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Trends and gaps in marine mammal research from Mexico during 1998 – 2021

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Abstract

Marine mammals are very diverse because of the oceanographic conditions of Mexican waters (where 36% of the current species worldwide are found); however, scientific research on many of these taxa is still at the basic stages. The goal of this study was to assess the scientific information available for these species and to determine research priorities through a GAP (from the acronym "Good", "Average", and "Poor") analysis. Information from the abstracts of the meetings held by the Mexican Society of Marine Mammalogy (SOMEMMA) and online databases (SCOPUS and Web of Science) between 1998 and 2021 was analyzed using temporal (years), geographic (oceans or states), taxonomic (species), and thematic (topics) classifications. On average, of the 44 species included in the Mexican legislation, only 16 - included in 14 families (with most of the records) - are studied every year, Delphinidae (n = 500; 25.9%), Balaenopteridae (n = 335; 17.4%), and Otariidae (n = 316; 16.4%). The Gulf of California was the most studied region (35.4%), followed by the Northeast Pacific (19.3%), the Gulf of Mexico (15.5%), and the Caribbean Sea (6.9%). The most frequent topics were population ecology (32.9%), conservation (16.7%), and animal health (10.4%). A significant decrease in the taxonomic and thematic diversity of such studies has been noted since SOMEMMA meetings began to be held on a biennial basis. It is noteworthy that marine mammals are protected by Mexican Federal laws. However, stock assessments are not mandatory, therefore biological aspects and trends of several (mostly oceanic) species remain unknown in many places, especially in regions where academic and scientific institutions are not involved in marine science.

Keywords:
bibliometric analysis, research priorities, GAP, taxa, topics, geography

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Introduction

Marine mammals are distributed in the oceans worldwide, with a total of 131 species (Committee on Taxonomy, 2022). The Exclusive Economic Zone (EEZ) of Mexico (approximately three million km^2) comprises waters of the Pacific and Atlantic oceans, each one with unique oceanographic characteristics (INEGI, 2007). This contributes to a great diversity of marine life, including mammals (Urbán & Rojas, 1999), with 44 living species recorded, including cosmopolitan, migratory, occasional, resident, endemic, threatened, and endangered (Aurioles-Gamboa, 2009; Heckel et al., 2018; Medrano & Urbán, 2019). Increasing human activities in coastal and ocean environments commonly produce encounters with marine mammals, in many cases risking their populations, thus conservation efforts are warranted.

Among the species with the highest risk, we find the vaquita (*Phocoena sinus*), an endemic and endangered species, prone to early extinction due to its small number and limited distribution (Upper Gulf of California), but most importantly due to fisheries bycatch (Norris & McFarland, 1958; Rojas-Bracho & Taylor, 1999; D'agrosa et al., 2000; Rojas-Bracho et al., 2006). Another well-known example is the Antillean manatee (*Trichechus manatus manatus*), which is distributed in the Gulf of Mexico (GoM), the Caribbean Sea (CS), and the Atlantic coast of Central America and Brazil (Morales-Vela & Olivera-Gómez, 1997; Rentería et al.,

2012); the main threats to this species are hunting for the use of meat, skin, fat and bones, human pressure, and modifications on its habitat, leading to populations' decrease (Rodríguez & Olivera-Gómez, 2012; IUCN, 2014).

In Mexico, all marine mammal species are included in the Official-Mexican-NOM-059 (SEMARNAT, 2010), which aims to identify threatened wild species, and establishes criteria for changing, excluding, or including these species (or their populations) from/into different risk categories. Within this standard, most species (81%) are "Subject to Special Protection (Pr)", except for the vaquita, the manatee, the sea otter (*Enhydra lutris lutris*), the North Atlantic right whale (*Eubalaena glacialis*), and the Guadalupe fur seal (*Arctocephalus philippii townsendi*) which are categorized as "Endangered (P)", and the Caribbean monk seal (*Neomonachus tropicalis*), which is currently classified as "Extinct (E)" (SEMARNAT, 2010; IUCN, 2022).

