have witnessed a decline in at least one marine species population, including sawfishes. Fishers in Campeche were only asked about elasmobranch species, 100% of the interviewees noted a decrease of sawfishes, with only one person believing that they still exist in the area. The general comments of fishers refer to a decrease in the abundances of elasmobranch species in their fishing areas.

4.2 | Spatial data on *Pristis* spp. In Quintana Roo and Campeche

The maximum number of *Pristis* spp. Records per grid were eight in Laguna de Yalahau and five in Cabo Catoche (Quintana Roo). The rest of the surrounding areas in Quintana Roo had between one and four records. On Cozumel, there were only three records (Figure 4). Most (70%) of the records for the state of Campeche were for the area of Laguna de Términos. Here, the highest number of records ($n = 4$) were at the mouth of a river known as Boca Chica. The following nine records are in the three grids close to Puerto Real and Isla Aguada. The grid with the maximum number of records in Campeche,

TABLE 5 Fishers' quotes related to sawfishes on Campeche.

Year born	Age class	Fishers' quotes
1934	E	Two species entered the rivers. *Pejeblanco* (white sawfish) had a smaller but broader blade (rostrum); *Chavache* had a thinner but larger blade
1940	E	Sawfishes weighed over a ton, and their meat was white. *Pejeblanco* has the shortest blade. I captured one that had eight pups. They inhabited the Bajo; we find the young ones in the seagrass areas
1942	E	The sword of *pejeblanco* is wider but smaller, and the sword of *chavache* is narrower but larger. The young sawfishes inhabited the shore and tide pools, and we caught them for food. I only saw *chavache* when they got caught in the net. It's been a while since we saw sawfishes
1943	E	Sawfishes occur in the lagoons. *Chavache* has a thin but large sword, and the *pejeblanco* has a small but broad blade
		Fishers' quotes about young sawfishes
1935	E	The young sawfishes were killed with wooden bows and arrows with a flag. The fishers made crosses with their swords. The young sawfishes were almost a metre long
1939	E	There were many sawfish newborns
1941	E	The newborns were in the rivers
1944	E	A ton of white meat could be obtained from a sawfish. Sawfishes were all over the lagoon. Females give birth near the mud, where newborns grow. Also, young ones were in the mangrove roots and ate shrimp
1951	E	We ate the little *chavache* sawfishes
1955	E	Sawfishes got entangled in ray nets. Sawfishes entered the lagoon to leave their young. The little ones were on the shore. People grabbed them by hand
1956	E	The adult sawfishes also came to the coast to leave their young
1959	E	Sawfishes disappeared in the lagoon. No more young sawfishes were seen
1960	E	Sawfishes had calves of 1.5 metres
1971	M	There were many sawfish newborns. Above the grass, the *chavache* I grabbed was about a ton and had seven small *chavachitos*. It was the last one; no one else had caught one. We salted the meat, and sold it in Campeche and Mexico City

Note: E, elder fishers; M, middle-aged fishers.

TABLE 6 Information collected from fishers' narratives related to sawfishes in the coastal areas of Campeche.

Year born	Age class	Fishers' narratives
1934	E	Fishers mentioned adults were seen going in and out of the lagoon. Fishers narrated that there were two types, the whitefish (*P. pristis*) and the *cavache* (*P. pectinata*), differentiated by the shape and size of their heads. The catch was generally incidental. The long faces of sawfishes were entangled in the nets. Fishers recall that these fish were a target of fishing, to be consumed
1939	E	Fishers mentioned that newborn sawfishes were very common at El Remate. Adult individuals became entangled in fishing nets. After the 1950s, sawfish populations decreased notably. Since 1958, fishers have mentioned not seeing a live sawfish in this locality
1940	E	On Isla Aguada, fishers mentioned that between 1973 and 1985, it was common to see sawfishes in lagoons and rivers. They considered it a peaceful animal. We could see two types based on his rostrum. The small-toothed sawfish, known as *cavache* swordfish (*P. pectinata*), has a long, thin sword. The large-toothed sawfish was called *pejeblanco* (*P. pristis*), with a short and broad sword. The catch of these fish was incidental. Fishers mentioned sawfish populations declined dramatically
1941	E	For the Sabancuy site, fishers mentioned that in 1972 sawfish were common
1942	E	In Laguna de Términos, juvenile sawfishes were common
1944	E	The fishers of Lerma mention that since the late 1950s, sawfishes were rare, and 1971 was the last time a sawfish was seen in this town
1944	E	At Punta Piedra, fishers mentioned sawfishes were considered typical. They were associated with lemon sharks, as there were simultaneously many individuals of both species. By 1983 sawfish populations declined, and no more have been seen here
1946	E	A fisher from San Joaquín mentioned that sawfishes were popular at this site
1947	E	In Champotón, fishers mentioned that in the 1970s, sawfishes were very rare. Although years ago, they had been very abundant. In Champotón, gillnets were used for fishing. The observed sawfishes were entangled in the nets. In 1972, a sawfish was sighted for the last time here
1952	E	In Nuevo Campechito, fishers commented here that sawfishes were very common. An average catch was between one and three individuals. The largest sawfishes were 4–5 m long. By 1975, fishers mentioned sawfish populations began to decline
1955	E	Fishers at Isla Arena recall that before 1959 sawfishes were quite common, mainly hatchlings; a catch of 500 juveniles was recorded here. Fishers mentioned fishing the sawfish with wooden bows and arrows to obtain their swords to make crosses
1960	E	Fishers interviewed in Xicalango mentioned the abundance of sawfishes and remembered seeing hatchlings of 1.5 m. The last catch of sawfishes here was in 1968

Note: E, elder fishers.

however, was at Isla Arena, with six records. This site is the most isolated location close to the state of Yucatan. In the other parts of the state, there were isolated records from Seybaplaya, San Joaquín, and El Remate, with the exception being Champoton, where two sightings correspond to the same grid (Figure 5).

4.3 | Literature sources

Seventy-four literature sources of sawfishes around the world were reviewed and 18 sources were from Mexico. Throughout these publications, one study mentions the value of LEK in understanding the ecological history of *P. pristis* and *P. pectinata* in Mexico (Bonfil et al., 2018). In particular, four of the Mexican publications confirm the overexploitation and overfishing that sawfish suffered in the past decades (Del Monte et al., 2009; Gómez et al., 2014; Fernández, 2017; Bonfil et al., 2018). Archaeological literature regarding sawfishes is scarce and most of their remains are in the Maya area, which includes the YP, but also Chiapas, Guatemala, and Belize.

4.4 | Faunal data from Maya zooarchaeological sites in the YP

In the Maya area, archaeological remains of sawfishes exist from the Archaic Period (*c*.3000–2000 BC) to the Post-Classic Period (AD 1250–1521) at archaeological sites in the YP on the Gulf of Mexico, including Champotón (Campeche), Xcambo (Yucatán), Isla Cerritos (Yucatán), Conil (Quintana Roo), and Vista Alegre (Quintana Roo). Sawfishes have also been reported at inland sites, including Mayapan (Yucatán) and Tikal (Guatemala), as well as other localities outside the YP, such as Chantuto (Chiapas) (Voorhies, 1976; Moholy, 2004; García & Götz, 2013; Jiménez, 2017; Jiménez & Sierra, 2018; Jiménez & Cobos, 2019; Jiménez, 2022). Vertebrae of the genus *Pristis* spp. Are easily identifiable in the archaeological record, as they do not present dorsal and ventral foramina and have broad vertebral ridges (Figure 6a). Although easily identified, they are not common in the assemblages of these sites, comprising less than 1% of the cartilaginous fishes identified (Jiménez, 2017).

