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Conservation

Confirmed presence of the Neotropical otter, *Lontra longicaudis*, in Laguna Bacalar, Quintana Roo, Mexico

Confirmación de la presencia de la nutria neotropical, Lontra longicaudis*, en la laguna de Bacalar, Quintana Roo, México*

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Abstract

The Neotropical otter *Lontra longicaudis* is one of the least studied mammals of the Yucatán Peninsula and its presence in some water bodies of this region is questionable. Laguna Bacalar is the largest freshwater body located in the Yucatán Peninsula and faces several conservation problems due to its high potential for tourism development. We confirmed the presence of *L. longicaudis* in Laguna Bacalar by conducting interviews with residents, and the search for direct (sightings) and indirect (e.g., footprints) evidence of the species in 2013. We also include recent direct and indirect evidence (2019-2020). We classified the records into levels of certainty, according to the type of evidence (photographs, videos). We obtained 9 records of Neotropical otter through interviews (level 3), 3 sightings and 4 footprints (level 1), and 4 sightings (3 of these with level 2 and 1 with level 3 of certainty). It is necessary to increase the research effort to determine the conservation status and distribution of the Neotropical otter in the lagoon.

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We recommend making efforts in terms of socialization and education to facilitate the conservation of the Neotropical otters and their habitat in Laguna Bacalar.

Keywords: Mustelidae; Yucatán Peninsula; Freshwater habitat; Aquatic mammal

Resumen

La nutria neotropical *Lontra longicaudis* es uno de los mamíferos menos estudiados en la península de Yucatán y su presencia en algunos cuerpos de agua de esta región es cuestionable. La laguna de Bacalar es el mayor cuerpo de agua dulce de la península de Yucatán y enfrenta varios problemas de conservación debido a su alto potencial de desarrollo turístico. Confirmamos la presencia de *L. longicaudis* en la laguna de Bacalar mediante entrevistas con los residentes locales y la búsqueda de evidencias directas (avistamientos) e indirectas (p. ej. huellas) de presencia de la especie en 2013. Incluimos observaciones directas recientes (2019-2020). Clasificamos la información por niveles de certeza, según el tipo de evidencia que la respalda (fotografías, videos). Obtuvimos 9 registros de nutria neotropical a través de entrevistas (nivel 3); 3 avistamientos y 4 huellas (nivel 1), y 4 avistamientos (3 con nivel 2 y 1 con nivel 3 de certeza). Es necesario incrementar los esfuerzos de investigación para determinar el estado de conservación y la distribución de la nutria neotropical en la laguna. Recomendamos realizar esfuerzos en cuanto a la socialización y a la educación para facilitar la conservación de esta especie y su hábitat en la laguna de Bacalar.

Palabras clave: Mustelidae; Península de Yucatán; Hábitat dulceacuícola; Mamífero acuático

Introduction

The Neotropical otter, *Lontra longicaudis* (Olfers, 1818), is an elusive mustelid, with a wide distribution from northwestern and northeastern Mexico to Uruguay, Paraguay, and northern Argentina (Larivière, 1999). This species inhabits rivers, streams with strong currents, and lagoons located between 0 to 3,000 m in altitude (Larivière, 1999; Rheingantz et al., 2021; Trujillo & Arcila, 2006). In Mexico, *L. longicaudis* occurs in the southern area of the state of Tamaulipas and the slope of the Gulf of Mexico, and in the northern area of Sonora, Chihuahua, and Durango, and the continental slopes of the Sierra Madre Occidental and Sierra Madre Oriental, southward to the border with Guatemala (Aranda-Sánchez, 2015; Gallo-Reynoso, 1997; Gallo-Reynoso & Meiners, 2018).

In Mexico, information about distribution, population status, ecology, and conservation aspects of *L. longicaudis* has been obtained from systematic studies mainly from the northwestern (Cruz-García et al., 2017; Gallo-Reynoso, 1997; Gallo-Reynoso et al., 2008; García-Silva et al., 2021; Rangel-Aguilar & Gallo-Reynoso, 2013), western (Brito-Ríos, 2017; Casariego, 2013; Espinoza-Medinilla et al., 1998; Gallo-Reynoso, 1989), central (Guerrero-Flores et al., 2013) and Gulf of Mexico (Macías-Sánchez, 2003; Santiago-Plata et al., 2013) regions. In Quintana Roo, this species has been reported for the Reserva de la Biosfera Sian Ka'an, Laguna Guerrero, Laguna Chile Verde, the north and northeastern portion of Chetumal Bay, and in the Río Hondo along the border with Belize (Calmé & Sanvicente, 2009; Escobedo-Cabrera et al., 2002, 2009; Gallo-Reynoso, 1997; Morales-Vela & Olivera-Gómez, 1991, 1994; Morales-Vela et al., 2011; Orozco-Meyer, 1998). However, efforts to monitor this species in Quintana Roo have been scarce.

Neotropical otters are top predators in the trophic food chain of riverine systems, feeding predominantly upon fishes, but also consuming other groups of organisms (Santiago-Plata et al., 2013; Gallo-Reynoso et al., 2008). The communal latrines of this species represent a food resource for vertebrate and invertebrate communities, therefore playing an important role in the trophic chain (Laurentino et al., 2019). Populations of *L. longicaudis* have been extirpated in several areas of its historical distribution due to the fur trade, their capture and use as pets, and conflicts with fishermen (Gallo-Reynoso, 1989; Santiago-Plata et al., 2013). Nowadays, *L. longicaudis* is listed as Near Threatened by the International Union for Conservation of Nature (Rheingantz et al., 2021); as Threatened in the Official Mexican Norm 059 (NOM-059- ECOL-2010) (Semarnat, 2010), and included in the Appendix I of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES, 2019).

The Laguna Bacalar is located in the southern part of Quintana Roo, between the municipalities of Bacalar and Othón P. Blanco (Gómez-Pech et al., 2018). This lagoon and its surroundings have an enormous potential for tourism due to the attractive landscape and other environmental attributes (Semarnat, 2015). In 2018, around 90,000 tourists visited Bacalar, and tourism is expected to increase in the near future, which has serious implications on the transformation of land use in the human settlements near the lagoon (Gómez-Pech et al., 2018; Yanez-Montalvo et al., 2020).

Several governmental policies protect the Laguna Bacalar such as the establishment of defined environmental management units in order to maintain ecosystem connectivity and the conservation of biological diversity (Semarnat, 2015). Additionally, several lagoons interconnected with the Laguna Bacalar (e.g., Chile Verde) are included within the Natural Protected Area Santuario del Manatí-Bahía de Chetumal (DOF, 2008). Nevertheless, productive activities with low environmental impact are allowed in Laguna Bacalar, with restrictions that guarantee conservation and promote a minimum change in land use (Semarnat, 2015). Until now, information regarding *L. longicaudis* along the shoreline of Laguna Bacalar consisted in anecdotes told by people living in the surrounding area of the lagoon (Morales-Vela & Olivera-Gómez, 1991). Here, we compiled evidence that confirms the contemporary occurrence of *L. longicaudis* in this intense use touristic lagoon.

Materials and methods

The study area corresponds to the shoreline of Laguna Bacalar, which encompasses the lagoon itself, the surrounding wetlands (from 18º56’49.35” N, 88º08’58.97” W, and 18º31’37.27” N, 88º28’06.80” W), and the human settlements next to the lagoon (Xul-Ha, Bacalar, Aarón Merino Fernández, Buenavista, and Pedro Antonio Santos) (Fig. 1). The Laguna Bacalar has an area of 9,572.74 ha, and consists of 43% of surface waters and 49% of mangrove forest (*Rhizophora mangle*, *Conocarpus erectus* and *Laguncularia racemosa*); the remaining 8% corresponds to vegetation of tular (*Typha sp.*), secondary shrub and tropical deciduous forest, and cultivated pastures for cattle (Semarnat, 2015).

The origin of the Laguna Bacalar is not completely karstic, its physiognomy is the product of the tectonic dynamic that occurred at the Upper Miocene age along the lagoon and the Río Hondo (Ceballos-Martínez, 2002). This lagoon has a length of 54 km in a straight line from the southern to the northern orientation and a maximum width of 2 km; it communicates superficially with the Río Hondo through the Chac stream (Ceballos-Martínez, 2002), and through several shallow streams with the Laguna Chile Verde, which flows into Laguna Guerrero (Fig. 1) (Morales-Vela & Olivera-Gómez, 1991). The region is characterized by a subhumid warm climate, with an average annual temperature of 26.8 °C (range, 16.15 °C - 34.9 °C) and an accumulated average annual precipitation of 1,040.8 mm (range, 12 mm - 2,243.6 mm), which intensifies between June and September (SMN & Conagua, 2020). The municipality of Bacalar has a population of 41,754 inhabitants, being the town of Bacalar the main human settlement with 12,527 inhabitants (INEGI, 2020).

During April to August 2013, we conducted 30 semi-structured interviews with key inhabitants such as boatmen, fishermen and hosts from Xul-Há, Bacalar, Buena Vista, and Pedro Antonio Santos to gather information on the presence of *L. longicaudis* in the lagoon. The choice of the interviewees depended on the characteristics of each town visited in terms of people’s occupation and proximity of the residences to the lagoon. In parallel, we conducted 16 field trips to the sites reported by the interviewees as potential areas of the Neotropical otter presence. The surveys consisted of navigations in kayak along the shore of the lagoon in search of evidences of *L. longicaudis* presence, such as shelters, latrines, feces, or footprints (Orozco-Meyer, 1998). When possible, we walked on ground to examine approximately 1 m of the lagoon edge, depending on the site characteristics. When footprints were found, we measured their length and width *in situ* and used field guides to verify the identification (Aranda, 2000; Reid, 1997). These field trips were carried out from May to August 2013, between 6:30 a.m. to 3:40 p.m.

To include recent data on the presence of *L. longicaudis* in the lagoon, we searched for published literature obtained from Google Scholar and information published between 2014-2020 in local newspapers, social media (e.g., Facebook, Twitter), and virtual databases (e.g., iNaturalist, GBIF) as secondary sources of information. All data were compiled in a database accompanied by the date, time, geographic coordinates, and the name of the observer, and included reliable records of opportunistic observations obtained in March, July, and September 2019.

We classified the records into indirect signs of the presence of Neotropical otter (e.g., footprints, feces, latrines, or shelters), and direct sightings (e.g., individuals of the Neotropical otter). We also assigned a level of certainty to each obtained record, as follows: level 1, indirect and direct records consisting in confirmed sightings with a high degree of certainty and corroborated with evidence (e.g., photographs, videos). We also included observations made by villagers with some supporting evidence (photographs, videos). Level 2, indirect and direct records made by coauthors, but without evidence (photographs or videos). Level 3, indirect and direct records without evidence or detailed descriptions obtained through interviews or observations made by villagers.