Scientific marine mammal studies in Mexico by Mexican researchers began in the 1950s, with the research by Berdegué (1956, 1957) and Luch-Belda (1969, 1970). However, it was not until 1979 that the Mexican Society for Marine Mammalogy (SOMEMMA) was created. Interestingly, to date scientific knowledge is still incipient for several marine mammal species and their populations. This could be the consequence of their populations having no direct commercial value, and thus there is little economic support to assess the most basic aspects of their biology/ecology; however, documented threats grow every day worldwide with the development of fishing, touristic and commercial activities (Ortega-Ortíz et al., 2004; Aurioles-Gamboa, 2009; Serrano et al., 2011). Urbán & Rojas (1999) summarized the available information on marine mammal species in Mexico presented at the SOMEMMA meetings from 1979 to 1998 and reported annual variations in the number of scientific abstracts. Most of these works were carried out in the Gulf of California (GC; n = 18), and the most representative topic was population biology (42%). The most studied species were the California sea lion *(Zalophus californianus)* (n = 87), the gray whale (*Eschrichtius robustus*) (n = 49), the common bottlenose dolphin (*Tursiops truncatus*) (n = 39), and the humpback whale (*Megaptera novaeangliae*) (n = 26). Similarly, Aurioles-Gamboa (2009) reported continuous growth in the number of abstracts between 1982 and 2004, and found that whales and dolphins were the most represented subjects, followed by pinnipeds, possibly because these species are easier to observe compared to other taxa. The same geographic trend was reported for the Mexican Pacific, the GC, the GoM, and the CS. However, they all emphasized the limitation on data for several areas, where marine mammal species are known to inhabit, thus leading to uneven knowledge on certain species, topics, and regions; hence, the need to prompt studies such as the GAP analysis (from the acronym "Good", "Average", and "Poor"), which informs what aspects must be considered priority, producing specific goals for research and conservation of species.

It is noteworthy that Mexican policies have clear and well-defined objectives for conservation and research for marine mammals, and these are based on the best (but still scarce) information available on the biology and ecology of the species they seek to protect; thus, in many cases, the measures used may be inappropriate or even harmful to these animals. In addition, the lack of long-term monitoring of the implementation of these measures has prevented a comprehensive assessment of the conservation status of these taxa in most cases.

Over the years, the interest of the scientific community has managed to make a difference in the government regarding the conservation of marine mammals in Mexico. In addition, relationships among governmental and research institutions have evolved, allowing the development of studies and activities focused on meeting the goals of a national marine mammal program. This study aims to update, summarize, and make a critical review on the information available for marine mammal species in Mexico, to determine the trends of these studies and provide a documented set of priorities for scientific research to help generate lacking information for their conservation and management.

Methods

Data collection

The number and scientific names of the species present in territorial waters in the EEZ of Mexico were taken from government official regulations (NOM-059-SEMARNAT-2010) and two revisions of marine mammals identified in Mexico based on the Committee on Taxonomy of the Society for Marine Mammalogy (Heckel et al., 2018; Medrano & Urbán, 2019; Committee on Taxonomy, 2022). A bibliographic search was carried out for publications involving marine mammals from 1998 to 2021 (updating and upgrading the revisions by Urbán & Rojas, 1999 and Aurioles-Gamboa, 2009) in three phases: 1) Memories of the international meetings for the study of marine mammals held by SOMEMMA, since - according to our preliminary observations - most of the researchers working with these taxa in Mexico are part of this society, thus a large part of the information is generated in these meetings; 2) Scientific articles in journals, based on the membership of SOMEMMA, since - according to the directory - most of the papers on marine mammals in the country are published by academics in this society; 3) Search in two databases of indexed journals, "Scopus" and "Web of Science", using keywords from the list of species, families, as well as oceans and the actual country, as they cover approximately 10,000 titles and publishers from all areas of knowledge, which provide a more precise search for information about marine mammal species. It is noteworthy that abstracts from meetings by the Society for Marine Mammalogy (SMM) and the Latin American Society of Specialists in Aquatic Mammals (SOLAMAC) were not included to avoid potential duplicates. That is because our preliminary search noted that many, if not most of the abstracts presented on both conferences (or at least a variation of the work), have already been presented in SOMEMMA meetings.

Each bibliographic entry obtained from the SOMEMMA abstract books and scientific journals was organized in a spreadsheet as follows: 1) Year (in which the work was carried out and in which it was published); 2) Title of the work; 3) Authors; 4) Study site (with coordinates if available and divided into four different categories: a) Ocean, b) Biogeographical Regions based on Medrano (2006) and Heckel et al. (2018), c) State of the Republic, and d) Municipality or specific location; 5) Families and species studied; and 6) Thematic classification key - this key was assigned from Dewey's (1979) classification and the

topics studied according to Guevara-Chumacero et al. (2001), which due to their specificity allow easy and efficient access to information, covering a wide range of topics.