Even in Maya settlements in the YP, where large ichthyoarchaeological assemblages have been collected from habitats

ideal for sawfishes, such as estuaries, very few remains exist. This is the case for Xcambo, with 26 remains (from about 2,917 fish remains and more than 10,000 vertebrate remains), and Vista Alegre, with 19 specimens (from over 20,000 vertebrate remains). The remains of sawfishes were also recovered in Champotón (Campeche), at Reducto de San Antonio (Figure 6b). This is an 18th century coastal fort constructed on top of a prehispanic settlement. Unfortunately, detailed contextual information is lacking, and it is uncertain whether the faunal remains correspond to the prehispanic or to the historical layers of the site.

Although sawfishes may have been consumed for food, as evidence of a burned vertebra from Conil might show, the remains of the sawfishes are often recorded with anthropogenic modifications. Examples include the drilling of the notochordal centre of the vertebrae (Jiménez & Sierra, 2018), associated with the manufacture of decorative artefacts such as beads (Canto, 2009: 87). At Xcambo a

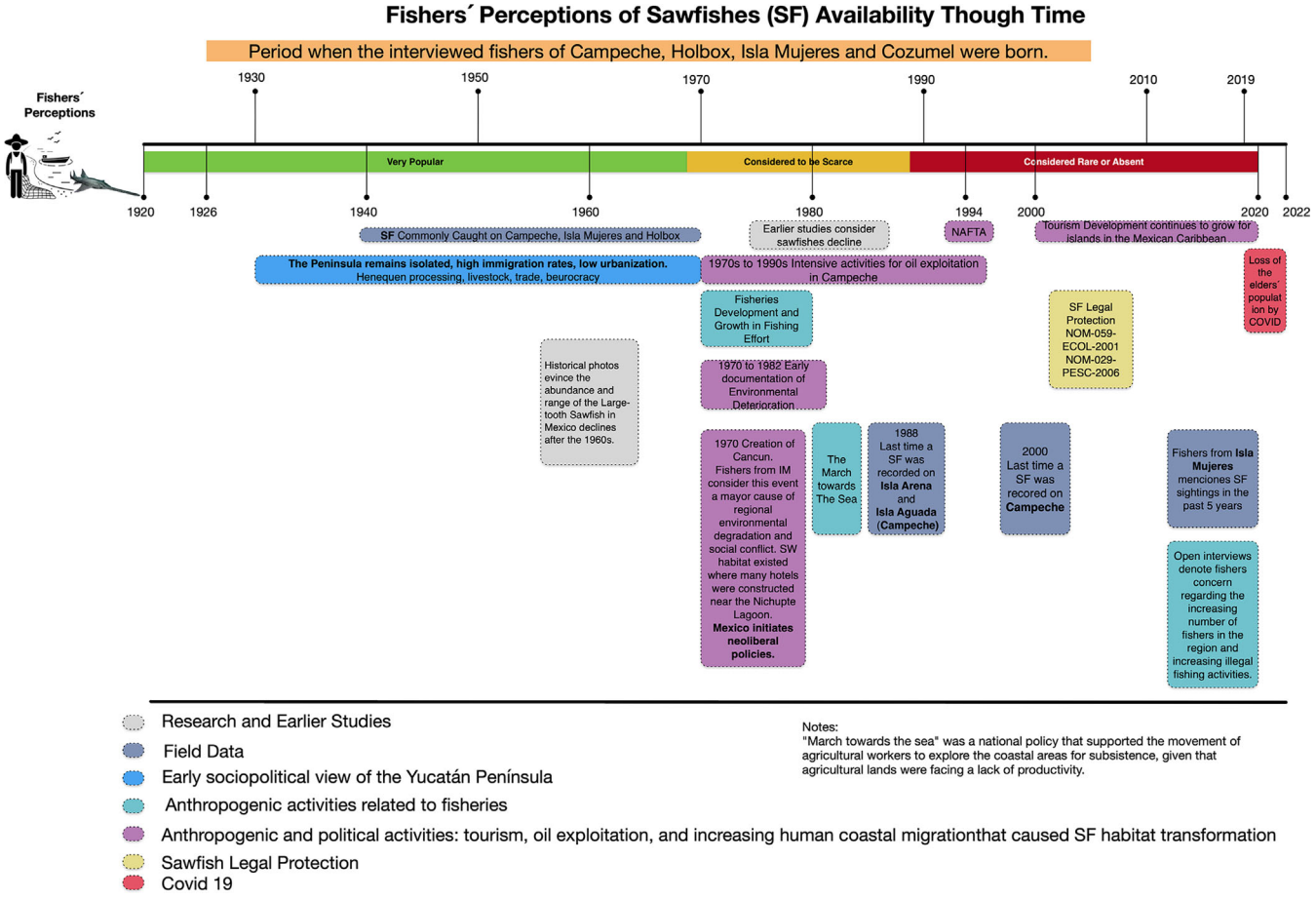

FIGURE 5 Timeline of relevant events that influenced the presence of sawfishes at the study sites.

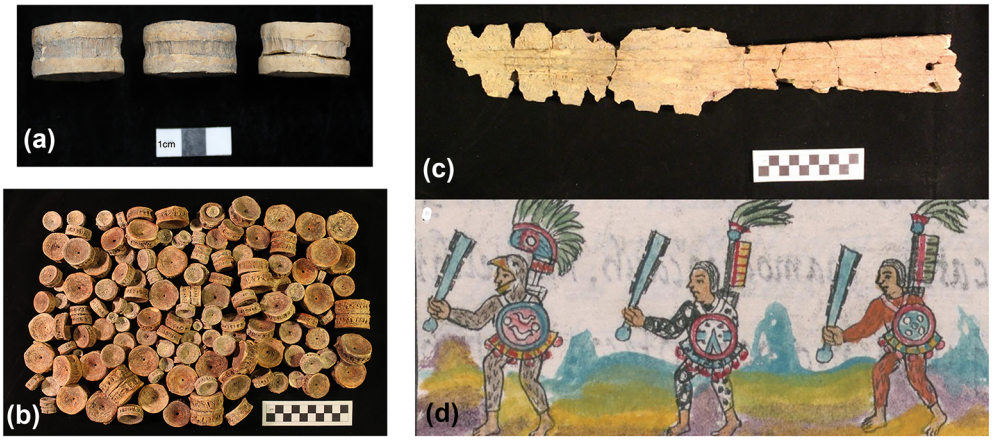

FIGURE 6 (a) Sawfish vertebrae from Xcambó, Yucatán (AD 250–750). (b) Assemblage of sawfish remains from Reducto de San Antonio, Champotón, Campeche. (c) Modified sawfish sword (*macahuitl*) from Xcambó, Yucatán (AD 250–750) (photo by N. Jiménez Cano). (d) Example of Mexica (Aztec) warriors with *macahuitls* (swords) from the *Florentine Codex* (de Sahagun 1577).

sawfish (*Pristis* sp.) rostrum was also identified with a modification made by polishing the distal end to make it narrower and then drilling a perforation of 3 mm in diameter near the proximal end (Jiménez, 2017: 150). This element was previously reported to be like a *macuahuitl*, a weapon utilized by the Mexica (Aztec Period) (Jiménez & Götz, 2011: 46), and recent restoration supports this suggestion (Figure 6c). Interestingly, this could be the first time a *macuahuitl* made of a modified sawfish rostrum has been reported in the Maya area, and probably in Mesoamerica.