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Results

We obtained 9 records of *Lontra longicaudis* sightings in different areas of the Laguna Bacalar through interviews (level 3 degree of certainty; Fig. 1). Additionally, between 2013 and 2020, we compiled 11 records of the species during surveys, opportunistically or by review of secondary sources, consisted of indirect (footprints, n = 4; Fig. 2) and direct (sightings, n = 7; Fig. 3) records (Table 1). Indirect and direct records with evidence (photographs, videos) correspond to level 1 degree of certainty (Table 1). Also, we recorded 4 sightings, 3 with level 2 degree of certainty and made by a villager with level 3 degree of certainty (Table 1). Detailed results are described below.

Interviews. We conducted 30 interviews to key people between 15 and 85 years old, but the majority (37%) were between 35-50 years old. The main activities of the interviewees in Bacalar town were workers of the hotel sector (37.7%) and boat captains (20%), while in Buena Vista and Pedro Antonio Santos villages were mostly farmers (40%). Of the total sample, only 16 interviewees (53.3%) indicated sightings of *L. longicaudis* in different environments such as in the water, mangrove forest, docks, and beaches at 4 sites: Bacalar town, 'Los Rápidos', Pedro Antonio Santos, and the Laguna Mariscal (Fig. 1). Additionally, interviewees indicated that they have seen *L. longicaudis* in the study area at least once or twice in their lives (average age = 36 years old, range = 15-85). Among the people who have had direct sightings of Neotropical otters, 36.7% have seen solitary individuals, while 6.7% have seen pairs and 10% have seen groups larger than 4 individuals.

Surveys. The systematic search for *L. longicaudis* conducted in 2013 covered 51.2 km of shoreline, channels, and wetlands, with a total sampling effort of 114 h (7 h daily). We found 3 footprints of *L. longicaudis*, 2 of them close to each other in a small channel located on the eastern edge of the lagoon, on Isla de los Pájaros (Fig. 2A, B). These footprints indicated that the individual was running and measured 6-8 cm long and 5-6 cm wide. A third footprint was found in the Pedro Antonio Santos village and measured 7 cm long by 6 cm wide (Fig. 2C). Additional footprints were found but they were very old or not clear, and we decided not to include them. None of these individuals were observed, or their feces found during these surveys.

Opportunistic records. On 29th July 2020, another footprint was recorded by Pablo M. Beutelspacher-García (PMB-G) in the southern part of the lagoon near Xul Há (Fig. 2D). This footprint was 4 cm wide, and the

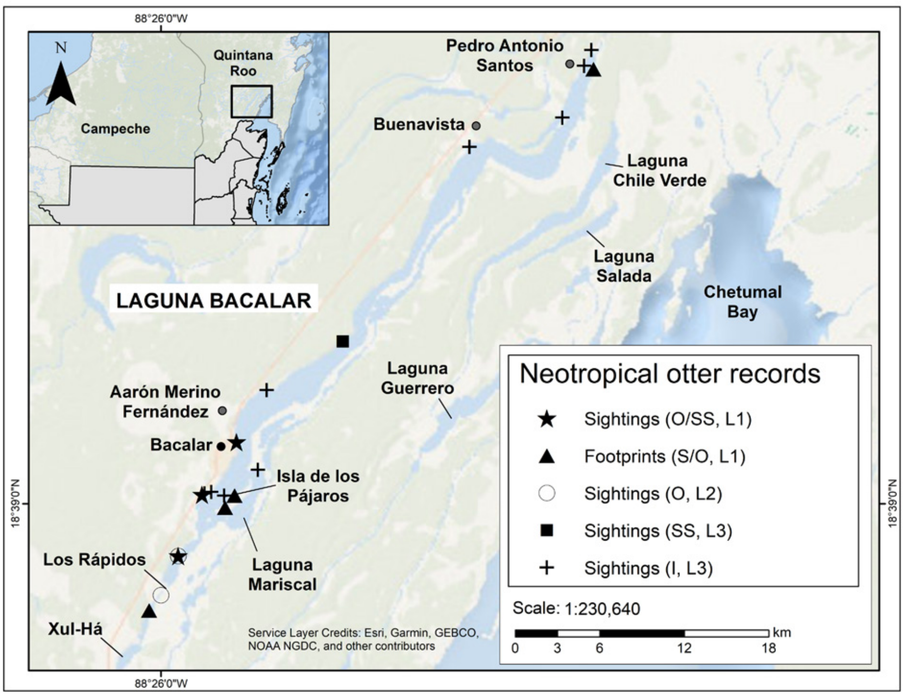

Figure 1. The coastline of Laguna Bacalar where Neotropical otter (*Lontra longicaudis*) sightings and footprints were recorded between 2010, 2013 and 2020. Methods: O = opportunistic, SS = secondary sources, S = surveys, I = interviews. L1, L2 and L3 correspond to the certainty levels.

plantar surface was more evident as a Neotropical otter. All following sightings of *L. longicaudis* were obtained opportunistically and recorded during daylight hours at a short distance from the west shore of the lagoon. Sightings 1 (Table 1; Fig. 3A): on 8th March 2019 an adult *L. longicaudis* was observed swimming on the southwest side of the lagoon by Pablo M. Beutelspacher-García (PMB-G) at 16.54 h in an area of mangroves and aquatic grasses. Days later (March 13th and 14th, 2019) and around the same time, PMB-G observed an adult Neotropical otter in the same place again. We do not have evidence to indicate whether it was the same or a different individual; however, we consider both sightings as different records (Table 1: sighting 2 and 3). Sighting 4: this sighting was made on September 1st 2019 by Silvana Marisa Ibarra-Madrigal (SMI-M) corresponding to an adult *L. longicaudis* observed in Los Rápidos, an area where the lagoon narrows about 5 m, with an average depth of 4 m, increasing the water flow (1.03 to 2.06 m/s) compared to the rest of the lagoon.

Secondary sources. The following records correspond to opportunistic sightings. Sighting 5: an adult of *L. longicaudis* was sighted by a villager in 2010, who contacted Jonathan Pérez-Flores (JP-F); however, no details of the observation were obtained. Sighting 6: on 31st August 2019 a villager recorded a 46-second video of an adult *L. longicaudis* in the southern end of the lagoon. The video showed the individual swimming, breathing, and moving southward (Fig. 3B-D). José Rogelio Cedeño-Vázquez (JRC-V) contacted the villager to retrieve the information and video about this sighting. Sighting 7: on 12th April 2020 a 55-second video of an adult *L. longicaudis* was recorded near the shoreline of Laguna Bacalar by a local villager. The individual was swimming, breathing, and moving northward (Fig. 3E-G). The video was broadcast on social media and a journalist contacted Delma Nataly Castelblanco-Martínez (DNC-M) to write a note about the sighting in a local newspaper.

Discussion

We report the presence of the Neotropical otter in the Laguna Bacalar through photographs of an individual and 4 footprints, complemented with secondary information obtained through interviews with local inhabitants and videos recorded by villagers.

Although the raccoon (*Procyon lotor*), and other mustelids such as the greater grison (*Galictis vittata*) and the tayra (*Eira barbara*) have been recorded in the area (Lorenzo et al., 2008; Pozo de la Tijera, 1997; Pozo de

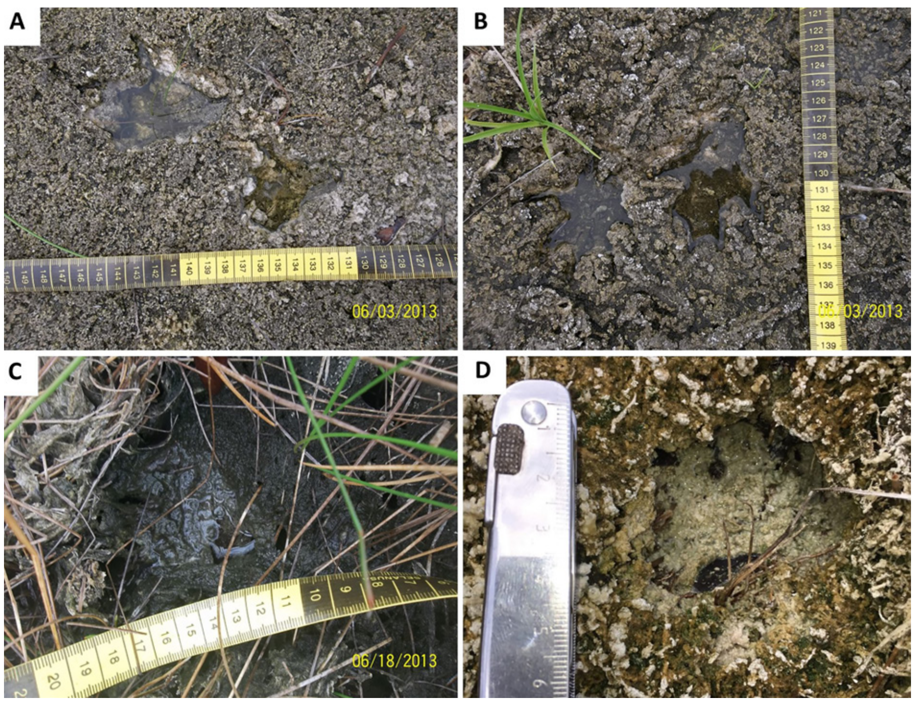

Figure 2. Indirect records of the Neotropical otter (*Lontra longicaudis*) in Laguna Bacalar. A and B: footprints found in the Isla de los Pájaros; C: footprint found in the nortern zone near to Pedro A. Santos; D: footprint found in the southern zone between Xul-Há and Los Rápidos. See Table 1 for more details.

la Tijera et al., 1991), the possibility of confusing the sets of footprints of these species with *L. longicaudis* were demoted based on the measurements obtained in the field, which were consistent with the identification guides (Aranda-Sánchez, 2015; Gallo-Reynoso & Casariego, 2005; Reid, 1997). The Neotropical otter's front and hind feet have very short and thick claws whereas the hind claws are relatively longer. In deep footprints, it is possible to distinguish the interdigital membrane on both front and hind feet (e.g., Fig. 2A, B). In contrast, footprints of the greater grison, tayra, and raccoon have short and thin claws (Aranda-Sánchez, 2015); in addition, raccoon tracks present elongated, rounded and long toes without an interdigital membrane.