For the GAP analysis, we used the same spreadsheet, and information was graphed in temporal, spatial, taxonomic, and thematic histograms to show the lack of information on marine mammal research within the country. Entries that did not specify the species/families, region, or subject were not included. Also, abstracts containing data originated outside Mexican territorial waters were excluded because our work was focused exclusively on marine mammal species in Mexico.

All records with available geographic locations were mapped using ArcGIS ESRI (v. 10.8.1). Entries with missing coordinates were obtained from the text to locate oceans, marine regions, and the state of the Republic in which they were conducted using Google Earth Pro. Contributions with unavailable geo-references were not included. We used a word cloud diagram to represent the frequency of studies on the different species using Python (v. 3.10.6) package Word Cloud (Muller, 2018).

Results

In total, 1,426 scientific documents on marine mammals were published between 1998 and 2021 both in the proceedings of the international SOMEMMA meetings and in scientific journals. Of these, 1,283 were carried out in Mexican waters; from the latter, 1,107 were conference abstracts, and 176 were scientific papers (Table 1). We found no records of abstracts by SOMEMMA meetings during 2005, 2007, 2009, 2011, 2013, 2015, 2017, and 2019 (Fig. 1), because as of 2004, these meetings turned into biennial conferences.

On average, 53.5 (± 40.7 SD) documents were published per year from 1998 to 2021, where the number of contributions increased overall during the first years, stabilizing after 2004 (excepting the years in which there were no SOMEMMA meetings), and increased drastically during 2014. This trend was marked mainly by the documents presented at the SOMEMMA conference since the number of articles published per year was consistent ($\bar{x}$ = 7.3 ± 3.9 SD) across the years.

Table 1. Total number of scientific documents on marine mammal research carried out in Mexico (1998 – 2021).

Type of document	Count	%
Abstracts of SOMEMMA meetings	1,107	86.3
Scientific papers	176	13.7
Total	**1,283**	**100**

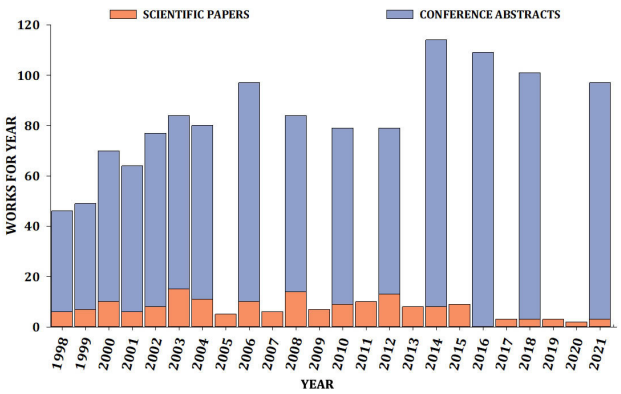

Figure 1. Number of scientific documents on marine mammals within Mexican waters from 1998 to 2021 (n = 1,283), according to publication type.

Taxa

For the period 1998 – 2021 we found 1,931 records of studies carried out on species of marine mammals in Mexico. On average, 16 species of the 44 registered in the Mexican territory are studied every year. This number varied throughout the study, decreasing when there were no SOMEMMA conferences. These records include fourteen families, being Delphinidae (n = 500; 25.9%), Balaenopteridae (n = 335; 17.4%) and Otariidae (n = 316; 16.4%) the most frequently studied, compared to Mustelidae (n = 6; 0.3%) and Balaenidae (n = 1; 0.05%). As stated earlier, some studies included species that are not distributed in Mexico, such as Dugongidae (n = 2; 0.1%) and Monodontidae (n = 1; 0.05%) (thus grouped in category "Other" for this analysis). The first case dealt with fossil records, whereas the second was a bibliographic review on the immune system of two species of marine mammals, including the narwhal *Monodon monoceros.* On the other hand, there were 236 records where the studied species were not specified (NS).

The highest number of research records in Mexico occurred between 2000 and 2010, where the most relevant families were Balaenopteridae, Delphinidae, Otariidae, Trichechidae, and Eschrichtiidae. From these, only the Delphinidae family increased the number of records during the last decade (2011 – 2021) (Fig. 2).

Specifically, the five species with the highest number of records were the California sea lion (n = 267), the common bottlenose dolphin (n = 253), the humpback whale (n = 156), the manatee (n = 154), and the gray whale (n = 121); whereas the sea otter (n = 2) and the Gervais' beaked whale (n = 1) presented the least records between 1998 and 2021 (Fig. 3).