In addition, other discoveries substantiate the ritual significance of sawfishes for past Mayan (and Mesoamerican) peoples. At Tikal, *Pristis* sp. Teeth were found in ritual cached offerings (Moholy, 2004: 199). Perhaps the most famous ritual deposit involving a sawfish comes from the rich offerings at the Aztec (Mexica) Templo Mayor in modern-day Mexico City (Guzmán, 2007; Robles et al., 2018). The sawfish is part of offerings associated with *Ciplactli*, the earth monster (McDavitt, 2002; Robles et al., 2018). It is possible that the swords had a function in performing rituals. For example, Sahagún describes using this element as a sacrificial tool in one of the ritual festivities (Robles et al., 2018:22).

5 | DISCUSSION

5.1 | Importance of interdisciplinary data for addressing conservation needs

Mexico's biodiversity of sharks and rays is only preceded by Australia. Mexico has between 214 and 217 identified species that represent over 17% of chondrichthyan species (Del Moral et al., 2015; Ehemann et al., 2018). Blanco & Niño (2022) accounted for 85 species of elasmobranchs, 36 rays, and 49 sharks in the Mexican Caribbean. However, baseline information is scant for chondrichthyans, including sawfishes, and the expansion of such data could prove a vital progression towards their conservation and future management (Koubrak, 2018; Poulakis & Grubbs, 2019; López et al., 2021; Becerril et al., 2022).

The interdisciplinary results presented here present new knowledge of the commonality and regional loss of sawfishes on a short temporal scale in coastal communities of the YP. The study sites continue to face increasing anthropogenic threats related to the oil and tourism industries. The results evidence defaunation in the oceans by human actions ascribed to targeted fisheries, incidental catches, and habitat loss (Field et al., 2009; Tittensor et al., 2014; Dulvy et al., 2014a; McCauley et al., 2015; Dulvy et al., 2021) (Figure 5). These results complement earlier coastal exploitation studies that documented defaunation of Holbox's marine fauna, such as groupers, snappers, sharks, rays, gastropods, and crustaceans (lobster) (Rubio et al., 2019).

The results of this study indicate that people have been harvesting sawfishes in small numbers since the Pre-Columbian Period. However, fishers' LEK and the literature review reveal that intense fishing efforts over the past decades have contributed to their present low or null numbers. Elder fishers noted that sawfishes were possibly overfished in the 1970s (Figure 5). The results from Campeche demonstrated that sawfishes were more commonly encountered in fishing activities and incidental catches there, compared with Quintana Roo. These qualitative results can help give managers an idea of the past landscapes and their biodiversity, although the unavailability of fisheries data for sawfish is a considerable limitation when considering the results of this work (Robillard & Séret, 2006; Bonfil et al., 2017).

Documenting the defaunation of YP aquatic megafauna provides insight into the region's vulnerability to biodiversity loss. The rapid transformation of coastal ecosystems and the associated changes in sociocultural values can lead to the growing exploitation of natural resources (Castillo, Martínez & Viga, 2019; Rubio et al., 2019; Medina & Palafox, 2020; Rubio et al., 2022).

Interdisciplinary results show that when fishers mentioned sawfishes from past decades, coastal towns in the YP were facing changes in fishery policies, people were migrating from agricultural fields to the coast for fishing, and rapid and unplanned coastal and tourism development was beginning (Wiese, 2000; Carte et al., 2010; Marín, 2012; Huitrón, 2017; Rubio et al., 2018; Rubio et al., 2019; Medina & Palafox, 2020; Rubio et al., 2022). In Campeche, tourism development is not an extreme landscape changer as seen in Quintana Roo, but fishing policies related to enhancing subsistence fishing, along with human migration to the coast for fishing and oil exploitation, are drivers that afflicted sawfish survival (Azcorra & Dickinson, 2020; Peña et al., 2021).

Based on the fishers' LEK analysed here, it appears, counterintuitively, that sawfishes were overexploited at a moment when Mexico established more fishing regulations (Bezaury et al., 1999; Murray, 2005; Valdez et al., 2006; Bonfil et al., 2017; Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación, 2017). However, as sawfishes continued disappearing in most coastal areas, more fisheries and conservation policies were introduced in the late 1990s and early 2000s (Valdez et al., 2006). Official protection for sawfishes in Mexico was included in the Mexican Official Norm (NOM) NOM-059-ECOL-2001 (Diario Oficial de la Federación, 2002) and a further NOM-029-PESC-2006 has focused on the creation of responsible fisheries for sharks and rays (Diario Oficial de la Federación, 2007). Sadly, these measures came too late for the sawfishes.

The YP continues to yield to ever-increasing demands in urban and tourism development and, subsequently, biodiversity loss is a regional problem (Field et al., 2009; Dulvy et al., 2014a; Dulvy et al., 2014b; Domínguez, García & Palafox, 2021). Even considering the significant decline of sawfishes as a once-prominent ecological member, the continued impacts of climate change such as ocean acidification, habitat fragmentation, and seagrass depletion are also happening concurrently (Gissi et al., 2021; Weiskopf et al., 2021). Although conservation policies have continued to grow in the past 20 years, there is still a trend towards losing natural capital in an important region for Mexico's economy that depends on healthy and biodiverse ecosystems to gain nature's revenues. The interdisciplinary

results presented here can help managers understand the legacy of biodiversity that the YP has had through time, and possibly generate awareness that spurs actions against further defaunation.

5.2 | LEK of sawfishes to inspire future research

Fishers' LEK has benefited scientists in their study of sawfishes globally (Leeney & Poncelet, 2013; Leeney, 2017; Rubio et al., 2017; Bonfil et al., 2018; Leeney, Mana & Dulvy, 2018; Rubio et al., 2019; Martínez et al., 2020). Although the fishers' LEK depicts sawfishes as extirpated in some areas, this is not true in all regions of the YP. As reported here, a fisher saw a sawfish in a longline 5 years ago (in 2016) off Isla Mujeres, and another saw one between Cabo Catoche and Isla Contoy in 2020. These recent reports align with the catch of a small-toothed sawfish (*P. pectinata*) in Barra de Cazones, Veracruz, in 2015 (Díaz et al., 2017), as well as environmental DNA samples that tested positive for *Pristis* spp. In Veracruz and Campeche in 2016 and 2017, respectively (Bonfil et al., 2021). These new data bring hope in confirming the presence of sawfishes, incentivizing future research on sawfishes in Mexico.

5.3 | Sawfish nursery sites

Fishers' LEK, the literature research, and published environmental DNA studies by Bonfil et al. (2021) suggest that Laguna de Términos in Campeche is a nursery area for sawfishes. Also, fishers' LEK supported the existence of a target fishery there and described Isla Arena, El Remate, Seybaplaya, and Xicalango as sites where newborns and juveniles lived. Fishers' LEK on Isla Mujeres reported that the channel used for entering the coastal Laguna Nichupté was a common place to see newborn sawfishes in the 1980s. Nowadays, there is a hotel at this site and Laguna Nichupté faces extreme anthropogenic transformations, being adjacent to Cancun island (Bezaury et al., 1999). For Holbox, fishers mentioned that newborn sawfishes existed decades ago right offshore from Holbox beach. This area is now the most visited beach on the island, with rampant noise from beach clubs, boats, and swimmers negatively affecting the nearshore environment (Appendix S5).

