Latin American Journal of Aquatic Research, 54(5): 815-826, 2026
DOI: 10.3856/vol54-issue5-fulltext-3674

Research Article

Species composition and population structure of devil rays (*Mobula* spp.) in artisanal fisheries of Guatemala's Pacific coast

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ABSTRACT. Incidental capture of devil rays (*Mobula* spp.) occurs in several artisanal fisheries worldwide, yet biological information from many regions remains limited. This study examines species composition, morphometrics, sex ratio, and sexual maturity of devil rays incidentally captured in artisanal fisheries along Guatemala's Pacific coast. Fishing operations were monitored from February 2019 to February 2020 and from October 2022 to February 2024, including 246 fishing trips, 143 of which recorded mobulids. Data on species identification, disc width, total length, sex, and maturity stage were collected from landed individuals. A total of 453 devil rays were recorded. Of these, 447 were identified to species level: *Mobula munkiana* (n = 238), *M. thurstoni* (n = 205), *M. mobular* (n = 3), and *M. birostris* (n = 1); the remaining six individuals could only be identified to genus level (*Mobula* spp.). Of the total captures, 40.4% occurred in small-scale fisheries targeting *Caranx caballus*, 32.6% in fisheries targeting large pelagic species, and 27.0% could not be assigned to a specific fishery. In *M. thurstoni*, males exhibited a significantly larger mean disc width (131.78 ± 32.28 cm) than females (105.14 ± 26.46 cm; $P < 0.05$), with a male-biased M:F sex ratio of 2.01:1 ($\chi^2 = 22.56$; $P < 0.05$). Similarly, in *M. munkiana*, males were significantly larger (89.27 ± 10.28 cm) than females (82.12 ± 10.52 cm; $P < 0.05$), and the sex ratio was also male-biased (1.64:1; $\chi^2 = 13.65$; $P < 0.05$). These findings provide baseline information on species composition and morphometrics relevant to fisheries management and devil ray conservation.

Keywords: elasmobranch conservation; bycatch; length-frequency distribution; reproductive biology; Eastern Tropical Pacific

INTRODUCTION

The Pacific Ocean fishery, in terms of species diversity and catch volumes, represents one of the most productive sectors. This region contributes significantly to the world's marine catches, especially small pelagic fish, squid, and tuna (Peck et al. 2021). Fishing plays a vital role in Pacific coastal nations' economies by providing

Associate Editor: Leonardo Abitia

employment, income, and food security to millions of people. It also fulfills an essential ecological function, as many exploited species are key components of complex marine food webs that sustain biodiversity (Ortuño-Crespo & Dunn 2017, Ávila-Thieme et al. 2021). However, intensified fishing activities, including industrial and artisanal operations prevalent in the area, have created serious challenges for the conservation and sustainable management of marine resources (Lam et al. 2020, Selvaraj et al. 2022).

Fishing pressures affect rays of the genus *Mobula* Rafinesque, 1810, commonly known as mobulids or devil rays, which are widely distributed throughout the tropical and subtropical waters of the Pacific Ocean (González-Pestana 2022). These large, migratory filter feeders occur throughout the eastern Pacific, from Mexico to Peru, and inhabit both coastal and oceanic environments. Their tendency to form aggregations and spend time near the surface, where they feed on zooplankton and schools of small fish, increases their susceptibility to capture by artisanal and industrial fleets (Couturier et al. 2012, Thorrold et al. 2014, Rohner et al. 2017). However, some species also forage at depth (Sampson et al. 2010, Couturier et al. 2012, Rohner et al. 2017). Mobulid rays are caught in these fisheries as both target catch and incidental bycatch (Croll et al. 2016, Stewart et al. 2018, Lezama-Ochoa et al. 2019, 2020).

Historically, people have used mobulids as food and bait (Couturier et al. 2012, Ward-Paige et al. 2013). A recent study assessed *Mobula* catches worldwide (Palacios et al. 2025) and identified the eastern Pacific as a region with significant mobulid landings. In several coastal communities, these species have become a valuable fishery resource, used for local consumption or as a source of income through commercial trade (González-Pestana 2022). In Mexico, Ecuador, and Peru, people consume mobulids locally and export them as meat and gill plates (Palacios et al. 2025).