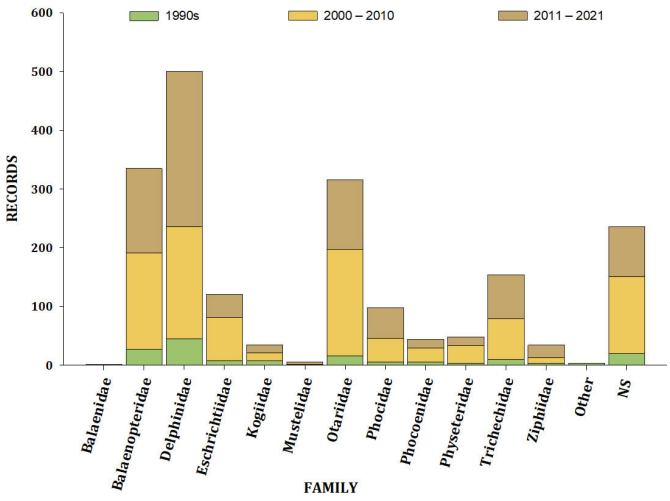

Figure 2. Records of studies on marine mammal families in Mexico by decade from 1998 to 2021 (n = 1,931). NS = not specified.

Figure 3. Word cloud of marine mammal species studied in Mexico from 1998 to 2021. The size of the words is directly proportional to the number of records obtained for the species (n = 1,931).

Overall, the families with the highest number of records were those with coastal distribution, and thus involved in the ecotourism and whale-watching industry. Within the Pacific side of the country (GC, NP, and Tropical Pacific), these include Balenopteridae (n = 311; 16.1%), Otariidae (n = 291; 15.1 %), and Delphinidae (n= 251; 13%). In the Atlantic side of the country (GoM and CS), most of the records were for Delphinidae (n = 211, 10.9%) and Trichechidae (n = 134; 6.9%), which are also of general interest to the public, and the most representative in the region (Fig. 4). Conversely, 196 records did not have any information (NS) on the location where they were conducted or were developed in captivity.

For the species inhabiting the marine regions of the Pacific, Otariidae (n = 193), Eschrichtiidae (n = 89), and Delphinidae (n = 78) were the most studied families in the GC, NP, and TP, respectively. On the other hand, the family with the least number of studies in the GC was Balaenidae (n = 1), the families Mustelidae (n = 2) and Kogiidae (n = 2) in the NP, and for the TP, the family Physeteridae (n = 1). For the marine regions on the east coast,

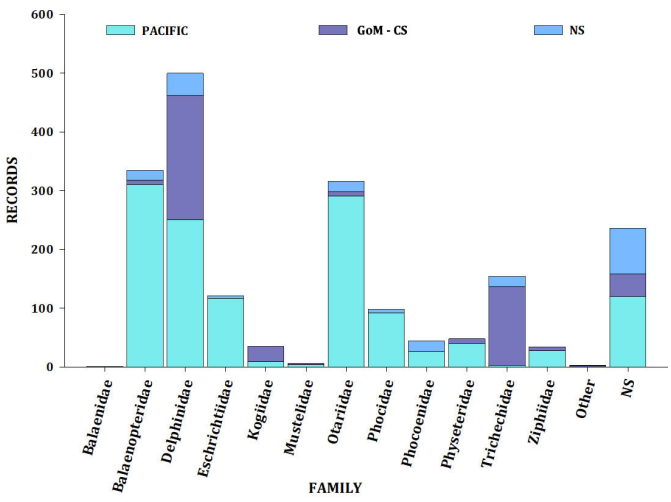

Figure 4. Number of records per family for the Pacific side (*i.e.* Gulf of California, North Pacific, and Tropical Pacific) and Atlantic side (*i.e.* Gulf of Mexico and Caribbean Sea) of Mexico between 1998 and 2021 (n = 1,931). Records with not-specified (NS) locations are also shown.

the family Delphinidae (n = 166) was the most represented in the GoM, whereas for the CS it was Trichechidae (n = 55).

Geography

The Pacific Ocean (GC, NP, and TP) was the most studied region with 1,294 (67.1%) records; conversely, the GoM and CS had only 443 (34.2%), whereas the remaining records (n = 194, 43.8%) did not inform where the studies were conducted. In the case of the Pacific, the highest number of studies was observed in the first decade of the 21st century, with 668 records, decreasing to 552 records in the following decade (2011 – 2021). On the other hand, for the GoM and CS, the highest number of records occurred during 2011 – 2021, being higher during 2018 (n = 66) and 2021 (n = 45). It should be noted that 194 studies did not inform the location in which the work was carried out or were developed in captivity (Fig. 5).