5.4 | Cultural importance and sociocultural challenges for collecting interdisciplinary data on sawfishes that are useful for conservation

The cultural importance of *Pristis* spp. In the past is documented as including uses of sawfish meat for human consumption, trophies (rostrum), liver oil, and fins (Bonfil et al., 2017). Fishers on Isla Mujeres mention a new use for sawfish rostrums as rakes to clean leaves. During Holy Week in Campeche, people built crosses with the rostrums of juvenile sawfishes. In Campeche and Quintana Roo, fishing techniques using harpoons and gillnets were reported for sawfishes (Carranza, 1959). For Campeche, fishers mentioned that people used wooden bows and arrows to catch juvenile sawfishes. Interestingly, in the 16th century, Diego de Landa reported catching rays with bow and arrow on the coast of Campeche (Landa, 2012: 94). Current reports on the use of these fishing gears could represent a continuity in the techniques for catching elasmobranchs in this locality. Archaeozoological information presented in this paper represents a potential contribution to sawfish conservation efforts by providing a most robust picture of ecological baselines over time scales that are usually absent in fisheries records.

The research presented here provides insight into the cultural importance of sawfishes for people who have inhabited the YP for a very long time. In recent times, COVID-19 was a contemporary challenge for the collection of sawfish data. Many elder fishers died during the pandemic. This is a historical moment where the loss of cultural heritage is happening, which gives policy and management an opportunity to value baseline interdisciplinary results like the ones presented here. In addition, environmental education actions on the importance of sawfishes in the ecosystem are also needed in Mexico, and this will also contribute to preventing the loss of cultural knowledge about these rays in Mexico's coastal waters. The scientific and education campaigns at the study sites can contribute to improve knowledge and awareness about sawfishes in Mexico.

A silver lining of the COVID-19 pandemic is the opportunity to change tourism practices, as post-pandemic many visitors want to be more aware of the places that they visit (Rubio et al., 2022). Government authorities can use this change in the mindset of tourists to help them establish and implement new conservation actions. Studies on tourist perceptions of the environment in Panama and Holbox indicate that tourists are willing to have more environmentally friendly behaviours but do not have the resources to effectively do so (Dorsett & Rubio, 2019; Rubio et al., 2022). Engaging visitors in the environmental issues of the places that they visit could generate an awareness to support payments for ecosystem services (ES) for biodiversity conservation.

The IUCN Shark Specialist Group suggests that Mexico should prioritize sawfish protection because they face local extinction. Dulvy et al. (2016) report on the extent of occurrence of sawfish species in the Atlantic Ocean and categorize the presence of *P. pristis* as uncertain and *P. pectinata* as likely extinct. The IUCN considers Mexico as having suitable legislation for sawfish protection, but insufficient enforcement; here, compliance with laws by enforcement is limited by the lack of funding. Payments for ES by tourists can facilitate financing actions that prevent chondrichthyan biodiversity loss in the YP. The interdisciplinary baseline data reported here can stimulate managers to bridge ideas between policies and management to establish financing options for continuing studying and protecting the natural and cultural heritage of sawfishes in the YP.

6 | CONCLUSION

The interdisciplinary approach used in our study provides a view of changing coastal landscapes in the YP, with sawfishes as uncommon contemporary inhabitants of the coastal area. Results highlight the urgent need to adapt existing conservation efforts to increase government and local compliance, to prevent the continuing elasmobranch defaunation in the region. For many elasmobranch species, little information about their ecology and conservation is known.

This matters because Mexico is a megadiverse country that faces a biodiversity loss scenario, where massive tourism and urban development grow together, transforming coastal habitats. Furthermore, illegal fishing continues to be an issue in the region. Results from this research bring relevance to the urgent need to integrate LEK to develop baseline studies related to humans understanding the coastal marine biodiversity of the recent past.

Our results show the need to foster cultural, educational, and scientific activities that improve knowledge about sawfishes for the general public as well as the scientific community. The above actions are crucial in a changing world facing increasing anthropogenic threats and climate challenges that make it difficult for many species to thrive in contemporary coastal waters, especially the megafauna.

Finally, this study highlights the usefulness of an interdisciplinary approach in understanding long-term human disturbances in coastal ecosystems. This approach also helps to avoid actions that continue the shifting baseline syndrome, to make existing conservation actions functional in real time. Thus, the knowledge of past coastal ecosystem conditions should help reinforce conservation actions, highlighting the biodiversity losses caused by human impacts and reducing people's tolerance for progressive environmental degradation.

AUTHOR CONTRIBUTIONS

Nadia T. Rubio-Cisneros: Conceptualization, investigation, funding acquisition, writing—original draft, writing—review and editing, visualization, validation, methodology, formal analysis, project administration, and supervision. **Ilse A. Martínez-Candelas**: Investigation, methodology, writing—original draft, writing—review and editing, formal analysis, and validation. **Diana Ordaz-García**: Investigation, writing—original draft, writing—review and editing, formal analysis, and validation. **Juan C. Pérez-Jiménez**: Conceptualization, investigation, writing—review & editing, validation, methodology, writing—original draft, and visualization. **Nayeli G. Jiménez-Cano**: Investigation, writing—original draft, writing—review and editing, methodology, validation, and formal analysis. **Jeffrey B. Glover**: Investigation, writing—original draft, writing—review and editing, validation, methodology, and formal analysis. **Brianna K. Montes-Ganzon**: Writing—review and editing, and resources. **Gabriel Ruiz-Ayma**: Writing—review and editing, and resources. **José I. González-Rojas**: Resources, writing—review and editing, and visualization.

ACKNOWLEDGEMENTS

We offer special thanks to the Save Our Seas Foundation and The Rufford Foundation, who supported NTR-C's research on the YP. Thanks to Save Our Seas Foundation who supported IAM-C´s research on Campeche. The authors acknowledge help in the field on Cozumel Island from Izaizel Libertad Cruz Gómez, a student from the Universidad Nacional Autónoma de México. We thank Thalia González Reyes from the Universidad Anahuac, Cancun, for her kind help with Figure 2. We also thank Alexa Berenice Juárez Gaspar, a student at Laboratorio de Biología de la Conservación y Desarrollo Sustentable, Facultad de Ciencias Biológicas, Universidad Autónoma de Nuevo León, for help with data organization. The authors are very grateful to the fishers of the YP and Mexico's Caribbean Islands, who enthusiastically and kindly shared their traditional knowledge about sawfishes and their time during the years of this study.

CONFLICT OF INTERESTS STATEMENT

The authors have no conflicts of interest associated with this work.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available upon request to the authors.

ORCID

Nadia T. Rubio-Cisneros https://orcid.org/0000-0001-7775-4132
Ilse A. Martínez-Candelas https://orcid.org/0000-0002-2822-8838
Nayeli G. Jiménez-Cano https://orcid.org/0000-0001-9973-2452
José I. González-Rojas https://orcid.org/0000-0003-2740-7305

REFERENCES

Azcorra, H. & Dickinson, F. (2020). *Culture, environment and health in the Yucatán Peninsula: a human ecology perspective*. Springer Nature Switzerland AG. https://doi.org/10.1007/978-3-030-27001-8

Becerril, E., Randall, A., Arellano, M., Bonfil, R., Ayala, A., Castillo, J. et al. (2022). Research priorities for the conservation of chondrichthyans in Latin America. *Biological Conservation*, 269, 109535. https://doi.org/10.1016/j.biocon.2022.109535

Bezaury, J., López, C., McCann, J., Molina, C., Rubinoff, P., Goddard, T. et al. (1999). Participatory coastal and marine management in Quintana Roo, México. In: Dight, I., Kenchington, R. & Baldwing, J. (Eds.) *Proc. of the international tropical marine ecosystems management symposium (ITMEMS), great barrier reef Marine Park authority*, Townsville. Qld. Australia, pp. 163–171. November, 1998, p 452.