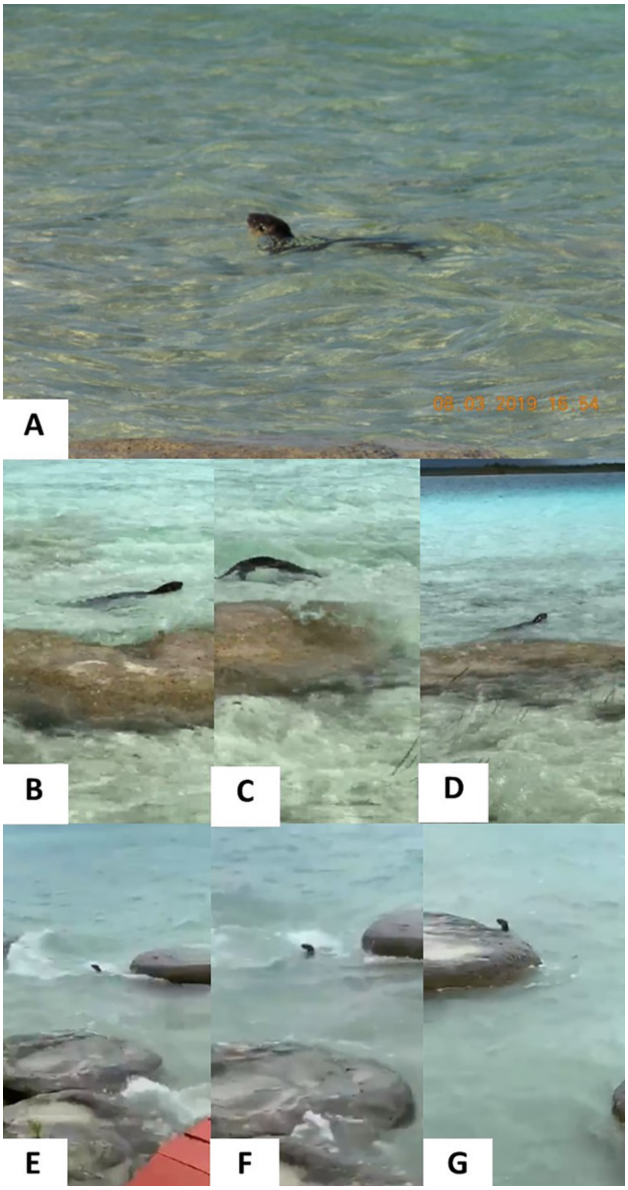

Figure 3. Direct records of the Neotropical otter (*Lontra longicaudis*) in Laguna Bacalar. A: An individual observed on March 8, 2019; B-D: video captures of the otter found in front of a residence located in the southern coast of the Laguna Bacalar, on August 31, 2019; E-G: video captures of the otter observed swimming in the lagoon, in an area near the Bacalar town, on April 12, 2020 (during the quarantine due to COVID-19).

The videos and photographic records are evidence of individuals with the distinctive external characteristics of *L. longicaudis*: a medium-size mammal, dark grayish-brown pelage, with a long tail, and a relative small and flat head (Larivière, 1999). Additionally, greater grison, tayras, and racoons are predominantly terrestrial (Chávez-Tovar, 2005a, b; Valenzuela-Galván, 2005). The sightings described in this study consisted of swimming individuals of *L. longicaudis*, which is a common behavior on their habitat (Kruuk, 2006). The reported footprints were also found close to the aquatic habitat of *L. longicaudis* (Gallo-Reynoso & Casariego, 2005; Kruuk, 2006; Muãnis & Oliveira, 2011).

We confirmed the presence of *L. longicaudis* in all the locations on the shoreline of Laguna Bacalar that were previously indicated by interviewees, except for the Laguna Mariscal. Previous authors reported the presence of *L. longicaudis* in nearby places, such as Río Hondo, Laguna Guerrero and Laguna Chile Verde (Calmé y Sanvicente, 2009), indicating the possibility of dispersion between water bodies. The Neotropical otter can move between streams that converge in different rivers, covering not only the course of water bodies, but also terrestrial environments (Gallo-Reynoso, 1989). The findings presented here indicate that *L. longicaudis* occurs in the western area of the Laguna Bacalar, which is connected to other karstic freshwater bodies, such as Laguna Milagros, Río Hondo (through the Chac stream), and Mariscal and Chile Verde brackish lagoons. Our observations suggest that *L. longicaudis* could benefit from this complex natural corridor, based on hydrological connections as means of dispersal and probable foraging behavior (Hernández-Arana et al., 2015).

The Neotropical otter does not strictly mark its terrestrial boundaries, instead, it uses scent marks, such as spraints, mucus, urine and feces for intraspecific communication and for habitat selection (Michalski et al., 2021; Roberts et al., 2016). Neotropical otters have high site fidelity, and their home range varies from 2 to 7 km in length (Gallo-Reynoso, 1989; Roberts et al., 2016). In addition, sex, food availability and the reproductive season generally determine the size of the otters home range (Blundell et al., 2000; Gallo-Reynoso, 1989; Kruuk, 2006). In this study, we collected direct and indirect records of Neotropical otters confirming its presence, but questions about how this species uses the habitat available in Laguna Bacalar and surroundings remain unresolved.

Previous research on the diet of *L. longicaudis* indicates preference for fish; nevertheless, mollusks, insects, crustaceans, amphibians, reptiles, birds and small mammals are also consumed (Gallo-Reynoso, 1997; Juárez-Sánchez et al., 2019; Platt & Rainwater, 2011; Santiago-Plata et al., 2013). Since Laguna Bacalar is an important habitat for several freshwater fish species (Arce-Ibarra, 2011; Gamboa-Pérez, 1991; Valdez-Moreno et al., 2019), there is a considerable availability and diversity of prey for the Neotropical otter. Other important potential prey for the species such as insects (e.g., Coleoptera; Morón-Ríos, 2011), amphibians (Bufonidae, Hylidae) and reptiles (Dermatemydidae, Emydidae, Geoemydidae, Kinosternidae, Iguanidae, Colubridae) (Pozo de la Tijera et al., 1991; Pablo M. Beutelspacher-García pers. obs.) are also part of the native fauna of the Laguna Bacalar ecosystem. The knowledge about feeding habitats of *L. longicaudis* in the area, including diet composition, prey preference, and seasonal variability is absent. Therefore, future studies on the Neotropical otter diet in this lagoon conducted in different climatic seasons would be informative to better understand the ecological role of the species in this region.

Neotropical otters can be found in areas with certain levels of anthropogenic disturbance, as long as there are food availability and places for refuge, and extensive aquatic networks (Gallo-Reynoso, 1997; Gallo-Reynoso et al., 2019; Larivière, 1999). However, the effect of environmental degradation needs to be further investigated at population level since it can affect refuge availability and space use patterns (Pardini & Trajano, 1999; Rheingantz et al., 2017). Although we did not measure environmental and habitat quality variables in the lagoon during this study, previous studies have indicated an incipient contamination of Laguna Bacalar and the Yucatán Peninsula waters due to agricultural practices, local wastewater contamination, and intensive tourism (Aranda-Cirerol et al., 2011; Tobón-Velázquez et al., 2019; Yanez-Montalvo et al., 2020). Considering the increasingly growing tourism and economic development of the Laguna Bacalar (Gómez-Pech et al., 2018; Ibarra-Madrigal et al., 2020), we suggest developing future studies on habitat quality to describe the human-related factors that could affect the lagoon as a suitable habitat for this species.

It is interesting to note that most of the opportunistic encounters with Neotropical otters occurred recently (2019-2020), suggesting an increase in population or improvement in conservation status. In this sense, a long-term monitoring program is needed to investigate changes in species abundance and distribution. Such studies can indicate connectivity between water bodies (Hernández-Arana et al., 2015), which could contribute to the proposal and establishment of effective strategies for the conservation of this species and habitat management, also expanding the polygon of the Natural Protected Area Santuario

Table 1

Neotropical otter (*Lontra longicaudis*) records along the shoreline of Laguna Bacalar in 2010, 2013, and between March 2019 and April 2020. See the text for more details about certainty level criteria.

No.	Date and time	Type of record	Method	Type of evidence	Certainty level
1	03 Jun 2013, 17.30 h	Indirect (footprints)	Survey	Photograph (Fig. 2A)	1
2	03 Jun 2013, 13.20 h	Indirect (footprints)	Survey	Photograph (Fig. 2B)	1
3	18 Jun 2013, 13.20 h	Indirect (footprints)	Survey	Photograph (Fig. 2C)	1
4	29 Jul 2019, 09.45 h	Indirect (footprints)	Opportunistic	Photograph (Fig. 2D)	1
5	08 Mar 2019, 16.54 h	Direct (sighting 1)	Opportunistic	Photograph (Fig. 3A)	1
6	13 Mar 2019, 16.08 h	Direct (sighting 2)	Opportunistic	None	2
7	14 Mar 2019, 15.15 h	Direct (sighting 3)	Opportunistic	None	2
8	01 Sep 2019, undefined	Direct (sighting 4)	Opportunistic	None	2
9	? ? 2010, undefined	Direct (sighting 5) *	Secondary sources	None	3
10	31 Aug 2019, afternoon	Direct (sighting 6) †	Secondary sources	Video (Fig. 3B-D)	1
11	12 Apr 2020, afternoon	Direct (sighting 7) ‡	Secondary sources	Video (Fig. 3E-G)	1

Sources: *Martínez, R., pers. comm. (villager), †Salazar Cruz, R. E. (villager), ‡Medios Primer Mestizaje (local newspaper).

del Manatí-Bahía de Chetumal towards the northern of Laguna Bacalar could be considered in the future. Since the Neotropical otter is an elusive semi-aquatic mammal, we recommend using new methodological approaches to estimate the presence and relative abundance of the species such as camera traps (Barocas et al., 2016; Gallo-Reynoso et al., 2019; Wagnon & Serfass, 2016), environmental DNA (eDNA) (Beng & Corlett, 2020; Ma et al., 2016; Padgett-Stewart et al., 2016), and drones (Bushaw et al., 2019; Christie et al., 2016).

Finally, it is critical to know the conservation status of the Neotropical otter at the local level to implement future awareness campaigns and sensitize stakeholders to work towards the conservation of this species. Our study benefited from information obtained by citizens and journalists, therefore, a citizen science project addressing *L. longicaudis* status in Laguna Bacalar is essential to both monitor the species and involve local inhabitants in its protection.

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Article

Citizen Science as a Tool to Get Baseline Ecological and Biological Data on Sharks and Rays in a Data-Poor Region

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Abstract: The Mexican Caribbean is in one of the regions with the greatest diversity of elasmobranchs in the world. However, the population status of most of the shark and ray species in this region is unknown. We used a citizen science program based on divers to collect data about the diversity, abundance, and distribution of elasmobranchs in this region. We visited dive centers in six locations and performed structured interviews with divemasters, instructors, and owners of the diving centers. In total, 79 divers were interviewed, of which 69% had more than five years' experience diving in the Mexican Caribbean. Divers could identify 24 elasmobranch species for this region. Most of the divers (82%) reported a decrease in sightings of sharks and rays. Rays were the most frequently sighted species by divers (89%), and the spotted eagle ray (*A. narinari*) was the most common elasmobranch species reported in the region. Citizen science was a useful approach gathering for baseline information about sharks and rays in the Mexican Caribbean, increasing our knowledge of the abundance and distribution of some species in this region. Citizen science affords the opportunity to obtain long-term data that can be useful for management and conservation.