Mobulid rays are especially vulnerable because of their slow growth, low reproductive rates, and high demand for their gill rakers, which Asian dried seafood markets trade and use in traditional Chinese medicine (Croll et al. 2016, Lawson et al. 2017, O'Malley et al. 2017). The genus *Mobula* currently includes 10 recognized species, including the recently described *Mobula yarae* Bucair & Marshall 2025 (Bucair et al. 2025). These species are often caught as bycatch in tuna purse-seine fisheries, particularly in the eastern Pacific, where high-aggregation areas and elevated capture rates have been documented (Croll et al. 2016, Lezama-Ochoa et al. 2019). In some regions, such as northern Peru, bycatch records indicate a predominance of juveniles, suggesting these areas may function as nursery habitats critical to population sustainability (González-Pestana 2022). The absence of effective regulations and monitoring programs further exacerbates the risk of overexploitation. Currently, all mobulid species are highly threatened, with multiple species listed as Endangered or Vulnerable, and others as Near Threatened or Data Deficient (Croll et al. 2016, Mohanraj et al. 2024). All mobulid species were recently transferred from Appendix II to Appendix I under CITES, reflecting increased conservation concerns (CITES 2025).

In Guatemala's Pacific waters, researchers recorded 21 batoid species between 1997 and 2023. However, only three mobulid species have been documented: *Mobula mobular* Bonnaterre, 1788, *M. thurstoni* Lloyd, 1908, and *M. munkiana* Notarbartolo-di-Sciara, 1987 (DIPESCA et al. 2018, Ávalos-Castillo & Santana-Morales 2021, MAGA 2021, Ávalos et al. 2022, Tewfik et al. 2022, Sánchez et al. 2023). Batoids such as *Aetobatus laticeps* Gill, 1865, *Rhinoptera steindachneri* Evermann & Jenkins 1891, and *Pseudobatos leucorhynchus* Günther, 1867 are frequently caught as bycatch. These are mostly used for self-consumption or bait. Larger species such as *Hypanus longus* Garman, 1880 are sold in local markets as salted dried meat (Tewfik et al. 2022). Fishermen report that pelagic batoid presence, particularly *M. thurstoni*, *M. munkiana*, and *A. laticeps*, peaks between February and March and is lowest from October to December (artisanal fisher *per.comm*.). However, despite these observations, information on population structure remains limited, hindering efforts to identify key habitats and understand their role in mobulid life history, knowledge that is critical for effective conservation.

Incidental catch of mobulid rays in Guatemala's Pacific waters has been documented in coastal artisanal fisheries. Under the General Fisheries and Aquaculture Law and its regulations (Governmental Agreement No. 20-2002; 223-2005), these fisheries are classified as demersal and small pelagic fisheries (Ixquiac et al. 2010, Ávalos-Castillo & Santana-Morales 2021, Tewfik et al. 2022).

In many regions, the absence of systematic monitoring programs or dedicated scientific surveys limits our understanding of mobulid ray populations. In such contexts, fisheries data, such as catch records, local ecological knowledge, and landing site observations, can provide valuable and complementary insights into the presence, distribution, and seasonal

patterns of these species. While scientific surveys yield more precise data, integrating them with observations from artisanal and small-scale fisheries helps fill critical knowledge gaps where formal monitoring remains limited.

In this context, this study analyzes mobulid ray landings in Guatemala's Pacific region by species, size, and sex to improve baseline catch data and identify potential weaknesses in current reporting systems. This baseline information is especially critical for species of conservation concern, such as mobulid rays, because it supports more informed decisions about habitat use, population dynamics, and threats.

In Guatemala, this data is increasingly relevant, as the government is expanding four existing coastal protected areas to include adjacent marine zones and establishing a new coastal marine protected area in the Pacific (CONAP & WCS 2025). These initiatives are part of the 2012-2022 Guatemalan National Strategy for Biological Diversity and Action Plan and National Maritime Policy 2023-2043, which aim to conserve at least 10% of coastal marine ecosystems (CONAP 2013, SEGEPLAN 2023). Furthermore, by providing empirical data on species composition and spatial patterns, our results can support the application of ISRA criteria, such as those proposed by García-Rodríguez et al. (2025) for the Central and South American Pacific, which help delineate critical habitats and prioritize conservation efforts.

MATERIALS AND METHODS

Ethics statement

All applicable national guidelines and regulations for the sampling and handling of organisms during this study were followed.

Field sampling

Between February 2019 and February 2020, and again from October 2022 to February 2024, mobulid rays were sampled in the fishing community of Iztapa, located in the department of Escuintla, on the Pacific coast of Guatemala (Fig. 1). The map shows the inferred fishing grounds based on spatial information provided by local fishers. Reported locations were estimated using the distance in nautical miles from the coastline, taking the mouth of the Buena Vista sandbar as the primary georeferencing point. Fishers also provided the navigation bearing followed during each trip, allowing us to approximate the directionality of fishing effort. Circle size represents the relative reporting frequency of each location, with larger symbols indicating areas of higher recurrence and, therefore, greater likelihood of sustained fishing activity.