Blanco, M. & Niño, C. (2022). Elasmobranchs of the Mexican Caribbean: biodiversity and conservation status. *Environmental Biology of Fishes*, 105(1), 151–165. https://doi.org/10.1007/s10641-021-01203-7

Bonfil, R. (1997). Status of shark resources in the Southern Gulf of Mexico and Caribbean: implications for management. *Fisheries Research*, 29(2), 101–117. https://doi.org/10.1016/S0165-7836(96)00536-X

Bonfil, R. & Abdallah, M. (2004). *Field identification guide to the sharks and rays of the Red Sea and Gulf of Aden*. Food and Agriculture Organization of the United Nations. pp. 37–47.

Bonfil, R., Mendoza, O., Ricaño, M., Palacios, P. & Bolaño, N. (2017). Former widespread abundance and recent downfall of sawfishes in Mexico as evidenced by historical photographic and trophy records. *Fisheries*, 42(5), 256–259. https://doi.org/10.1080/03632415.2017.1276339

Bonfil, R., Palacios, P., Mendoza, O., Ricaño, M. & Díaz, P. (2021). Detection of critically endangered marine species with dwindling populations in the wild using eDNA gives hope for sawfishes. *Marine Biology*, 168(5), 60. https://doi.org/10.1007/s00227-021-03862-7

Bonfil, R., Ricaño, M., Mendoza, O., Méndez, I., Pérez, J., Bolaño, N. et al. (2018). Tapping into local ecological knowledge to assess the former importance and current status of sawfishes in Mexico. *Endangered Species Research*, 36, 213–228. https://doi.org/10.3354/esr00899

Bravo, A., Saenz, A., Fulton, S., Espinoza, A. & Sosa, E. (2021). Goliath grouper *Epinephelus itajara* oral history, use, and conservation status in the Mexican Caribbean and Campeche Bank. *Endangered Species Research*, 45, 283–300. https://doi.org/10.3354/esr01135

Bunce, L., Townsley, P., Pomeroy, R. & Pollnac, R. (2000). *Socioeconomic manual for coral reef management*. Townsville, Australia: Australian Institute of Marine Science, Global Coral Reef Monitoring, Australian Institute of Marine, Science, The world Conservation Union. United States. National Oceanic and Atmospheric Administration.

Canto, P. (2009). *Análisis tipológico y funcional de los artefactos de hueso, asta y diente de Xcambó, Yucatán*. BA Disertation.

Carlson, J., Wiley, T. & Smith, K. (2013). *Pristis pectinata* (errata version published in 2019). *The IUCN Red List of Threatened Species*, 2013, E. T18175A141791261. https://doi.org/10.2305/IUCN.UK.2013-1.ReLTS.T18175A141791261.en

Carr, H. (1986). *Fauna utilization in a late Preclassic Maya Community at Cerros, Belize*. PhD Dissertation. Tulane University, New Orleans.

Carranza, J. (1959). Pesca y Recursos Pesqueros. In: Beltrán, E. (Ed.) *Los Recursos Naturales del Sureste y su Aprovechamiento. III Parte, Estudios Particulares Tomo 3o*. A. C., México DF: Instituto Mexicano de Recursos Naturales Renovables, pp. 151–238.

Carte, L., McWatters, M., Daley, E. & Torres, R. (2010). Experiencing agricultural failure: internal migration, tourism and local perceptions of regional change in the Yucatán. *Geoforum*, 41(5), 700–710. https://doi.org/10.1016/j.geoforum.2010.03.002

Castillo, M., Martínez, M. & Viga, M. (2019). Natural resources knowledge socialization in Yucatan, Mexico: promoting a mutually beneficial society-nature relationship. *Ecology and Society*, 24(3), 21. https://doi.org/10.5751/ES-11016-240321

Charnley, S., Fischer, A. & Jones, E. (2007). Integrating traditional and local ecological knowledge into forest biodiversity conservation in the Pacific Northwest. *Forest Ecology and Management*, 246(1), 14–28. https://doi.org/10.1016/j.foreco.2007.03.047

Comisión Nacional de Áreas Naturales Protegidas (CONANP). (2019). *Parque Nacional Costa Occidental de Isla Mujeres, Punta Cancún y Punta Nizuc. Gobierno de México*. https://www.gob.mx/conanp/documentos/costa-occidental-de-isla-mujeres-punta-cancun-y-punta-nizuc

Del Monte, P., Castro, J., Brook, B., De la Cruz, J. & Cruz, V. (2009). Putative extinction of two sawfish species in Mexico and the United States. *Neotropical Ichtyology*, 7(1), 509–512. https://doi.org/10.1590/S1679-62252009000300020

Del Moral-Flores, L.F., Morrone, J.J., Alcocer Durand, J., Espinosa-Pérez, H. & Pérez-Ponce De León, G. (2015). Lista patrón de los tiburones, rayas y quimeras (Chondrichthyes, Elasmobranchii, Holocephali) de México. Version 1.11. Museu de Ciències Naturals de Barcelona. https://doi.org/10.15470/hrl1kv

Diario Oficial de la Federación. (2002). *Norma Oficial Mexicana NOM-059-ECOL-2001, Protección Ambiental – Especies nativas de México de flora y fauna silvestres- Categorías de riesgo y especificaciones para su inclusión, exclusión o cambio- Lista de especies en riesgo*. Segunda sección. Gobierno de México.

Diario Oficial de la Federación. (2007). *Norma Oficial Mexicana NOM-029-PESC-2006, Pesca responsable de tiburones y rayas. Especificaciones para su aprovechamiento*. Primera sección. Gobierno de México.

Díaz, P., Bonfil, R., Palacios, P., Bolaño, N. & Bayona, N. (2017). Mitochondrial genome of the critically endangered smalltooth sawfish *Pristis pectinata* from Veracruz, Mexico. *Conservation Genetics Resources*, 10(4), 663–666. https://doi.org/10.1007/s12686-017-0896-9

Domínguez, F., García, A. & Palafox, A. (2021). *Percepción de los impactos del desarrollo turístico en Tulum, Quintana Roo. Mérope. Revista Del Centro De Estudios En Turismo, Recreación E Interpretación Del Patrimonio, (4)*. http://revele.uncoma.edu.ar/index.php/merope/article/view/3403

Dorsett, C. & Rubio, N. (2019). Many tourists, few fishes: using tourists' and locals' knowledge to assess seafood consumption on vulnerable waters of the archipelago of Bocas del Toro, Panama. *Tourism Management*, 74, 290–296. https://doi.org/10.1016/j.tourman.2019.03.011

Dulvy, N., Allen, D., Ralph, G. & Walls, R. (2016). The conservation status of Sharks, Rays and Chimaeras in the Mediterranean Sea. https://doi.org/10.7554/eLife.00590

Dulvy, N., Davidson, L., Kyne, P., Simpfendorfer, C., Harrison, L., Carlson, J. et al. (2014a). Ghosts of the coast: global extinction risk and conservation of sawfishes. *Aquatic Conservation: Marine and Freshwater Ecosystems*, 26(1), 134–153. https://doi.org/10.1002/aqc.2525

Dulvy, N., Fowler, S., Musick, J., Cavanagh, R., Kyne, P., Harrison, L. et al. (2014b). Extinction risk and conservation of the world's sharks and rays. *eLife*, 3, e00590. https://doi.org/10.7554/eLife.00590

Dulvy, N., Pacoureau, N., Rigby, C., Pollom, R., Jabado, R., Ebert, D. et al. (2021). Overfishing drives over one-third of all sharks and rays toward a global extinction crisis. *Current Biology*, 31(21), 4773–4787.e8. https://doi.org/10.1016/j.cub.2021.08.062

Eghenter, C. (2000). *Mapping peoples' forests: the role of mapping in planning community-based management of conservation areas in Indonesia*. Washington, D.C.: Biodiversity Support Program. 40.