Keywords: sharks; rays; monitoring; coral reef; scuba diving

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1. Introduction

Elasmobranchs constitute a diverse group that occupies a wide range of aquatic habitats around the world. Some species spend their lives in the same habitat, but the majority are often mobile and move between different habitats during their lifetime. Shark and ray populations have decreased dramatically due to climate change, overfishing, and habitat degradation, and in some regions, the status of their populations is unknown, impeding the creation and application of management strategies [1]. The last global IUCN Red List of Threatened Species assessment of elasmobranchs (2013 to 2021) revealed a critical reduction in their populations, estimating that over one-third of the shark and ray species are globally threatened with extinction and more than 75% of species are threatened throughout tropical and sub-tropical coastal and pelagic waters [1].

The Western Central Atlantic Region including the Caribbean Sea is considered one of the hotspots of shark and ray biodiversity in the world, showing the highest diversity and regional endemism of elasmobranchs in tropical America [2,3]. In the Mexican Caribbean, 85 elasmobranch species (49 sharks and 36 rays) are reported that represent 41% of the country's biodiversity [4], but the population status of most of these species is unknown. Information about the elasmobranch population in this region is only available for the most charismatic species, such as the whale shark (*Rhincodon typus*), oceanic manta ray (*Mobula birrostris*), and whitespotted eagle ray (*Aetobatus narinari*) [5–7].

Sharks and rays represent an important resource for the local fisheries and the tourism industry in the Mexican Caribbean, contributing significantly to the local economy [8]. Multiple species are targeted or caught as bycatch in coastal and artisanal fisheries in this region and rays are an important component of the bycatch in the shrimp fishery [9,10]. Regionally, several management strategies have been implemented, such as temporal bans, net regulations, and no fishing areas for sharks and rays, but the lack of enforcement is evident and consistent in the Mexican Caribbean, decreasing the impact of these tools for shark and ray conservation. The lack of long-term monitoring of elasmobranch populations as well as data concerning ecological and biological aspects of these species complicate the evaluation and implementation of regional management tools.

Elasmobranch population status is often estimated using data from fisheries (dependent or independent). In most cases, only the commercially important species are included, and extractive sampling is sometimes used, which can affect the population and is not recommended for rare or threatened species, as is the case for many elasmobranch species [11]. More suitable alternatives to extractive methods for describing and monitoring elasmobranch populations include underwater visual censuses (UVC) conducted by scientific divers and the baited remote under water video stations (BRUVS). However, the implementation of these methods can require significant effort and financial investment, limiting their potential use for long-term monitoring [12].

To improve elasmobranch conservation, ecological and biological data are needed around the world [1], which necessitates a large logistical effort and high financial investment. This is the main concern for low, lower-middle, and middle-income countries where governmental investment in research is very poor and biodiversity conservation is not a priority. In those countries with limited data availability, it is important to implement other cost-effective methods to collect ecological and biological data, which can enable long-term monitoring to increase knowledge of the status of elasmobranch populations [1].

Citizen science programs to collect data about the environment and species have been widely used and represent a cost-effective tool to collect data in marine environments [13]. Citizen science is a method that integrates public outreach and scientific data collection, which allows amateur participation in scientific research and monitoring [13,14]. These programs are valuable for conservation and promote the reconnection between people and nature [14]. However, while citizen science programs are now popular and increasingly used in several countries, they are lacking in many others. Citizen science programs have improved our understanding of the abundance, diversity, presence, and distribution of different elasmobranch species [15]. Most of the citizen science projects on sharks and rays have involved non-scientific divers in the collection of ecological and biological data, demonstrating the method's success in compiling observations for the determination of long-term population trends [11,16–18].

The Mexican Caribbean has a large tourism industry and is considered one of the best diving destinations in the world. Therefore, in the present study, our goal was to explore the utility of a citizen science program based on divers to collect baseline data on the diversity and distribution of elasmobranch species in the Mexican Caribbean.

2. Materials and Methods

2.1. Study Area

The Mexican Caribbean Region is comprised of the coastal zone of the State of Quintana Roo, delimited between Cape Catoche in the north of the state (21°36′18″ N; 87°06′13″ W) to the border with Belize in the South (18°09′45″N; 87°48′50″ W), with approximately 865 km of coastline (Figure 1). This region is part of the northern portion of the Mesoamerican Barrier Reef System (MBRS), the second-largest coral reef system in the world, and the Atlantic Ocean. This system extends to the coastal waters of Mexico, Belize, Guatemala, and Honduras and has high marine biodiversity.

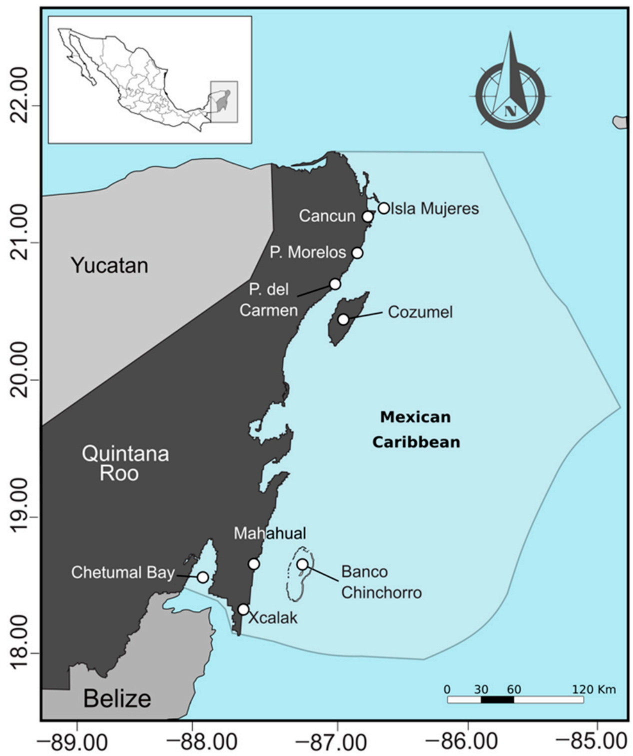

Figure 1. Study area showing the five locations in which interviews were performed.

2.2. Data Collection

We used two citizen science approaches [13,14] to collect information about sharks and rays in the Mexican Caribbean. We conducted surveys to collect data using local ecological knowledge (LEK) and collected data from the diver's direct observations (sighting reports) of sharks and rays in this region.

In August 2018, we performed an online data search looking for the contact information of the main dive centers in Cancun, Isla Mujeres, Puerto Morelos, Cozumel, Mahahual, and Xcalak to create a database. Between September 2018 and December 2020, we visited dive centers and performed structured interviews with divemasters, diving instructors, and when possible, the owners of each dive center to collect information about the shark and ray species. The interview consisted of four sections: (i) diver personal data; (ii) scuba diving experience in years of each diver internationally and in the Mexican Caribbean; (iii) knowledge of shark and ray species identification, where an image of elasmobranch species was shown to ask what species divers could identify, and the main sites of shark and ray sightings in the Mexican Caribbean; and (iv) information concerning the perception of the status of shark and ray populations, the trends of the populations, and the main factors that influence those trends. We also asked each diver about their interest in being part of a monitoring program for sharks and rays in the Mexican Caribbean. An identification guide (ID guide) for coastal shark and ray species in the Mexican Caribbean was designed to present to the divers during the interview to accurately identify individuals to the species level.

We created a sighting report on paper and online in Google forms (Google Inc., Mountain View, CA, USA) to share with the divers who wanted to be part of the monitoring. Divers contributed their data by filling out this form every time they observed a shark or ray during their diving activities. In the sighting report, we asked for information about the dive site (name and coordinates if possible), dive characteristics (date, time, duration, depth, water temperature, visibility, current), and the species observed by the diver (common or scientific name, behavior, estimated size and if possible, sex, and a photograph). Finally, we left a space to add any comments divers wanted to share with us. We gave the ID guide to each diver involved in the monitoring to help in the identification of future sightings. Additionally, we gave three IDs regarding sharks and rays in the Mexican Caribbean, including characteristics of the coastal species likely observed during a recreational dive, to improve the identification and quality of the reports to divers, rangers, and personnel working in the marine protected areas in this region. A database with all the sighting reports and associated data was created and summary analyses were performed.

3. Results

We visited in total 31 dive centers in the Mexican Caribbean, namely 22 in the north (Cancún, I. Mujeres, Puerto Morelos, and Cozumel) and nine in the south (Mahahual and Xcalak). During our visits, we performed 79 surveys with divers, and between August 2018 and December 2020 we received 499 sighting reports from 14 divers (four from Isla Mujeres, three from Cancún, four from Puerto Morelos, one for Cozumel, two from Mahahual).

3.1. Local Ecological Knowledge

In total, 79 divers (divemasters and instructors) were interviewed, of which 69% had more than five years of diving in the Mexican Caribbean. The mean number of years of diving experience in the region was 17 years. Mahahual and Xcalak were the locations in which we found the higher percentage of divers with less than five years of experience diving in the Mexican Caribbean.

During the interviews, divers identified 24 elasmobranches (10 rays and 14 sharks) species for this region. The locality in which divers identified a higher number of species was Cancún (22 species, 12 sharks, and 10 rays), followed by Puerto Morelos (19 species, 12 sharks, and seven rays) and Isla Mujeres (18 species, 11 sharks, and seven rays) (Table 1). The most common species reported by the divers were southern stingray (*Hypanus americanus*), yellow stingray (*Urobatis jamaisensis*), nurse shark (*Ginglymostoma cirratum*), blacktip shark (*Carcharhinus limbatus*), Caribbean reef shark (*Carcharhinus perezi*), and bull shark (*Carcharhinus leucas*) (Table 1).

Table 1. Sharks and rays species identified by divers in the Mexican Caribbean. (*) Presence of the specie.

Species	Cancun	Puerto Morelos	Cozumel	Isla Mujeres	Mahahual-Xcalak
Pseudobatos lentiginosus	*				
Narcine brasiliensis	*				*
Hypanus americanus	*	*	*	*	*
Hypanus guttatus	*	*	*	*	*
Aetobatus narinari	*	*	*	*	*
Urobatis jamaicensis	*	*	*	*	*
Styracura schmardae	*				
Mobula hypostoma	*	*		*	
Mobula birostris	*	*		*	*
Rhinoptera sp.	*	*		*	*
Isurus oxyrinchus	*	*	*		
Rhincodon typus		*		*	
Ginglymostoma cirratum	*	*	*	*	*
Rhizoprionodon sp.		*		*	*
Negaprion brevirostris	*	*		*	*
Galeocerdo cuvier	*	*	*	*	*
Carcharhinus leucas	*	*	*	*	*
Carcharhinus limbatus	*	*	*	*	*
Carcharhinus perezi	*	*	*	*	*
Carcharhinus plumbeus	*				
Carcharhinus longimanus	*				
Sphyrna tiburo	*	*		*	
Sphyrna mokarran	*	*	*	*	*
Sphyrna lewini	*	*		*	
Total	22	19	11	18	15

Most of the divers interviewed (73.4% n = 58) perceived a change in the abundance of sharks and rays in the Mexican Caribbean, and 81% of those divers reported a decrease in shark and ray population, attributing this change mainly to fisheries (41%), climate changes (38%, change in water temperature and natural events like hurricanes), and coastal development (24%). Other threats to sharks and rays that divers mentioned in this region are the increase of sargassum (10%), tourism, and pollution (14%). Only 26.6% of the divers interviewed reported no changes in shark and ray populations or an increase particularly reported for offshore areas near Cozumel (Table 2).