At landing sites, all mobulid rays were identified to species level, and their sex (male or female) was recorded. Morphometric data were collected, including disc width (DW, cm).

Fishing operation

Mobulid ray catches in the region are incidental, as no targeted fisheries are known for species in the genus *Mobula*. However, landings of mobulid rays have been documented in Iztapa, particularly in the months leading up to Easter ("Semana Santa"), when fishing activity increases.

Two artisanal fisheries were identified as sources of incidental mobulid ray catch: 1) small-scale fishery targeting *Caranx caballus* Günther, 1868 (locally known as "quinoa"). This fishery operates in coastal waters 0-5 nm offshore. Boats are small (23 feet long) and use 40 HP outboard motors. Fishing trips last 12-18 h and involve 2-3 fishers. Like the pelagic fishery, it uses surface set trammel nets; 2) large pelagic fishery: this is the primary fishery associated with mobulid bycatch. It uses "tiburonera"- type boats over 25 feet long, equipped with one or two 75 HP outboard motors. Fishing trips last between 24 and 48 h and involve 2-3 fishers. The gear consists of pelagic trammel nets approximately 500 m in length, with a 10-inch mesh size and 50 mesh drops. This fishery operates 20-50 nm offshore.

Morphometric and statistical analysis

Morphometric and sex composition data of *M. thurstoni* and *M. munkiana* were analyzed in R version 4.5.1 (R Core Team 2025). Size data (DW) were first tested for normality using the Lilliefors test (nortest package; Gross & Ligges 2015) and for homogeneity of variances using Levene's test (car package; Fox & Weisberg 2019). Since normality assumptions were not met ($P < 0.05$), differences in DW between sexes were assessed using the Mann-Whitney U test (wilcox.test function). Sex ratios were expressed as male-to-female (M:F) ratios, and deviations from the expected 1:1 ratio were evaluated for each species using a chi-square goodness-of-fit test with Yates' continuity correction. Size frequency distributions were visualized through histograms with 5 cm class intervals in R (ggplot2 package; Wickham 2016), separately for males and females of each species.