Within the Pacific, the GC had the highest number of records

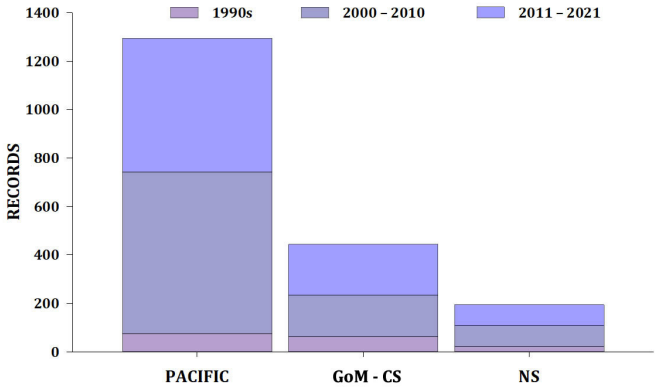

Figure 5. Proportion of records by decade (1998 – 2021) for marine mammal scientific studies in the Pacific (*i.e.* Gulf of California, North Pacific, and Tropical Pacific) and the Atlantic side of Mexico (*i.e.*, Gulf of Mexico and Caribbean Sea; GoM - CS) (n = 1,931). NS = not specified.

(n = 680, 35.2%), which showed an increase in the first years, and later reached the highest number in 2006. The second most studied marine region was the NP (n = 369, 19.1%), which reached the highest number of records in 2016 (n = 56), fluctuating in all study years. In the case of the TP (n = 203, 10.5%), a clear increase was observed throughout the sampling period, despite the years where there were no SOMEMMA meetings, reaching the highest number in 2018 (n = 45). All this coincides with the fact that the records were higher in the 2000 – 2010 decade in GC and NP, whereas for TP these records increased in the decade 2011 – 2021.

On the east coast of Mexico, the highest number of studies occurred in the GoM (n = 311; 16.1%), which peaked in 2006 (n = 71); whereas the CS had only 133 studies (6.9%). On the other hand, 235 studies (12.8%) did not report the study region. Interestingly in the years where no SOMEMMA meetings were held, there were no published works for the CS, except in 2013 and 2017. In this coast, the highest number of records occurred in the second decade of 2000, with 147 and 63 records for GoM and CS, respectively (Fig. 6).

The location of the records grouped by taxonomic family according to the division for marine regions shows the known distribution of the taxa (Fig. 7), following the natural distribution of

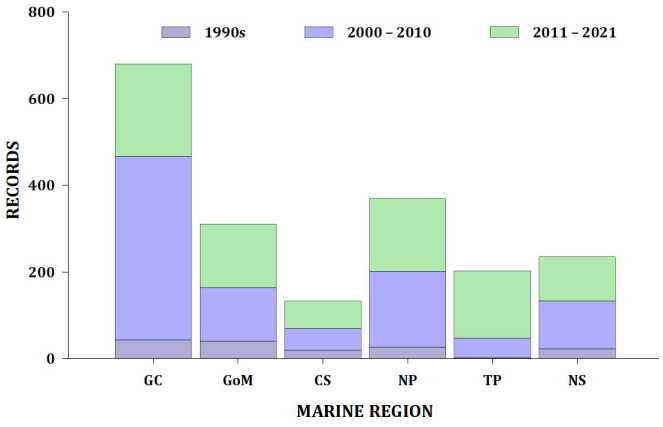

Figure 6. Proportion of records on marine mammal research by marine region between 1998 and 2021 (n = 1,931). GC = Gulf of California; GoM = Gulf of Mexico; CS = Caribbean Sea; NP = North Pacific coast of Mexico; TP = Tropical Pacific; NS = not specified

the species. For instance, studies about Delphinidae were located in both sides of Mexico, whereas those about Balaenopteridae were mostly located in the Pacific region (Fig. 7a-b).

The lack of records for any of these taxa within the state of Tamaulipas (TAM; northeastern GoM) is worth mentioning. Also, records for otariids in the GoM and the CS were notorious, as well as the records for manatees in the southeast Pacific (Chiapas, CHI), which were conducted on captive individuals (Fig. 7c-d).