Table 2. Number of divers with a perception of elasmobranch populations changes and the perceived causes of population decrease.

			Causes of Population Decrease				
Location	**No Changes or Increase**	**Population Decrease**	**Climate Change**	**Coastal Development**	**Fisheries**	**Tourism and Pollution**	**Sargassum**
Cancún	7	19	5	4	11	4	0
Cozumel	1	1	0	0	0	0	0
I. Mujeres	4	14	6	3	7	1	2
Mahahual	4	10	6		2		3
P. Morelos	5	14	5	7	4	3	1
Total	21	58	22	14	24	8	6

A high percentage of divers (85%) reported that sharks and rays were not their objectives in the diving activity and they did not sell special packages that guaranteed the observation of these species, except in the case of the whale shark (*Rhincodon typus*), mako shark (*Isurus oxyrinchus*), bull shark (*C. leucas*), the whitespotted eagle ray (*Aetobatus narinari*), and oceanic manta ray (*Mobula birostris*), which do have defined observation seasons in which sighting these species are the objective in snorkeling and diving activities.

3.2. Sightings Report Program

Of the interviewed divers (n = 79), 90% manifested interest in participating in the shark and ray monitoring but only 20% were active in sending their sighting reports. Therefore, we had at least one diver participating in the monitoring in each location. Between August 2018 and December 2020, we receive 499 sighting reports of elasmobranchs in the Mexican Caribbean, 51% from Isla Mujeres, 31% from Mahahual, 16% from Puerto Morelos, and 2% from Cancún. Rays were more frequently sighted by divers (89%) than sharks (11%), and the whitespotted eagle ray (*A. narinari*) was the most common elasmobranch species reported in the region. The oceanic manta ray and the Atlantic devil ray were the second and third ray species in terms of number of sightings but were reported as incidental sightings by divers in Isla Mujeres as they were not observed during the dive. Otherwise, the southern stingray (*H. americanus*) and the yellow stingray (*U. jamaisensis*) had more sighting reports in the region overall. For sharks, the species most frequently sighted was the nurse shark (*G. cirratum*), followed by the Caribbean reef shark (*C. perezi*) and the great hammerhead shark (*S. mokarran*) (Figure 2).

In cases where behavior of the individuals was reported by divers (n = 80), they reported mostly individuals resting on the bottom (51%), and 21% reported feeding behaviors. Regarding the reaction that the animals had in the presence of the divers, most of them moved away from the divers (58%) while a smaller percentage did not react (29%).

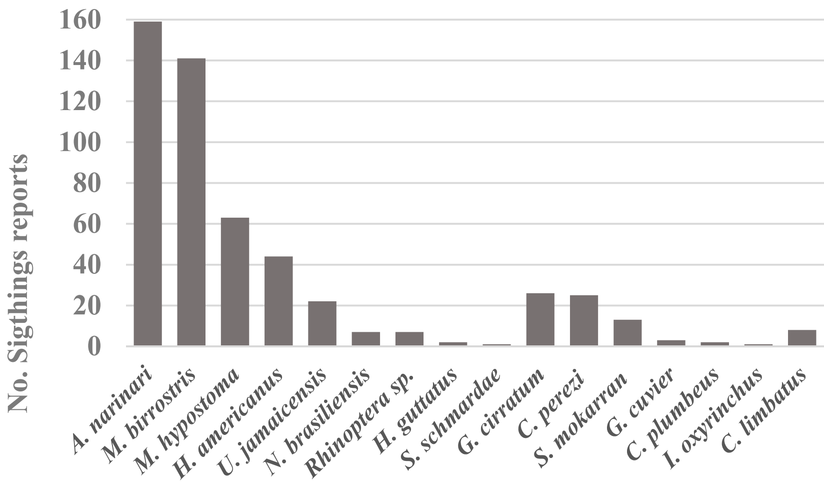

Figure 2. Number of sighting reports by specie in the Mexican Caribbean in 29 months.

4. Discussion

The integration of multiple knowledge sources for assessing species abundance, diversity, and distribution have increased over the past years as various studies have combined local ecological knowledge and scientific data to understand population trends. Although the Mexican Caribbean is in a hot spot of elasmobranch biodiversity, the scarcity of information concerning the abundance, diversity, distribution, and population status is evident. We took advantage of the high volume of diving activities in this region to collect data about sharks and rays by performing interviews with divemasters and instructors. Most of the divers interviewed have been diving for more than five years and were very knowledgeable about the shark and ray species distributed in the region. They could identify at least 24 elasmobranches (10 rays and 14 sharks) that they have seen in this region. The elasmobranch species reported by divers are mainly coastal species due to the depth limitation for this activity. In the Mexican Caribbean, other authors using fisheries monitoring and direct sampling reported a similar diversity of coastal sharks and rays in this region [19,20].

We observed that less experienced divers cannot identify the same number of species because they have spent less time diving in this region. A diver's experience is a key component to obtain accurate data about shark and ray diversity as has been reported in other studies explaining that experienced recreational divers (e.g., divemasters and instructors) are familiar with the features of regularly visited sites and the species diversity and can provide good information, even for more elusive species [16].

The elasmobranch species commonly observed by divers in the Mexican Caribbean were the southern stingray (*H. americanus*), yellow stingray (*U. jamaisensis*), nurse shark (*G. cirratum*), blacktip shark (*C. limbatus*), and Caribbean reef shark (*C. perezi*). This is concordant with other regions in the Caribbean, in which other methods have been used to determine the abundance and diversity of elasmobranchs. For example, in the Bahamas, where researchers used longlines and BRUVS to obtain the distribution and abundance of sharks, a high abundance of nurse sharks and Caribbean reef sharks was found [21]. Similarly, nurse sharks and Caribbean reef sharks were commonly captured on longlines in Belize [22]. For rays, other studies in the Caribbean showed the high abundance of the yellow stingray in the coral reef ecosystems [11], so the data obtained here through the local ecological knowledge are supported by other studies using conventional methods [23].

The decline of shark and ray populations worldwide in the last decades is well known [1,24], particularly in the Caribbean where recent studies have provided evidence of the decline of reef shark populations [23,25]. This is concordant with the perception of the divers interviewed in our study who perceived a decline in the number sharks and rays in the Mexican Caribbean in the last decade. The use of LEK was shown to be useful to collect invaluable data for describing population trends and providing insight into patterns that may warrant further investigation [16]. The main causes divers in the Mexican

Caribbean thought are contributing to the population decline of sharks and rays in this region were fisheries, climate change, particularly the changes in water temperature and the strengthening of natural events such as hurricanes, and coastal development, where they mention particularly the degradation of the coral reef and mangroves due to coastal infrastructure development. Other threats that divers mention for sharks and rays in this region are the increase of sargassum along the coast in recent years, the increasing number of tourists each year, and pollution. Globally, overfishing, habitat loss, climate change, and pollution are the main causes of the elasmobranch population decline worldwide [1] as described by the divers interviewed in this study in the Mexican Caribbean.

Divers reported that, from the 24 species commonly seen in the Mexican Caribbean, only five shark and ray species are targeted for the diving industry in this region, but only two have an established activity, the whale shark (*Rhincodon typus*) during summer and bull shark (*C. leucas*) during winter. The whale shark was not reported by divers here, because this species is observed mainly in the open sea during the aggregation season. The other three species, namely the mako shark (*I. oxyrinchus),* the whitespotted eagle ray (*A. narinari*), and the oceanic manta ray (*M. birrostris*), do not have a well-established activity and only some diving centers offer interactions with these species on their websites for tourism. Touristic activities, such as those performed with elasmobranchs in the Mexican Caribbean, have the potential to gather information through citizen science programs. Due to this, some of these species are the most studied in the Mexican Caribbean, and some citizen sciences programs have already estimated population sizes through photo ID approaches [5].

Because sharks and rays are charismatic fishes, divers in the Mexican Caribbean have showed high interest in participating in data collection for these species, but motivation decreased with time and at the end only 20% of divers were actively sending their sighting reports. Motivation is one of the hardest parts of the participation of citizen scientists for long periods, as has been reported before [13]. We have highly motivated people that signed up for our monitoring (90% of the interviewed divers) because sharks and rays are charismatic species and the monitoring incorporated SCUBA diving activity. These two points seem to increase the motivation of citizen scientists [13]. Motivating participants to continue or expand their participation is often a greater challenge, as we observed in this study. Other authors mention that this decrease in motivation occurred most of the time when the project involves reporting 'zero data', which disengages the participants [13] and is probably what happened in the Mexican Caribbean where the frequency of shark and ray observations is very low. Despite this, we expect more participation and sighting reports, with the participation of at least one diver in each location. This allows us to have data from each location and to reduce the need for repetitive reports from the same individual in the same area. So, we have reports from only one diver in one day in one diving site and this reduces abundance overestimations of the species, data that we will analyze in future publications.

The reduction in shark populations in the Caribbean has recently been documented where most of the reefs in this region have been reported with a very low abundance of sharks [23,25], as was seen in the Mexican Caribbean in the present study, based on the very low number of sightings. Additionally, batoids were more frequently sighted (89%) than sharks (11%). The prevalence of rays on coral reefs, as we found here, was also reported in other studies [26] and may be related to the decrease of sharks on coral reefs due to a trophic cascade [26–29]. However, further research is needed to make conclusive statements about this phenomenon in the Mexican Caribbean. The most frequently reported ray in the reefs was the spotted eagle ray (*A. narinari*), the southern stingray (*H. americanus*), and the yellow stingray (*U. jamaisensis*). These species are common coral reef users and exhibit site affinity, as other authors have demonstrated using conventional methods, such as BRUVS and Photo ID, as well as citizen science methods [11,30–32]. In the Caribbean, the most abundant shark species in the reef are the nurse shark (*G. cirratum*) and the Caribbean reef shark (*C. perezi*) [22,30,33], as was found in the Mexican Caribbean based on the sighting reports. Another species that was reported frequently on the reefs of the Mexican Caribbean was the great hammerhead shark (*S. mokarran*), as occurred in other reefs in this region as in the Turks and Caicos [30]. This finding is of important regional concern since this hammerhead species is considered Critically Endangered worldwide, so more data are needed on the distribution and abundance of the species to improve the conservation actions to preserve the population in the Mesoamerican reef.

Since 2005, there has been a growing demand for sharks and rays in tourist activities worldwide [33–35], especially in the Mexican Caribbean, where the inclusion of shark and ray species in local ecotourism packages has aroused greater interest in the conservation of populations. Several authors have shown that elasmobranch populations can be affected by anthropogenic activities, such as fishing and boat traffic [34,35], which can affect the degree to which the species leave the areas and seek refuge in other regions [36]. The health of the reefs also affects the abundance of reef elasmobranch species [37,38], which is important to take into account, especially in the study area located within the Mesoamerican reef system.