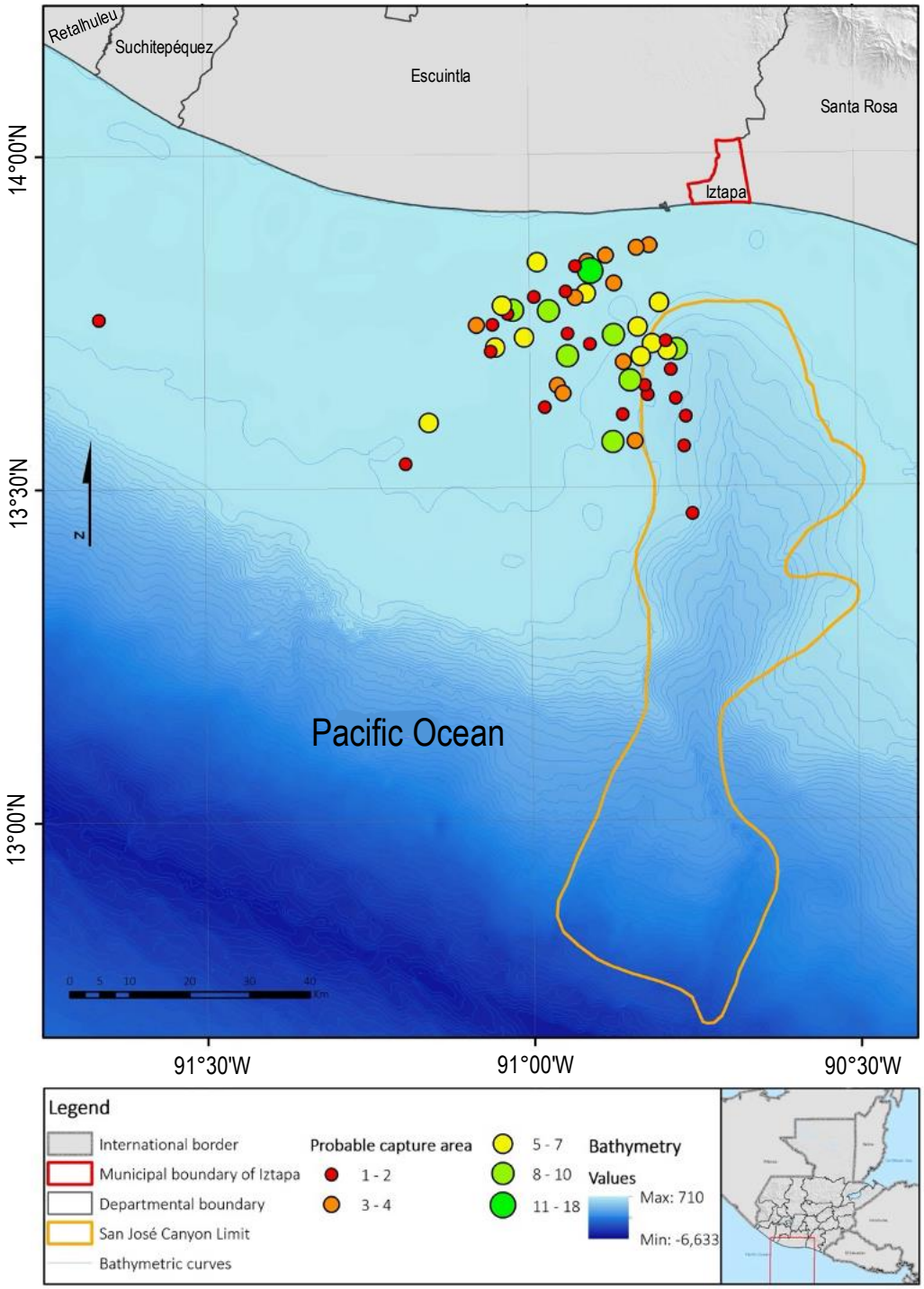


Figure 1. Study area showing the inferred fishing grounds of *Mobula* spp., based on spatial information provided by local fishers.

Trade data collection

To assess the dynamics of mobulid meat trade, informal interviews were conducted with fishers, intermediaries, and local vendors in Iztapa between 2019 and 2024. Information was collected regarding prices at landing sites, processing practices, distribution channels, and seasonal fluctuations in demand. Field visits to local markets and landing sites also documented price changes and identified trade patterns over time.

RESULTS

Spatial characterization of fishing grounds

The fishing grounds are closely associated with the geomorphological feature known as the San José Canyon. The large pelagic fishery typically operates directly over or along the canyon flanks, where oceanographic dynamics favor the presence of target species. In contrast, the small-scale fishery that captures *C. caballus* operates in front of the canyon, in shallower waters adjacent to the coastline. The map (Fig. 1) shows the areas where fishers most frequently report, highlighting the spatial distribution of fishing effort across both fisheries.

Landings

On Guatemala's Pacific coast, we identified a previously undocumented aggregation zone for two *Mobula* species. Data were collected from 246 fishing trips, of which 143 included mobulid ray landings, allowing for the collection of morphometric information. A total of 453 mobulid rays were recorded during the study period. Of these, 447 were identified to species level: *M. thurstoni* (n = 205), *M. munkiana* (n = 238), *M. mobular* (n = 3), and *M. birostris* (n = 1); six specimens could only be identified to genus level. *M. birostris* was recorded only once, based on video evidence (Table 1).

The large pelagic fishery most frequently catches *M. munkiana* and *M. thurstoni*, while *M. birostris* and *M. mobular* are caught only occasionally; due to its large size, *M. birostris* is typically not landed. Similarly, the small-scale fishery's bycatch primarily includes *M. munkiana* and *M. thurstoni*.

Of the rays with known fishery origin, 40.4% were caught by the small-scale fishery targeting *C. caballus*, accounting for 32% *M. munkiana* and 8% *M. thurstoni*. The origin of 27% of the specimens could not be determined. The remaining 32.6% were landed by the large pelagic fishery, comprising 17% *M. thurstoni* and 15% *M. munkiana*.

Morphometric data

This information was obtained for the two most frequently landed species, *M. thurstoni* and *M. munkiana*.

For *M. thurstoni*, measurements were recorded from 205 ind (68 females, 137 males). Females had an average DW of 105.14 ± 26.46 cm (range: 67-180 cm), while males averaged 131.78 ± 32.28 cm DW (range: 72.5-180 cm). Both size distributions were non-normal (Lilliefors test, $P < 0.05$), and males were significantly larger than females (Mann-Whitney U test, $P < 0.05$; Levene's test, $P < 0.05$). The M:F sex ratio was 2.01:1 ($\chi^2 = 22.56$; $P < 0.05$), indicating a male-biased composition (Fig. 2).

Table 1. *Mobula* species reported in Iztapa landings.