Ehemann, N., González, L., Chollet, J. & De la Cruz, J. (2018). Updated checklist of the extant chondrichthyes within the exclusive economic zone of Mexico. *ZooKeys*, (774), 17–39. https://doi.org/10.3897/zookeys.774.25028

Fernández, K. (2017). *Determinación de la dieta y hábitos alimenticios en cautiverio del pez sierra de dientes cortos (Pristis pectinata) en el acuario de Veracruz*. (Tesis de licenciatura). Instituto Tecnológico de Boca del Río, México.

Field, I., Meekan, M., Buckworth, R. & Bradshaw, C. (2009). Chapter 4. Susceptibility of sharks, rays and chimaeras to global extinction. In: *Advances in marine biology*. Vol. 56: Academic Press, pp. 275–363.

French, L. & Naylor, G. (2018). Pristis pectinata. Discover fishes. *Florida Museum of Natural History*. [En línea].

Gallardo, A., Badillo, M., Rivera, F., Rubio, J., Galindo De Santiago, C., Loera, J. et al. (2014). *Catálogo de Peces de la Costa Norte de Yucatán*. Segunda Edición: Universidad Nacional Autónoma de México – CONCIYTEY, p. 265. ISBN:978-607-9060-15-2

García, C. & Götz, C.M. (2013). Informe de la Evaluación de la muestra Faunística del sitio arqueológico de Vista Alegre, Quintana Roo. In: Glover, J.B., Rissolo, D. & Mathews, J. (Eds.) *El Proyecto costa Escondida: una investigación Paleoambiental y Arqueológica del puerto maya Vista Alegre y la costa norte de Quintana Roo. México. Temporada de Campo 2011 y Análisis 2012: 89–114*: Informe Técnico Anual al Consejo de Arqueología del Instituto Nacional de Antropología e Historia.

García, J.A., Arreguín, F., Hernández, S. & Lluch, D. (2004). *Impacto ecológico de la industria petrolera en la Sonda de Campeche*. México, tras tres décadas de actividad: Una revisión. *Interciencia*, 29(774), 311–319.

Gissi, E., Manea, E., Mazaris, A., Fraschetti, S., Almpanidou, V., Bevilacqua, S. et al. (2021). A review of the combined effects of climate change and other local human stressors on the marine environment. *Science of the Total Environment*, 775(1), 142564. https://doi.org/10.1016/j.scitotenv.2020.142564

Glover, J., Rissolo, D., Beddows, P., Goodman, B. & Smith, D. (2014). El Proyecto Costa Escondida: una investigación paleoambiental y arqueológica del puerto Maya Vista Alegre, Quintana Roo, México. In:

Arroyo, B., Salinas, L.M. & Rojas, A. (Eds.) *En XXVII Simposio de Investigaciones Arqueológicas en Guatemala, 2013*. Guatemala: Museo Nacional de Arqueología y Etnología, pp. 1025–1036.

Glover, J.B., Rissolo, D., Beddows, P., Jaijel, P., Smith, D. & Goodman, B. (2022). The proyecto costa escondida: applying historical ecology approaches to study past coastal landscapes in the Maya area. *Journal of Island and Coastal Archaeology*, 1–20. https://doi.org/10.1080/15564894.2022.2061652

Glover, J.B., Rissolo, D. & Mathews, J. (2013). *El Proyecto costa Escondida: una investigación paleoambiental y arqueológica del puerto maya vista alegre y la costa norte de Quintana Roo. México. Temporada de campo 2011 y análisis 2012: 89–114*: Informe Técnico Anual al Consejo de Arqueología del Instituto Nacional de Antropología e Historia.

Gómez, S., Caldas, J., Acero, A., Martínez, M., Sáenz, P., Lasso, C. et al. (2014). Geographic distribution and conservation status of sawfish *Pristis spp* (Pristiformes: Pristidae) in the southern Caribbean Sea. *Biota Colombiana*, 15(1), 109–117.

Gonzalez, M. (2005). Use of *Pristis* spp. (Elasmobranchii: Pristidae) by hunter-gatherers on the coast of São Paulo. Brazil. *Neotropical Ichthyology*, 3(3), 421–426. https://doi.org/10.1590/S1679-62252005000300010

Goodman, L. (1961). Snowball sampling. *Annals of Mathematical Statistics*, 32(1), 148–170. https://doi.org/10.1214/aoms/1177705148

Götz, C.M. (2008). Coastal and inland patterns of faunal exploitation in the prehispanic northern Maya lowland. *Quaternary International*, 191(1), 154–169. https://doi.org/10.1016/j.quaint.2008.02.003

Grant, S. & Berkes, F. (2007). Fisher knowledge as expert system: a case from the longline fishery of Grenada, the Eastern Caribbean. *Fisheries Research*, 84(2), 162–170. https://doi.org/10.1016/j.fishres.2006.10.012

Guzmán, A. (2007). *Los peces de las ofrendas del Complejo A del Templo Mayor: una aproximación biológica y arqueozoológica*. Tesis doctoral. Universidad Autónoma de Madrid. Departamento de biología.

Hernández, L., Null, K., Ortega, D. & Paytan, A. (2015). Water quality assessment in the Mexican Caribbean: impacts on the coastal ecosystem. *Continental Shelf Research*, 102, 62–72. https://doi.org/10.1016/j.csr.2015.04.015

Herrera, J., Aranda, N., Troccoli, L., Comín, F. & Madden, C. (2004). Coastal eutrophication in the Yucatán Peninsula. In: Caso, M., Pisanty, I. & Ezcurra, E. (Eds.) *Environmental analysis of the Gulf of México*. USA: Harte Research Institute, pp. 512–516.

Herrera, J. & Morales, S. (2010). Subtropical karstic coastal lagoon assessment Southeast Mexico. In: Kennish, M. & Paerl, H. (Eds.) *Coastal lagoons critical habitats of environmental change*. Boca Raton: CRC Press, pp. 307–333.

Hueter, R., Castillo, J., Márquez, J. & Tyminski, J. (2007). The use of Laguna Yalahau, Quintana Roo, Mexico as a primary nursery for the blacktip shark. *American Fisheries Society Symposium*, 50, 345–364. https://doi.org/10.1016/j.csr.2015.04.015

Huitrón, T. (2017). *Áreas naturales protegidas y tenencia ejidal; binomio perfecto para la acumulación por desposesión desde el discurso del desarrollo turístico sustentable: Holbox*. Quintana Roo (Masters), Universidad de Quintana Roo, Quintana Roo, México.

Humann, P., & DeLoach, N. (2014). Reef fish identification: Florida, Caribbean, Bahamas. 537pp. Book ID: 41421.