The citizen science approach used here, based on the local ecological knowledge and the participation of citizen scientists to collect data, was a valuable tool to collect baseline data in the Mexican Caribbean. Our study provided important data about the diversity of coastal elasmobranch species associated with coral reefs and their distribution. Information about habitat use and the abundance of the species could also be collected and analyzed using citizen science [16]. Our work offers a wide view of the population status and allowed us to generate new hypotheses and gave us guidance for further research to improve the conservation of this species in the region. Finally, citizen science is a useful tool to describe important ecological patterns that might otherwise go unnoticed due to poor data or insufficient timeframes [15,16]. This is of particular importance in the most vulnerable and rapidly changing ecosystems that are also among the most data-poor regions, especially in low, lower-middle, and middle-income countries, such as the ones in the Mesoamerican reef region. Therefore, we conclude that the use of citizen science is a very useful tool to generate valid long-term data on the most vulnerable elasmobranch species in countries in which the financial investment in other monitoring methods is limited.

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Institutional Review Board Statement: All activities were performed according to Mexican laws and regulations. No animal manipulation was performed. No ethical conflicts exist in the realization of this work.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: All data generated or analyzed during this study are included in this published article.

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Evidence of a nursery area for bull shark, *Carcharhinus leucas* (Müller y Henle, 1839) in the Mesoamerican Reef System region

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Abstract Nursery areas are essential habitats for sharks, offering protection and increasing the survival of newborns. We conducted interviews with local fishers and collected data from artisanal fishery landings between January 2013 and December 2019 to investigate Chetumal Bay as a nursery area for the bull shark (*Carcharhinus leucas*) in the Mesoamerican Reef region. The bull shark is a coastal euryhaline shark that inhabits temperate and tropical waters worldwide. In the Mexican Caribbean, bull sharks are caught mainly as bycatch in a multi-specific artisanal fishery using nylon bottomset gillnets, longlines, and hand lines. We record 63 bull sharks in the catches ranging from 67 to 125 cm TL corresponding to immature individuals, 23 neonates with either open or healing umbilical scars (67 and 78 cm TL), and 40 YOY with present but healed umbilical scars (79 to 125 cm TL), with a notable absence of large size juveniles and adults in the catches. Bull sharks were present in landings between May and November; the highest abundance was during July. Our data provide evidence to recognize Chetumal Bay as a nursery area for bull sharks, meeting all the criteria proposed to identify nursery areas. These findings constitute the first documented evidence of a bull shark nursery area in an estuary within the Mexican Caribbean as well as within the entire region of the Mesoamerican Reef System. Moreover, we discuss the importance of this nursery in light of a newly described distinct lineage of bull sharks in Chetumal Bay.

Keywords Bull shark · Nursery area · Chetumal Bay · Artisanal fisheries

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Introduction

The bull shark, *Carcharhinus leucas* (Müller and Henle 1839), is a shark species of the Carcharhiniformes order, inhabiting temperate and tropical waters worldwide (Ebert et al. 2013). This species is found mainly at depths between 1 and 30 m and is euryhaline, occupying a wide range of habitats, including coastal habitats, e.g., hypersaline lagoons, bays, river mouths, upstream in warm rivers, and turbid freshwater lakes (Ebert et al. 2013). Females give birth in estuaries (Heupel and Simpfendorfer 2011; Ebert et al. 2013), and immature individuals tend to remain in estuaries for several years (Curtis et al. 2011). According to the IUCN Red List of Threatened Species, bull shark populations are declining worldwide, and the species' threat category has changed from "*Near Threatened*" to "*Vulnerable*" according to the latest assessment in 2021 (Rigby et al. 2021). Due to their unusual life history characteristics, their presence in the coastal fisheries, and their habitat occurrence (i.e., coastal estuarine and freshwater systems), bull sharks are more vulnerable to human impacts and habitat modification than other elasmobranch species (Ebert et al. 2013; Rigby et al 2021). Bull sharks are caught in some fisheries around their distribution range and are also caught as bycatch in some coastal fisheries (Rigby et al 2021). Within the Mexican Caribbean, it is one of the main species caught in artisanal fisheries (Blanco-Parra et al. 2016; Marcos-Camacho et al. 2016) and also represents an important resource for tourism due to the seasonal aggregation along the coast of Playa del Carmen.

Nursery areas are considered essential habitats for sharks, offering habitats that increase the survival of newborns (Castro 1993). Species exploitation and habitat alteration of these areas may cause population declines for many shark species. The identification of these areas is of major concern for conservation as they become key habitats when considering management and conservation strategies to preserve both regional and global biodiversity (Kinney and Simpfendorfer 2009). Many large shark species have life history traits (large body size, slow growth, late maturity, and low fecundity) that make them particularly vulnerable to fishing and other anthropogenic threats such as habitat degradation. Moreover, conservation and management of adult sharks is more difficult due to the wide distributional range attained for most species (Kinney and Simpfendorfer 2009). The identification and protection of nursery areas is an important component that should be considered to delineate broader shark conservation management strategies, as they can both replace individuals removed from populations and serve as a repository of gene diversity (Kinney and Simpfendorfer 2009).

Shark nurseries are defined as areas used by gravid females to give birth to their progeny or deposit their eggs and are the areas sharks grow from birth to sexual maturity (Castro 1993). These areas are commonly located in shallow estuaries, where there is an abundance of food and protection from other predators (Castro 1993). An area should meet three criteria to be considered as a shark nursery according to Heupel et al. (2007): (1) neonate and young sharks encounters are more common than in other areas, (2) sharks tend to remain and come back during long periods, and (3) the area or habitat is repeatedly used across years.

The Chetumal Bay (Corozal Bay in the Belizean portion) is the largest estuarine area in the Mesoamerican Reef region and has been recognized as an important ecosystem for breeding, and serves as nursery and feeding grounds for multiple animal species including elasmobranchs (Schmitter-Soto et al. 2009). The Chetumal bay was designated as a natural protected area in 1996 as the "Manatee sanctuary" due to the large population of the Antillean manatee (*Trichechus manatus manatus*) found in this region. Because of this designation, the artisanal and recreational fisheries inside the bay were regulated and the use of nets was forbidden; since then the artisanal fisheries have decreased, at 2009 there were approximately 50 registered fishers that fish on invertebrates (crabs) (using traps) and bony fishes (using longlines, gillnets, and cast nets) (Medina-Quej et al. 2009). Applegate and Espinosa (1993) and Bonfil (1997) were the first authors to suggest Chetumal Bay as a nursery area for bull sharks based on the presence of juvenile bull sharks in some fisheries. Unfortunately, no data of abundance, size, or seasonality was presented in these publications. The suggestion of the importance of Chetumal Bay as a bull shark nursery area, combined with the recent finding of a novel mitochondrial lineage within the bay (Sandoval-Laurrabaquio-Alvarado et al. 2021), inspired this project which aimed to provide evidence of the use of the Chetumal Bay as a nursery area for bull sharks, based on the criteria proposed by Heupel et al. (2007).

Materials and method

Study area

Chetumal Bay (named Corozal Bay in the Belizean portion) is a shallow, oligotrophic, and extensive (~2550 km^2) coastal lagoon (estuary) found between the southern region of the Mexican Caribbean and the northern portion of Belize. The mean depth is 4 m with a maximum of 18 m (with the exception of some deep pools with depths of 40 m) at the mouth; the water surface temperature has a mean of 27 °C (ranges from 24 to 31 °C). Salinity ranges from 4 to 16 psu in the Mexican portion, whereas the bay mouth in Belize is influenced by the Caribbean Sea water (Carrillo et al. 2009) (Fig. 1). In Mexico, Chetumal Bay is a marine protected area and was declared as a manatee sanctuary in 1996. Since then, the use of nets in fisheries has been banned within the Mexican portion of the bay, along with other fisheries regulations (Espinoza-Ávalos et al. 2009). This study was conducted in the Mexican portion of the Chetumal Bay (Fig. 1).

Data collection

Data were collected from Chetumal Bay through two sources of information: interviews with local fishers and monitoring the artisanal fisheries landings. Between January 2013 and December 2019, we conducted semi-structured interviews (Young et al. 2018) with local fishers in three localities: Xcalak, Calderitas, and Chetumal