Species	N	Male	Female
M. munkiana	238	148	90
M. thurstoni	205	137	68
M. mobular	3		
Mobula birostris	1		
Mobula spp.	6		

For *M. munkiana*, morphometric data were collected from 238 ind (90 females, 148 males). Females had an average DW of 82.12 ± 10.52 cm (range: 46-120 cm), and males averaged 89.27 ± 10.28 cm DW (range: 39-101 cm). As with *M. thurstoni*, both distributions were non-normal (Lilliefors test, $P < 0.05$), and males were significantly larger than females (Mann-Whitney U test, $P < 0.05$; Levene's test, $P > 0.05$). The M:F sex ratio was 1.64:1 ($\chi^2 = 13.65$; $P < 0.05$), also reflecting a predominance of males in the landings (Fig. 3).

Regarding sex ratios, *M. munkiana* showed the highest proportion of females in November and March, while for *M. thurstoni*, female abundance peaked in January and April (Table 2).

Mobulid trade and market dynamics

Historically, mobulid meat had limited commercial value in Guatemala's Pacific region. About six years ago, the price per kilogram of whole weight at landing sites ranged from 0.22 to US$0.50. However, in recent years, demand and prices have increased significantly because other commonly targeted species, such as sharks, billfishes, and finfish, have become less available, and seasonal demand has grown, especially in the months leading up to "Cuaresma y Semana Santa" (Lent and Holy Week).

Currently, prices at landing sites can reach up to US$1.50 per kilogram of whole weight. At the local level, only the meat is used commercially; intermediaries sell it fresh at landing sites, then process it (salt and dry). Dried salted mobulid meat is in high demand during Guatemala's dry season and can fetch up to US$4.40 per kilogram in coastal communities. In Guatemala City supermarkets, prices can reach US$17 per kilogram.

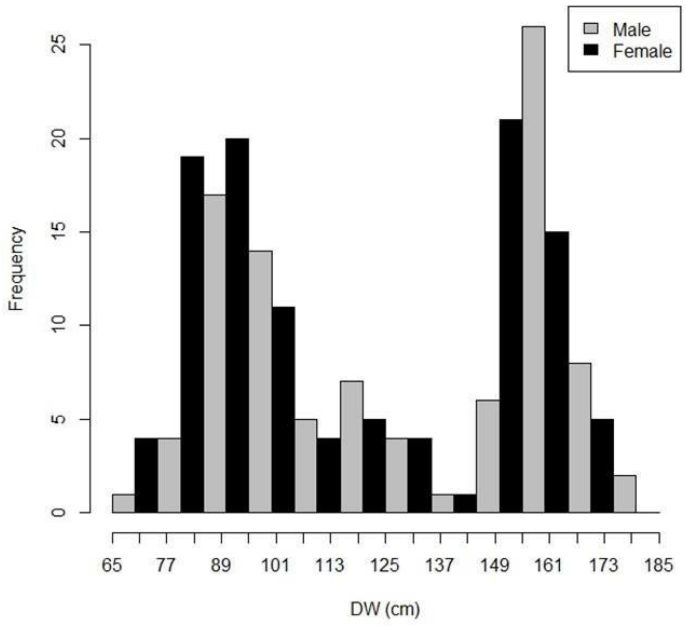


Figure 2. Size frequency histogram of males and females of *Mobula thurstoni*. DW: disc width. Frequency represents the number of individuals in each size class.

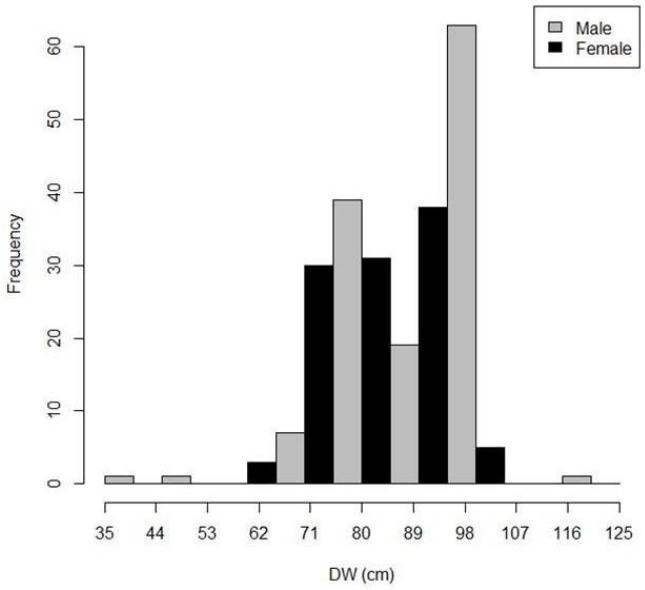


Figure 3. Size frequency histogram of males and females of *Mobula munkiana*. DW: disc width. Frequency represents the number of individuals in each size class.