Jabado, R., Al Ghais, S., Hamza, W., Henderson, A., Spaet, J., Shivji, M. et al. (2015). The trade in sharks and their products in the United Arab Emirates. *Biological Conservation*, 181, 190–198. https://doi.org/10.1016/j.biocon.2014.10.032

Jackson, J.B.C. (1997). Reefs since Columbus. *Coral Reefs: Journal of the International Society for Reef Studies*, 16, 23–32. https://doi.org/10.1007/s003380050238

Jiménez, N. (2017). *Ictioarqueología del Mundo Maya: evaluando la pesca prehispánica (250-1450d.C.) de las Tierras Bajas del Norte*. PhD Disertation. Universidad Autónoma de Madrid, Madrid.

Jiménez, N. (2019). Pre-Hispanic Maya fisheries and coastal adaptations in the northern lowlands from the classic (500–900 AD) to Postclassic (900–1400 AD) periods. *International Journal of Osteoarchaeology*, 29(3), 469–476. https://doi.org/10.1002/oa.2790

Jiménez, N. & Cobos, R. (2019). *Aprovechamiento y captura de fauna vertebrada e invertebrada durante el periodo Clásico en Isla Cerritos: una perspectiva zooarquelógica. Paper presented at XXX Encuentro Internacional Investigadores de la Cultura Maya*. Universidad Autónoma de Campeche, Campeche.

Jiménez, N. & Götz, C.M. (2011). Subsistencia costera en Xcambó, Yucatán, durante épocas prehispánicas: un acercamiento paleoecológico a través de los restos de fauna marina. In: *Memorias. Los investigadores de la Cultuta Maya 19, Tomo 1*. Campeche: Universidad Autónoma de Campeche, pp. 43–57.

Jiménez, N. & Sierra, T.N. (2018). Pesquerías de un asentamiento costero del Clásico Maya: análisis ictioarqueológicos en Xcambó (Yucatán, México). *Antípoda*, 31, 25–44. https://doi.org/10.7440/antipoda31.2018.02

Jiménez, N.G. (2022). *Identificaciones taxonómicas del material arqueozoológico del Reducto de San Antonio (Champotón, Campeche): base de datos entregada a la Dr. Socorro Jiménez*. Internal report.

Juárez, A. (2002). Ecological degradation, global tourism, and inequality: maya interpretations of the changing environment in Quintana Roo, Mexico. *Human Organization*, 61(2), 113–124. https://doi.org/10.17730/humo.61.2.dbyeyrdgcc0c5kga

Kemp, G., Day, J., Yáñez, A. & Peyronnin, N. (2016). Can continental shelf river plumes in the northern and southern Gulf of Mexico promote ecological resilience in a time of climate change? *Water*, 8(3), 83. https://doi.org/10.3390/w8030083

Koubrak, O. (2018). A future for a forgotten predator: an assessment of international legal frameworks for protection and recovery of the Caribbean sawfishes. *Journal of International Wildlife law & Policy*, 21(2–3), 79–121. https://doi.org/10.1080/13880292.2018.1481597

Kramer, P., Richards, P. & McField, M. (Eds.) (2002). *Ecoregional conservation planning for the Mesoamerican Caribbean Reef*: WWF, p. 1.

Landa, D. (2012). *Relación de las Cosas de Yucatán*. Barcelona: Red Ediciones SL.

Leal, R., Lenczewski, M., Morgan, C., Gahala, A. & McLain, J. (2013). Assessing fecal contamination in groundwater from the tulum region, Quintana Roo, México. *Journal of Environmental Protection (Irvine, Calif)*, 4(11), 1272–1279. https://doi.org/10.4236/jep.2013.411148

Leatherman, T., Goodman, A. & Stillman, T. (2010). Changes in stature, weight, and nutritional status with tourism-based economic development in the Yucatán. *Economics and Human Biology*, 8(2), 153–158. https://doi.org/10.1016/j.ehb.2010.05.008

Leeney, R. (2017). Are sawfishes still present in Mozambique? A baseline ecological study. *PeerJ*, 5, e2950. https://doi.org/10.7717/peerj.2950

Leeney, R., Mana, R. & Dulvy, N. (2018). Fishers' ecological knowledge of sawfishes in the Sepik and Ramu rivers, northern Papua New Guinea. *Endangered Species Research*, 36, 15–26. https://www.int-res.com/abstracts/esr/v36/p15-26/. https://doi.org/10.3354/esr00887

Leeney, R. & Poncelet, P. (2013). Using fishers' ecological knowledge to assess the status and cultural importance of sawfish in Guinea-Bissau. *Aquatic Conservation: Marine and Freshwater Ecosystems*, 25(3), 411–430. https://doi.org/10.1002/aqc.2419

López, Á. (2015). Desarrollo sustentable y turismo de naturaleza: reevaluación y acción colectiva en torno a recursos comunes en Holbox, México. Otra Economía. *Revista Latinoamericana de Economía Social y Solidaria*, 9(17), 187–198. https://doi.org/10.4013/otra.2015.917.07

López, J., Cubillos, J., Villate, M., Del Cid, A., Díaz, J., Cooke, R. et al. (2021). Bright spots for research and conservation of the largetooth sawfish *Pristis pristis* in Colombia and Panamá. *Endangeres Species Research*, 46, 147–160. https://doi.org/10.3354/esr01150

Lotze, H., Lenihan, H., Bourque, B., Bradbury, R., Cooke, R., Kay, M. et al. (2006). Depletion, degradation, and recovery potential of estuaries and coastal seas. *Science (Washington D C)*, 312(5781), 1806–1809. https://doi.org/10.1126/science.1128035

Marín, G. (2012). Los tristes trópicos del turismo en México: industria, reflexividad y otras ficciones. In: Guardado, G.M., de Fuentes, A.G. & Godás, M.D. (Eds.) *En Turismo, globalización y sociedades locales en la península de Yucatán. México*. El Sauzal (Tenerife. España): ACA y PASOS, RTPC, pp. 17, 275–44.

Martínez, I. (Director). (2022). *Entre Redes: documentary of the shark and ray fisheries on Campeche*. [Mar Sustentable YouTube Channel].

Martínez, I., Pérez, J., Espinoza, A., McClenachan, L. & Méndez, I. (2020). Use of historical data to assess changes in the vulnerability of sharks. *Fisheries Research*, 226, 105526. https://doi.org/10.1016/j.fishres.2020.105526

McCauley, D., Pinsky, M., Palumbi, S., Estes, J., Joyce, F. & Warner, R. (2015). Marine defaunation: animal loss in the global ocean. *Science*, 347(6219), 247–255. https://doi.org/10.1126/science.1255641

McClenachan, L. & Cooper, A. (2008). Extinction rate, historical population structure and ecological role of the Caribbean monk seal. *Proceedingds Biological Sciences/the Royal Society*, 275(1641), 1351–1358. https://doi.org/10.1098/rspb.2007.1757

McDavitt, M.T. (2002). Cipactli's sword, Tlaltecuhtli's teeth: deciphering the sawfish & shark offerings in the Aztec Great Temple. *Shark News: Newsletter of the IUCN Shark Specialist Group*, 14, 6–7. https://doi.org/10.1098/rspb.2007.1757

Medina, G. & Palafox, A. (2020). La vulnerabilidad de Holbox, Quintana Roo, México, Como destino turístico. *El Periplo Sustentable*, (38), 42–68. https://doi.org/10.36677/elperiplo.v0i38.10694

Moholy, H. (2004). Vertebrates in Tikal Burials and Caches. In: Emery, K.F. (Ed.) *Maya Zooarchaeology: new directions in methods and theory: 193–205*. Monograph 51. Los Angeles: Cotsen Institute of Archaeology, University of California.