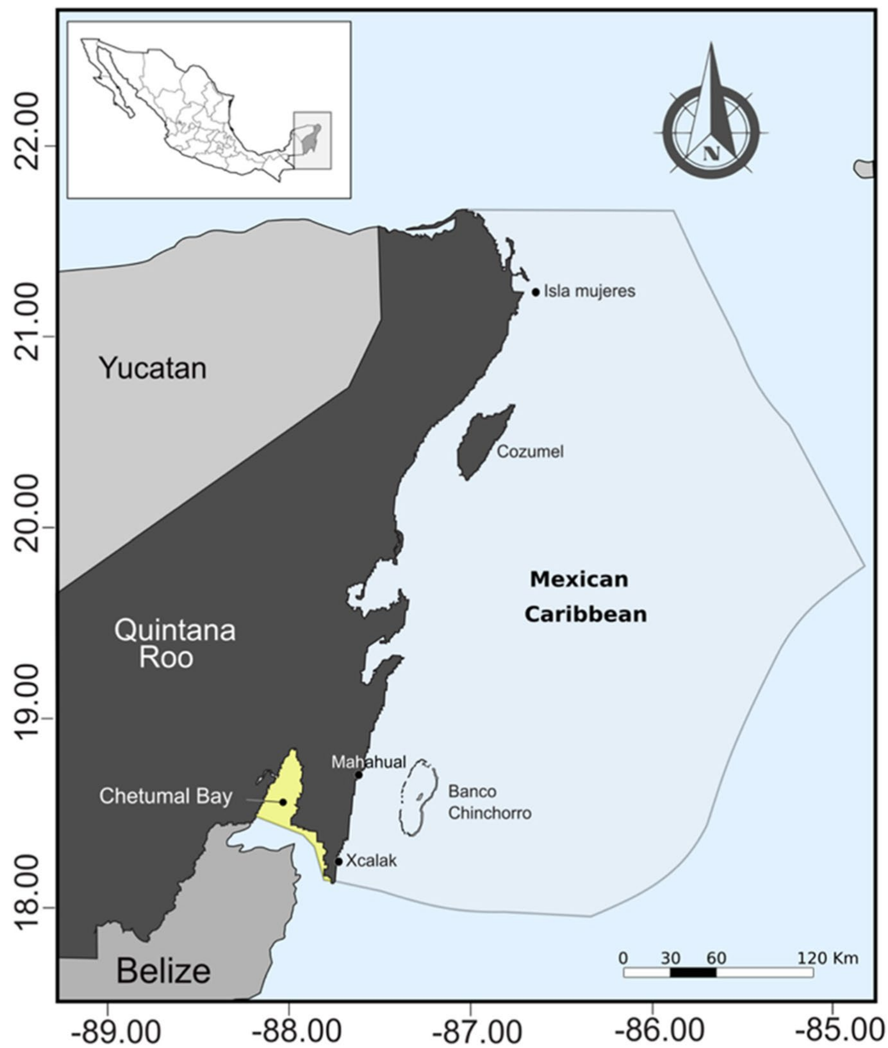


Fig. 1 Study area (yellow shaded area), Chetumal Bay, Quintana Roo, Mexico

City. The interviews were focused on the characteristics of local fisheries (e.g., type of gear, seasons, fishing areas), species composition, the fishers experience in years, and their knowledge regarding the presence of bull sharks in the bay. During the monitoring, fisheries landings were recorded for all elasmobranch species. Individuals found in the catch were identified to species level, when possible, following Carpenter and De Angelis (2002). For bull sharks, the total length was measured to the nearest centimeter, following a straight line between the tip of the nose and the tip of the caudal fin. When possible, weight was taken using a portable hand scale with a ± 10 g precision. The presence and condition of the umbilical scar was recorded and cataloged as unhealed or healed. Sex was determined macroscopically based on the presence of claspers on males and absence in females. Male sexual maturity was determined based on the claspers size and calcification. Bull sharks were categorized into cohorts as follows: (a) neonates, when the umbilical scar was present, and unhealed or healing (Castro 1993); (b) young of the year (YOY), when they had a healed umbilical scar and belonged to the first year (according to the published length-at-age estimates for this species in the Gulf of Mexico) (Branstetter and Stiles 1987; Cruz-Martinez et al. 2005; Neer et al. 2005; Natanson et al. 2014); and (c) juveniles, when they were older than a year and were not yet sexually mature. The data were used to evaluate if Chetumal Bay met the criteria to be considered a nursery area for bull sharks according to Heupel et al. (2007). We compared the occurrences of neonates, YOYs, and juveniles in landings monthly and across years. Statistical analyses were performed with the PAST *Paleontological Statistics* [PAST ver 4.04 (Hammer et al. 2001)]. Sex ratios were tested using a chi-square test with Yates correction for continuity. The Kruskal–Wallis test and Bonferroni post hoc test were used to evaluate possible monthly differences in the bull shark total lengths. Significant differences were reported when p value > 0.05 (Zar 1996).

Results

Fisheries description

We interviewed 12 fishers between 37 and 60 years old with 10 to 30 years of experience fishing in Chetumal Bay. Only two of them had fishing permits for bony fish and most of them are dedicated to other activities for their economic support, so they do not subsist exclusively from the fishery. Bull sharks are caught in a multi-specific artisanal fishery in the Chetumal Bay using nylon bottomset gillnets with mesh sizes between 4.5 and 7 inches, longlines, and hand lines, and are also caught in a shore-based recreational fishery. Fishers use small boats called "pangas" between 23 and 25 feet long with outboard engines of 40 or 60 HP and some practice shore-based fishing as well. The target species are bony fishes known by the fishers as "escama" and could include at least 11 species such as *Scomberomorus maculatus*, *Eugerres plumieri*, *Gerres cinereus*, *Lutjanus griseus*, *Sphyraena barracuda*, *Megalops atlanticus*, *Haemulon plumierii*, and *Albula vulpes*. Many fishers (89%) reported they catch sharks and rays as bycatch, only one reported they target sharks during the month of May with longlines, hand lines, and rod and reels.

All fishers report that bull sharks are caught most frequently at sizes less than a meter, which are known as "cazón." Fishers report catching these size individuals primarily using longlines in the deepest points of the Chetumal Bay, known as "pozas" (deep pools), as well as from shore in front of Chetumal City (Fig. 2). Other sites in which fishers caught sharks are "Punta Calentura," "Dos Hermanos," and "Cayo Venado." Most fishers (90%) reported that adult bull sharks are commonly sighted in the bay during spring and summer (May to August) but due to the fishing gear they use, sharks bigger than 130 cm TL are not found in the catch. Bull sharks are also caught by recreational fishers from the shore in the Chetumal City using hand lines and fishing rods.

Catch composition

Between 2013 and 2019, 63 bull sharks (*Carcharhinus leucas*), 33 females and 30 males, were recorded during the surveys in the artisanal fisheries in Chetumal Bay. The sex ratio was 1:1 ($X^2 = 1.93$, $p = 0.18$). Individuals ranged in length from 67 to 125 cm TL with a mean of 83.13 ± 11.78 cm TL (Fig. 3) and weighed 2.15–12.5 kg with a mean weight of 5.59 ± 3.57 kg. We only observed immature individual in catches, 23 neonates with either open or healing umbilical scars (67 and 78 cm TL) and 40 YOY with present but healed umbilical scars (79 to 125 cm TL), with a notable absence of juveniles and adults in the catch.

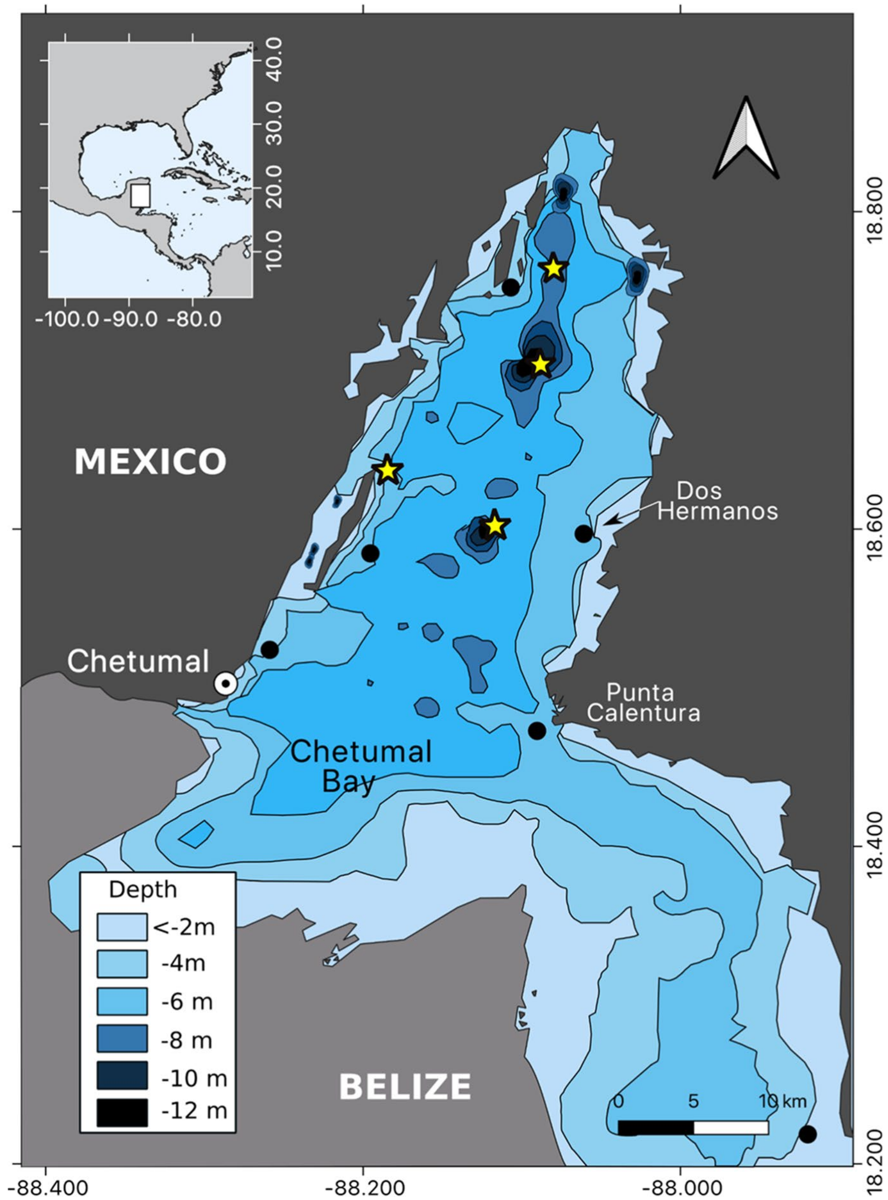


Fig. 2 Approximate location of the main catches' grounds for bull sharks (black dots); stars represent the "deep pools" reported by fishers in the Chetumal Bay. Bathymetry according to Carrillo et al. (2009)

The first observations of bull sharks being landed were during May of each year and the last individuals caught were in November. The month of July had the highest catch rate of bull sharks for the entire year. The size of individuals showed a tendency to increase from May to November (Fig. 4). Significant differences were found when comparing total length and month (Kruskal–Wallis $p > 0.05$). Especially influenced by differences among Nov–Aug (Bonferroni $p = 0.023$), Nov–May (Bonferroni $p = 0.023$), and Oct–May (Bonferroni $p = 0.023$). The mean size of the individuals during November was 44% and 36% higher compared with the mean size during May and August, respectively, and during October the mean size was 19% higher (17 cm longer) than during May.

Discussion

Despite some authors having previously suggested Chetumal Bay as a shark nursery area (Applegate and Espinosa 1993; Bonfil 1997), to date, there is

Fig. 3 Size frequency of bull sharks found in artisanal fishery landings within Chetumal Bay