The trade dynamics of mobulid products in Guatemala are strongly linked to the Semana Santa season. During this time, people consume large amounts of dried, salted meat from sharks, rays, and other marine fish, creating a spike in demand and, consequently, in mobulid prices. Landings begin to increase around September, with peak catch and trade activity occurring between January and April (Fig. 4). After Semana Santa, prices drop sharply, reducing fishers' interest in landing mobulid rays. This decline in market demand may discourage retaining some individuals, particularly larger species such as *M. thurstoni*, which are more difficult to handle and transport.

Table 2. Monthly sex ratios for *Mobula munkiana* and *M. thurstoni*. M: male, F: female.

Month	*Mobula munkiana*		M:F ratio	*Mobula thurstoni*		M:F ratio
	M	F		M	F	
January	10	4	2.50	10	12	0.83
February	81	37	2.19	52	8	6.50
March	2	15	0.13	17	2	8.50
April	20	2	10.00	18	25	0.72
May	18	4	4.50	9	0	N/A
June	0	1	0	0	0	N/A
July	0	0	N/A	0	0	N/A
August	1	3	0.33	8	2	4.00
September	1	5	0.20	2	3	0.67
October	0	4	0	5	3	1.67
November	4	7	0.57	15	13	1.15
December	11	8	1.38	1	0	N/A

DISCUSSION

This study adds to knowledge of mobulid rays using data from artisanal landings in Guatemala's Pacific region, specifically in the coastal community of Buenavista, Iztapa. Three species of the genus *Mobula* had previously been documented in the Guatemalan Pacific: *M. mobular*, *M. thurstoni*, and *M. munkiana* (DIPESCA et al. 2018, Ávalos-Castillo & Santana-Morales 2021, MAGA 2021, Ávalos et al. 2022, Tewfik et al. 2022, Sánchez et al. 2023). This study provides evidence of these three species being caught incidentally in surface gillnets. Additionally, video evidence recorded *M. birostris*, bringing the total number of mobulid species documented in the Guatemalan Pacific to four. The size and maturity composition of the individuals recorded also provides information on the life stages represented in these catches.

The size ranges recorded during the study, along with the presence of immature individuals, suggest that the artisanal fleet's fishing grounds may be biologically important for juvenile *M. thurstoni* and *M. munkiana*. According to a study on the reproductive biology of *Mobula* species in the Gulf of California (Serrano-López et al. 2021), *M. thurstoni* males reach sexual maturity at 151 cm DW, with completely calcified claspers around 155 cm DW. In contrast, females are considered mature around 150-160 cm DW, when they present developed oocytes and a well-defined uterus with trophonemata. Similarly, for *M. munkiana*, the size range observed during the study period (39-120 cm DW) includes individuals below the Gulf of California maturity sizes. In that region, males reach sexual maturity at 95 cm DW, with fully calcified claspers at 100 cm DW. In contrast, females reach sexual maturity at 95-105 cm DW, as determined by the development of reproductive structures (Serrano-López et al. 2021). Further research is needed to assess whether these fishing grounds include areas that serve as nursery habitats for these species.

The presence of individuals of both species below the maturity umbral in our study area and period reinforces the hypothesis that this habitat could serve as a juvenile aggregation area. This finding suggests the area is relevant for both *M. thurstoni* and *M. munkiana*, strengthening its importance as a potential nursery area for different *Mobula* species and highlighting its conservation value, as nursery areas are critical to species population sustainability. Effective management of these habitats is essential to reduce juvenile pressure and maintain species population dynamics in the area and region. Similar data have been recorded in other areas of the Eastern Tropical Pacific (e.g. Mexico and Peru). For example, in northern Peru, most incidental captures in the tuna fishery, as well as in the small-scale fishery in the same area, are juveniles. This high incidence suggests this area may also serve as a potential nursery area (Alfaro-Cordova et al. 2017, Lezama-Ochoa et al. 2019, González-Pestana 2022). However, for elasmobranchs, several criteria exist to consider an area as nursery grounds (Heupel et al. 2007, Martins et al. 2018): 1) neonates and juveniles visit this area more frequently in comparison with adjacent areas, 2) individuals tend to stay or return to the area during weeks or months, and 3) similarly, this area is used on a recurring basis over the years.