Moreno, M., Orr, B., Cudney, R. & Shaw, W. (2010). Using fishers' local knowledge to aid management at regional scales: spatial distribution of small-scale fisheries in the northern Gulf of California, México. *Bulletin of Marine Science*, 86(2), 339–353.

Murray, G. (2005). Multifaceted measures of success in two Mexican marine protected areas. *Society & Natural Resources: an International Journal*, 18(10), 889–905. https://doi.org/10.1080/08941920500248814

Newman, S. (2016). Sharks in the jungle: real and imagined sea monsters of the Maya. *Antiquity*, 90(354), 1522–1536. https://doi.org/10.15184/aqy.2016.218

Ojeda, E. (2020). *El aprovechamiento de los recursos de fauna vertebrada en la costa norte de la Península de Yucatán: el caso particular del Puerto prehispánico de Vista Alegre entre el Preclásico terminal al Posclásico (75 a.C. – 1550 d.C). [Tesis de maestría]*. Universidad de Granada.

Pauly, D. (1995). Anecdotes and the shifting base-line syndrome of fisheries. *Trends in Ecology & Evolution*, 10(10), 430. https://doi.org/10.1016/s0169-5347(00)89171-5

Peña, A., Pérez, J., Munguía, A. & Espinoza, A. (2021). Sistemas socio-ecológicos como unidad de manejo: el caso de las pesquerías de Campeche, México. *Economía, Sociedad y Territorio*, 21(65), 113–145. https://doi.org/10.22136/est20211601

Pérez, J. & Méndez, I. (2015). The small-scale shark fisheries in the southern Gulf of Mexico: understanding their heterogeneity to improve their management. *Fisheries Research*, 172, 96–104. https://doi.org/10.1016/j.fishres.2015.07.004

Poulakis, G. & Grubbs, R. (2019). Biology and ecology of sawfishes: status of research and future outlook. *Endangered Species Research*, 39, 77–90. https://doi.org/10.3354/esr00955

Robillard, M. & Séret, B. (2006). Cultural importance and decline of sawfish (Pristidae) populations in West Africa. *Cybium*, 30(4), 23–30.

Robles, E., Sanromán, A., Barajas, M., Hernández, K., Bolaño, N. & Mendoza, U. (2018). Un pez marino tierra adentro. Los peces sierra del Templo Mayor de Tenochtitlan. *Arqueología Mexicana*, 25(151), 20–27.

Rubio, E., Murad, M. & Rovira, J. (2010). Crisis ambiental en la costa de Quintana Roo como consecuencia de una visión limitada de lo que representa el desarrollo sustentable. *Argumentos*, 23(63), 161–185.

Rubio, N., Aburto, O., Jackson, J. & Ezcurra, E. (2017). Coastal exploitation throughout Marismas Nacionales Wetlands in Northwest Mexico. *Tropical Conservation Science*, 10, 1–26. https://doi.org/10.1177/1940082917697261

Rubio, N., Herrera, J., Morales, S., Moreno, M., Montero, J. & Pech, M. (2018). Water quality of inlets' water bodies in a growing touristic barrier reef island "Isla Holbox" at the Yucatan peninsula. *Regional Studies in Marine Science*, 22, 112–124. https://doi.org/10.1016/j.rsma.2018.06.006

Rubio, N., Montero, J., Rubio, I., Morales, S., Pech, M., Ruiz, G. et al. (2022). Tourists perceptions of Caribbean islands facing environmental threats before the COVID-19 health crisis: Holbox Island and archipelago of Bocas del Toro. *PLoS ONE*, 17(3), e0262014. https://doi.org/10.1371/journal.pone.0262014

Rubio, N., Moreno, M., Glover, J., Rissolo, D., Sáenz, A., Götz, C. et al. (2019). Poor fisheries data, many fishers, and increasing tourism development: interdisciplinary views on past and current small-scale fisheries exploitation at Holbox Island. *Marine Policy*, 100, 8–20. https://doi.org/10.1016/j.marpol.2018.10.003

Rubio, N., Pérez, C., Díaz, M., Cruz, I., González, J. &Favela, S. (2021). *El Club de los Tiburones México*. In Boletín Informativo, Noticias de los Miembros de la Alianza Kanan Kay. Issue December 2021. pp. 14–15.

Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación. (2017). Evolución del Instituto Nacional de Pesca (INAPESCA). Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación. pp. 491–516.

SEDETUR. (2019). *Indicadores Turísticos*. *Caribe Mexicano. Gobierno de México*. https://cptq.mx/inteligencia/indicadores-sedetur/

Sierra, T.N. (1996). Informe 1996. *Proyecto Arqueológico Xcambó. Instituto Nacional de Antropología e Historia, Mérida. Informe técnico*.

Sierra, T.N. (1997). *Proyecto arqueológico Xcambó. Informe segunda temporada. Instituto Nacional de Antropología e Historia, Yucatán, Mérida. Informe técnico*.

Sierra, T.N. (1998). *Proyecto arqueológico Xcambó. Informe tercera temporada. Instituto Nacional de Antropología e Historia, Yucatán, Mérida. Informe técnico*.

Simpfendorfer, C. (2001). Essential Habitat of smalltooth sawfish (*Pristis pectinata*). Mote Marine Laboratory Technical Report 786: 1–21.

Suchley, A. & Alvarez, L. (2018). Local human activities limit marine protection efficacy on Caribbean coral reefs. *Conservation Letters*, 11(5), e12571. https://doi.org/10.1111/conl.12571

Tittensor, D., Walpole, M., Hill, S., Boyce, D., Britten, G., Burgess, N. et al. (2014). A mid torm analysis of progress toward international biodiversity targets. *Science (New York, N.Y.)*, 346(6206), 241–244. https://doi.org/10.1126/science.1257484

Turvey, S., Barrett, L., Yujiang, H., Lei, Z., Xinqiao, Z., Xianyan, W. et al. (2010). Rapidly shifting baselines in Yangtze fishing communities and local memory of extinct species. *Conservation Biology*, 24(3), 778–787. https://doi.org/10.1111/j.1523-1739.2009.01395.x

Valdez, R., Guzmán, J., Abarca, F., Tarango, L. & Sánchez, F. (2006). Wildlife conservation and management in Mexico. *Wildlife Society Bulletin (1973–2006)*, 34(2), 270–282. http://www.jstor.org/stable/3785122

Varns, T., Cortez, R., Hovani, L. & Kingsbury, P. (2018). *Yucatán peninsula, Mexico: a jurisdictional approach to conserving the Maya forest*. Arlington, VA, USA: The Nature Conservancy.

Voorhies, B. (1976). *The Chantuto people: an archaic period society of the Chiapas littoral. Mexico*, Provo: New World Archaeological Foundation.

Weiskopf, S., Cushing, J., Morelli, T. & Myers, B. (2021). Climate change risks and adaptation options for Madagascar. *Ecology and Society*, 26(4), 36. https://doi.org/10.5751/ES-12816-260436

Wiese, P. (2000). *Environmental impact of urban and industrial development a case history: Cancún, Quintana Roo. México*. *UNESCO* Environment and development in coastal regions and in small islands.

SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

How to cite this article: Rubio-Cisneros, N.T., Martínez-Candelas, I.A., Ordaz-García, D., Pérez-Jiménez, J.C., Jiménez-Cano, N.G., Glover, J.B. et al. (2023). Interdisciplinary science and fishers' local ecological knowledge of sawfishes in the Yucatán Peninsula. *Aquatic Conservation: Marine and Freshwater Ecosystems*, 1–20. https://doi.org/10.1002/aqc.3981