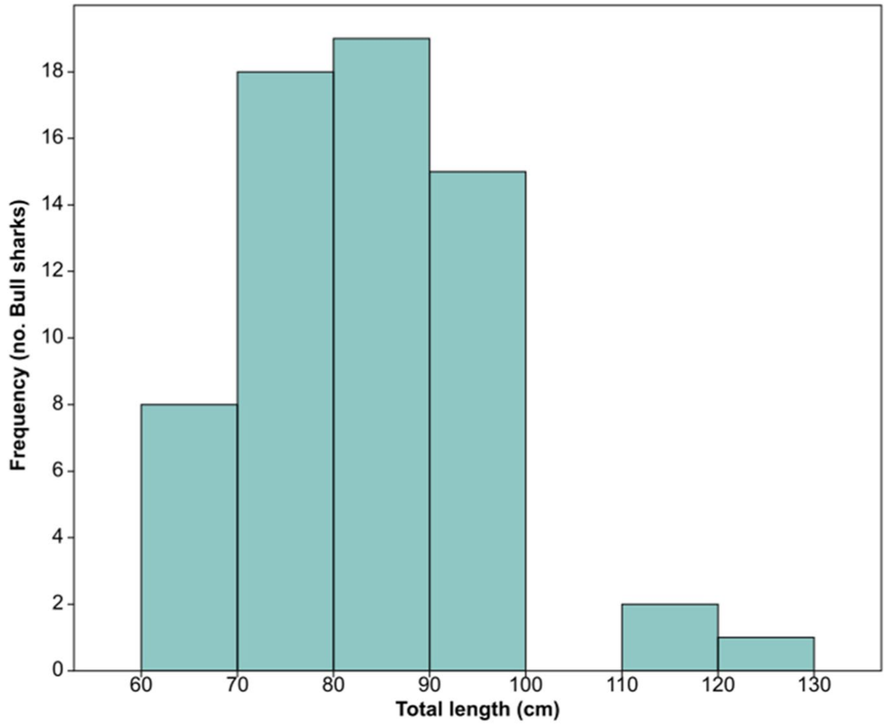
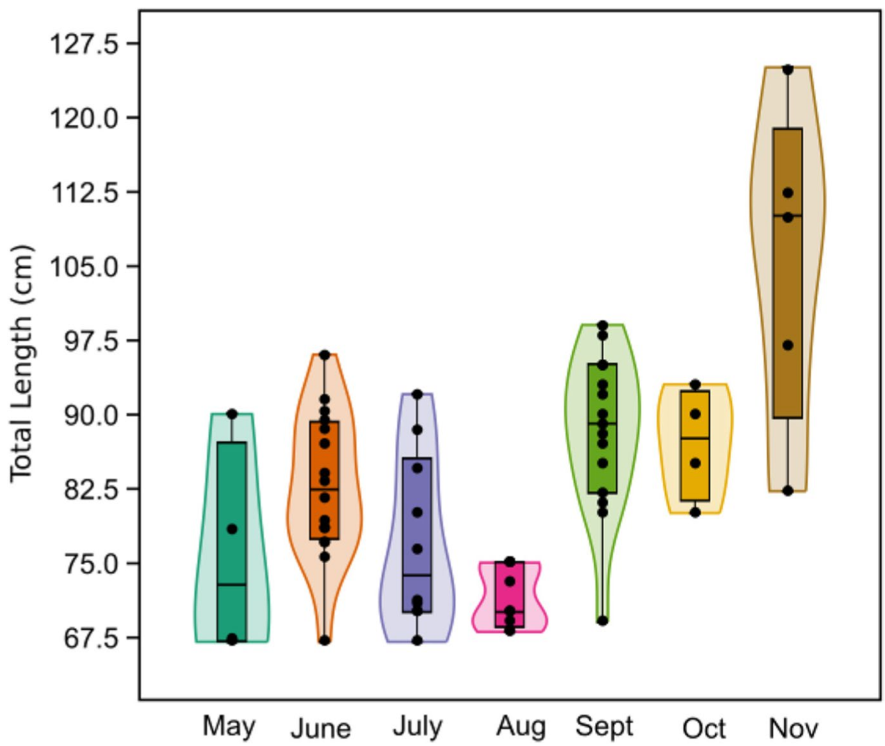


Fig. 4 Variation of the total lengths for bull sharks present in the catches of artisanal fisheries in Chetumal Bay by month. Box plot (mean ± Q1, Q3; whisker: max–min); jitter plot (showing each value recorded) and shadow areas (violin plot) are kernel distribution



no information about the abundance, seasonality, or time of residence for newborn and juvenile sharks in the bay. We present here the first evidence for the use of the Chetumal Bay as a nursery area by the bull shark in the Mesoamerican Reef region. Recently bull sharks from Chetumal Bay were reported as a unique and highly divergent lineage in the Caribbean Sea (Sandoval-Laurrabaquio-Alvarado et al. 2021). Therefore, the information presented here plays an incommensurable role to improve management strategies for the conservation of this recently identified population.

Bull sharks are not a target species in the fisheries in the Chetumal Bay. They are mainly caught incidentally by the artisanal (some cases subsistence fishery) bony fish boats using gillnets and hand lines as well as by shore-based recreational fishers using hand lines with small hooks. The features of the artisanal fishery in the Chetumal Bay are similar to those reported for other locations in the Mexican Caribbean and Gulf of Mexico, where fishers use small boat and gillnets to catch either bony fishes or sharks, cataloging this as multi-specific fisheries (Castillo-Géniz et al. 1998; Blanco-Parra et al. 2016). Castillo-Géniz et al. (1998) mentioned that local communities located on the Gulf of Mexico and Caribbean Sea coasts usually operate in elasmobranch nursery areas (identified some of those), especially with regard to teleosts, with the consequence of catching elasmobranchs as bycatch; as is also the case for Chetumal Bay.

Data presented here suggest a long-term presence of neonate and YOY bull sharks (67 to 125 cm TL) in Chetumal Bay based on registers of the fisheries landings and the fishers' reports. Similar to what was found by Schmitter-Soto et al. (2009), who reported bull sharks in the catch primarily during summer in this area, bull sharks have been observed most abundantly in catches during July in Chetumal Bay. Fishers in Chetumal Bay recognize that during May, bull sharks start to appear in their catch. One fisher reported they exclusively fish for shark during this month, using long lines in the deepest points of the bay. During the interviews, most fishers reported sightings of bigger bull sharks inside the bay during spring and summer. The abundance of neonates, YOY, and juveniles bull sharks during summer have also been reported in other estuarine nursery areas in the Western Atlantic (Simpfendorfer et al. 2005; Bangley et al. 2018), which is consistent with our findings here for Chetumal Bay.

Although the number of captured juvenile sharks in this study seems small for a 6-year period (63), it must be kept in mind that Chetumal Bay (and Corozal Bay in Belize) is a natural reserve area, and sharks are part of the bycatch, are presented as an artisanal fishery, closer to or related to a survival fishery. Therefore, obtaining information through this "small fishery industry" represents an important achievement, also considering that some individuals are captured during the ban season and most of them are not reported. Other bull shark nursery areas in the Caribbean and the Atlantic coast have reported, in the Gulf of Venezuela, 128 bull sharks caught in a 5-year period (representing 25 sharks/year; Tavares and Sánchez 2012), and for the Indian River Lagoon (Florida) a total of 449 bull sharks caught in a 30-year period (representing 15 sharks/year, Curtis et al. 2011). Also, Schwartz (2012) documented a total of 113 individuals captured (juveniles and adults) from 1965 to 2011 for the coastal and estuarine waters of North Carolina. Therefore, the results we present here with an approximate rate of ten sharks per year is consistent with the previous work on the species.

Recently a highly divergent lineage was found in the bull sharks that inhabit the Chetumal Bay, separating this population to the others found in the West Atlantic Ocean (Sandoval Laurrabaquio-Alvarado et al. 2021). Therefore, the information about this population is very poor and we present here evidence to prove that the Chetumal Bay is a critical habitat used as a nursery area for this population. Therefore, is highly recommendable the continuous monitoring of the fishery in the entire Chetumal Bay, in order to know different aspects of their ecobiology, as well if the local fisheries are a threat for the bull shark.

To determine whether Chetumal Bay is a nursery area for bull sharks, we followed the criteria proposed by Heupel et al. (2007): (1) Encounters with neonate and juvenile sharks are more common than in other areas; we monitored fisheries and conducted interviews in Chetumal Bay (Chetumal City and Calderitas, $n = 30$) and other areas of the Mexican Caribbean (Mahahual, Xcalak, Isla Mujeres, Isla Blanca, Holbox; $n = 60$), where only adult bull sharks were reported by fishers. This confirmed that the abundance of neonate and YOY bull sharks in the Chetumal Bay is higher than in other areas in this region. Additionally, we reviewed literature for other countries within the Mesoamerican Reef System and found no reports of neonates or YOY bull sharks. (2) Sharks tend to remain or return for long periods; we found reports and presence of neonates and YOY bull sharks for 6 months of the year and the sizes of the individuals increased from May to November, indicating that bull sharks are using this area for long periods. (3) The study area has been used repeatedly over the years; fishers reported the presence of small bull sharks as far as 40 years ago, also neonate and juvenile individuals have been caught every year for the duration of this study (2013–2019). Also during the interviews, fishers report the presence of apparently pregnant females, describing it as a big size female with a bulging abdominal region, but due to the selectivity of the gears these females were not part of the catches. As we previously mentioned, other authors have reported the presence of juvenile bull sharks since 1993 (Applegate and Espinosa 1993; Bonfil 1997; Schmitter-Soto et al. 2009); this evidence confirms the use of this area across multiple years. Based on the evidence presented in this study, we can conclude that Chetumal Bay is a nursery area for bull sharks in the Mexican Caribbean and the Mesoamerican Reef System region.

For the Quintana Roo State (Mexican Caribbean), elasmobranchs represent ~ 6% of the total catch, with bull sharks being one of the most abundantly captured species (Blanco-Parra et al. 2016). Fishing pressure has been reported on all age groups of bull sharks in Quintana Roo and the Gulf of Mexico since some decades ago (Bonfil 1997, Castillo-Géniz et al. 1998, Blanco-Parra et al. 2016), but neonates are commonly found in only a few places (Bonfil 1997). In Quintana Roo, just Chetumal and Yalahau lagoons are reported as potential nursery areas considering the presence of newborns and juveniles (Applegate and Espinosa 1993; Bonfil 1997; Hueter et al. 2007), but so far, there are not recent and focused evaluations in those areas.

The identification of nursery areas in the Gulf of Mexico and Mexican Caribbean is relevant for bull shark conservation, considering all threats the species is facing in this area. In the Mexican Caribbean, habitat destruction is growing due to anthropogenic coastal development. Additionally, the species is one of the most abundantly captured sharks in the Gulf of Mexico and Caribbean, and all age groups have been reported, including pregnant females (Bonfil 1997; Castillo-Géniz et al. 1998; Pérez-Jiménez and Mendez-Loeza 2015; Blanco-Parra et al. 2016). Therefore, Chetumal Bay could represent a reservoir for bull shark conservancy. Also, considering that recently a highly divergent lineage for the species was detected in Chetumal Bay (Sandoval Laurrabaquio-Alvarado et al. 2021), this species conservation in this area becomes more relevant as the evolutionary origin for this lineage has not been fully studied. Regional philopatry is a common reproductive characteristic for the bull shark (Karl et al. 2011; Tillett et al. 2012; Sandoval Laurrabaquio-Alvarado et al. 2019, 2021), which is an important factor to consider, as female bull sharks tend to use the same nursery area for years, as was also corroborated here and concordant with previous genetic analysis (Sandoval Laurrabaquio-Alvarado et al. 2021).

This work has important implications on the conservation of bull shark populations in the Western Atlantic, especially after the recently published findings about the existence of a highly divergent lineage in the Caribbean Sea for the bull sharks from Chetumal Bay (Sandoval Laurrabaquio-Alvarado et al. 2021). It is necessary to determine the extension range and interactions among the independent populations to preserve its evolutionary history. New research focused on the ecology, distribution, and movements of the bull shark in Chetumal Bay should be a priority to improve the management strategies for the conservation of the bull shark population in the Mexican Caribbean and the Mesoamerican Reef region.

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Data availability All data generated or analyzed during this study are included in this manuscript.

Declarations

Ethics approval All activities were performed according to the Mexican laws and regulations. All sharks analyzed proceeded from artisanal fisheries only. No ethical conflicts exist in the realization of this work.

Consent for publication All authors have reviewed and approved the present version to be published.

Competing interests The authors declare no competing interests.

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