For monthly variation in *Mobula* captures during this study, catches increase starting in October and peak in February, aligning with aggregation patterns reported

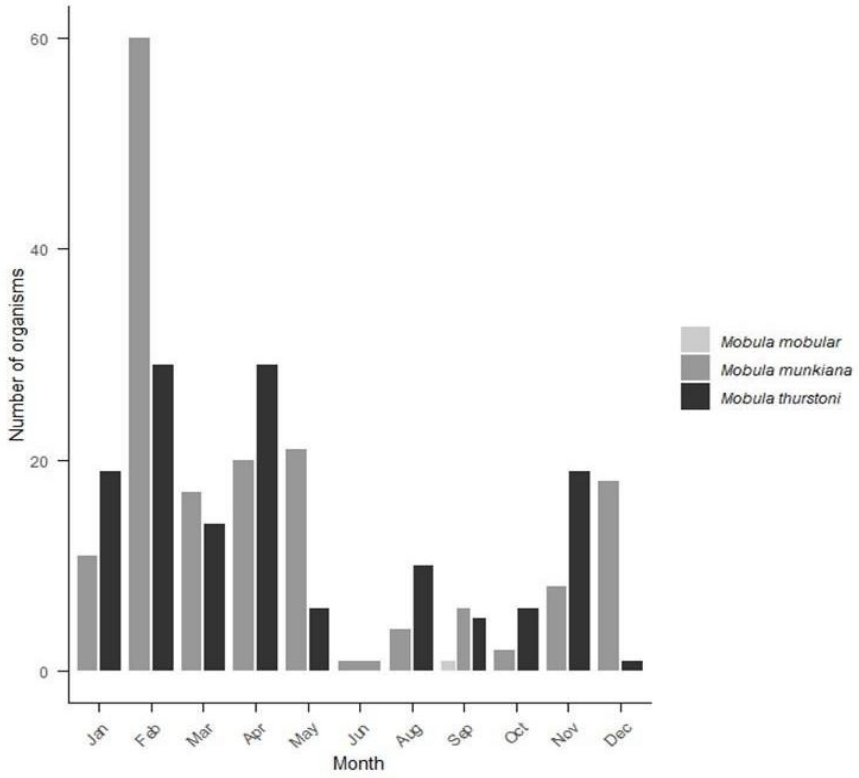


Figure 4. Monthly distribution of *Mobula* spp. captures by species in artisanal fisheries of the Pacific coast of Guatemala.

for the eastern tropical Pacific (Croll et al. 2016, Lezama-Ochoa et al. 2019). However, data collected during the study period (Fig. 4) were influenced by fishing efforts that coincided with an increase in shark and ray meat prices before Easter (Holy Week). Therefore, these observations underscore the importance of continued ecological research in the area, both spatially and temporally. The similarity in capture patterns along Guatemala's Pacific coast, especially the high proportion of juveniles and seasonal recurrence, may indicate that these areas serve critical ecological roles, such as nursery habitats and temporal aggregation habitats, highlighting the need for more detailed local-level studies.

Furthermore, it is important to examine the spatial distribution of devil ray captures, in addition to the temporal trends during the study period. In this sense, probable capture locations (Fig. 1) align with the San José Canyon, which previous studies have reported as an important aggregation region for marine mammals and large pelagic fishes (e.g. billfish and sailfish) (Quintana-Rizzo et al. 2021, Ehrhardt et al. 2025). Given this spatial overlap, it is important to consider the oceanographic characteristics that make San José Canyon biologically productive**.** The Middle America Trench sharply bounds the Guatemalan continental shelf, with the San José Canyon extending from the outer to the inner shelf. This topographic feature, combined with wind-driven seasonal upwelling, enhances nutrient availability and primary productivity in the region. As a result, the area supports high concentrations of marine life, including tunas, billfishes, and marine mammals that aggregate to feed (Quintana-Rizzo et al. 2021). Elevated sportfishing catch rates and the overlap of these productive zones with probable capture areas for *Mobula* species further emphasize San José Canyon's ecological importance as a key foraging and aggregation site.

The ecological productivity and species concentration observed in the area during this study, and in previous studies (Quintana-Rizzo et al. 2021, Ehrhardt et al. 2025), make the area attractive for sportfishing and commercial fishing. Additionally, growing commercial interest in devil ray meat in recent years has added pressure that may threaten these aggregations. Currently, devil ray meat has acquired commercial value, and locations with increased potential value have been identified. Landing data collected during this study provide information on the commercial value and fate of fishing-derived products

and also provide socioeconomic data for the comprehensive management of *Mobula* species. Previously, *Mobula* spp. captured by fishers used to be returned to the sea or used as bait. Today, especially in the months before Holy Week, devil ray meat has increased in value; for this reason, meat is seized at dry-salted meat markets. This study is relevant because it formally documents a market for mobulid ray meat in stores and markets.

Mobulid ray catches in Guatemala are currently considered incidental, but increasing demand for devil ray meat raises concern that a targeted fishery could develop in a previously identified aggregation area. Future fisheries regulations should therefore consider the economic incentives associated with this emerging market, along with the use of non-selective fishing gear. Guatemala currently lacks national regulations that specifically prohibit the capture or landing of *Mobula* species. Although the 2015 Punta de Manabique fisheries management plan recognized *M. birostris* as a CITES-listed species, *Mobula* species are not included in the current List of Threatened Species (LEA; CONAP 2022). In contrast, Mexico's NOM-029-PESC-2006 prohibits the capture and retention of several mobulid species and requires incidentally captured individuals to be released. At the international level, CITES lists all mobulid rays in Appendix I after their transfer from Appendix II at CoP20, which took effect on March 5, 2026. This listing generally prohibits international commercial trade but does not itself establish national prohibitions on capture. Mobulid rays are also listed in CMS Appendices I and II. At the regional level, the Eastern Tropical Pacific Marine Corridor (CMAR, by its Spanish acronym) promotes cooperation among Costa Rica, Panama, Colombia, and Ecuador. However, Guatemala is not currently a member, while Important Shark and Ray Areas (ISRAs) identify priority habitats that can guide spatial conservation measures. These international and regional mechanisms do not replace national fisheries regulations, but highlight the need for local data to support stronger management and conservation measures for mobulid rays in Guatemala.

Compared with alternative methods such as visual censuses or satellite monitoring, the data collected during this study provide practical fishing information, especially in developing countries. In Guatemala, where historical data on the devil ray fishery are unavailable, this study provides the first baseline for analyzing future trends and detecting changes in fisheries or populations.

Continuing to monitor landings in the area, even if the information does not directly measure population abundance, can provide information or warning signs about changes in fishing effort or shifts in target-species composition. In addition, these fisheries data, together with fisheries management and decision-making bodies, are highly useful and can inform temporal and/or spatial restrictions. Ongoing systematic monitoring, trend assessment, and evaluation of trade in these highly vulnerable *Mobula* species are vital for their conservation in Guatemala and the Pacific region. Continuous information, identification of key areas in the zone, and understanding habitat use within the zone are vital so that government entities responsible for species management and conservation have the tools to ensure sustainable management. In addition, this information can be vital for proposing management zones or temporary closures according to the identified seasonality. In addition, informing communities and involving them in conservation strategies is necessary, as they will help ensure the resource's sustainability and align species management with regional efforts (e.g. CMAR, CITES, CMS).

It is important to continue complementary lines of research, such as reproductive biology, age, and growth, which are essential for estimating species vulnerability and resilience from a fisheries perspective. On the other hand, studies of feeding ecology and habitat use help identify species' ecological roles, trophic interactions, and critical areas, an effort already supported by the designation of ISRAS at the regional level (García-Rodríguez et al. 2025). In this sense, it is important to maintain and understand the degree of connectivity between populations, which is key to establishing strategies at the local or international level.

Finally, Guatemala is currently promoting the designation of the San José Canyon and its area of influence as a Marine Protected Area. In this context, this study provides biological evidence supporting the region's ecological relevance, particularly as a key aggregation and potential nursery area for *Mobula* species. The high incidence of juveniles, the seasonal recurrence of captures, and the spatial overlap with a highly productive oceanographic feature underscore this area's importance to the life cycle of mobulid rays. From a conservation perspective, formally protecting San José Canyon could reduce fishing pressure on vulnerable life stages, safeguard critical habitats, and strengthen ecosystem-based management in Guatemala's Pacific region. Therefore, this study highlights the biological justification for advancing protection measures in the area and supports its consideration as a

priority site for marine conservation and fisheries management.

Credit author contribution

A. Hacohen-Domené: conceptualization, validation, methodology, formal analysis and writing-original draft; F. Polanco-Vásquez: conceptualization, validation, methodology, formal analysis and writing-original draft; J.F. Moreira-Ramírez: review and editing; J. Ortiz-Aldana: investigation, review and editing; C.A. Avalos-Castillo: formal analysis, review and editing; Miriam Castillo Villeda: review and editing. All authors have read and accepted the published version of the manuscript.

Conflict of interest

The authors declare no conflict of interest.

ACKNOWLEDGMENTS

We thank the Wildlife Conservation Society (WCS) Guatemala and Semillas del Océano for providing the financial support that made this research possible. Their support was essential to implementing field activities, collecting data, and coordinating logistics throughout the study period. We also thank the Fisheries, Biodiversity, and Protected Areas Authority for supporting biological monitoring. Finally, we thank Diego Incer (Centro de Estudios en Informática Aplicada, CEIA-UVG) for his assistance in preparing the map.

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Received: June 26, 2026; Accepted: October 13, 2026

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