According to the political division of Mexico, a higher number of studies was consistently recorded for the states bordering the Pacific Ocean, being Baja California Sur (BCS) (n = 355; 18.4%) and Baja California (BC) (n = 284; 14.7%) those with the most studies; both had an increasing intermittent pattern (*i.e.,* interrupted by interannual gaps). Conversely, the states of Michoacán (MIC) (n = 4; 0.2%) and CHI (n = 8; 0.4%) possessed the lowest number of records and appeared in only eight of the 24 years of this study. Within the states bordering the GoM, Veracruz (VER) (n = 111; 5.8%) had the highest records. Quintana Roo (QROO) was second (n = 108; 5.6%), but there were no records in recent years. Also, TAM (n = 9; 0.5%) had the lowest numbers, but all studies occurred in 2009 and 2018. Interestingly, 576 (29.8%) studies did not mention the state in which they were developed.

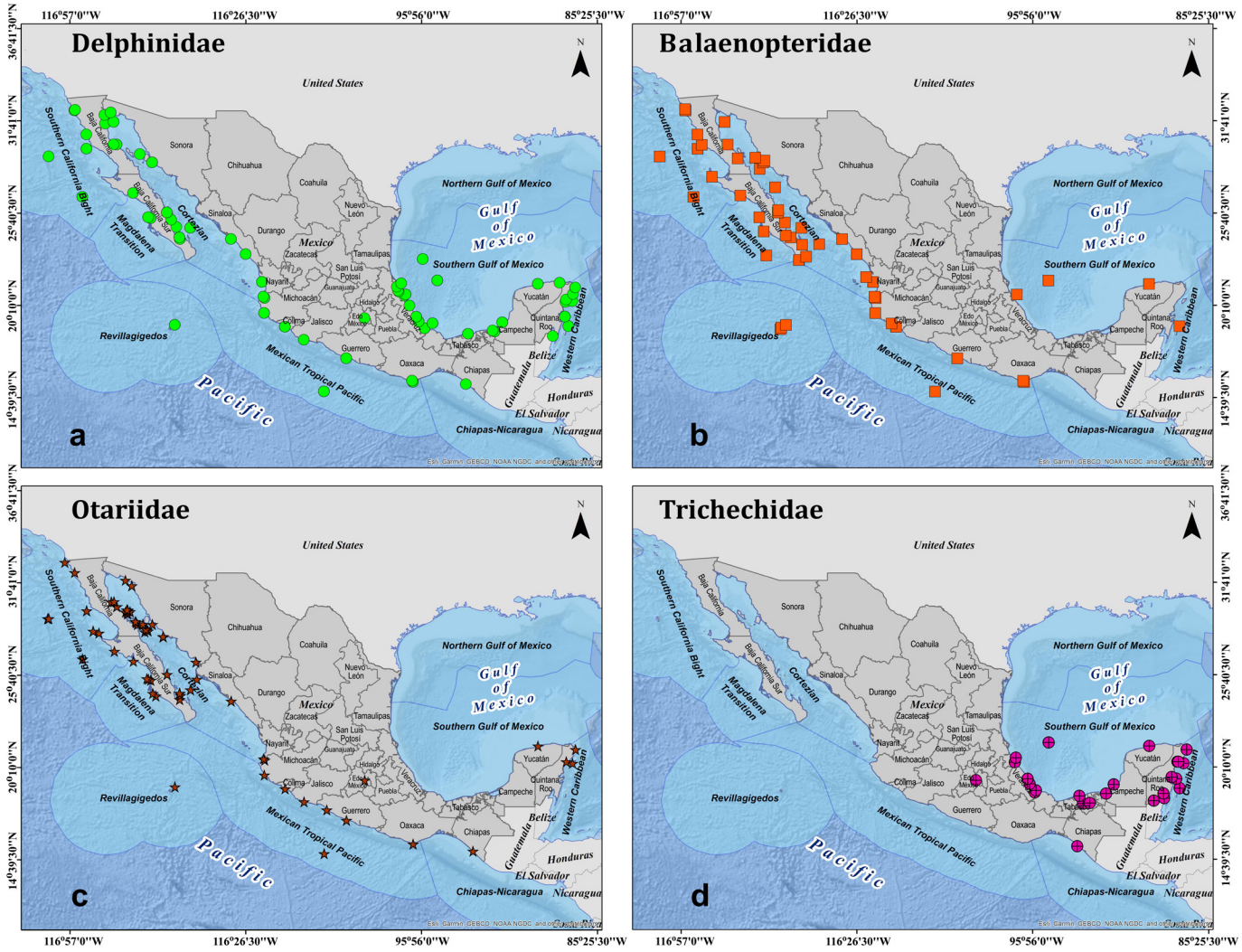

Figure 7. Location of taxonomic families of marine mammals most studied by marine region in Mexico between 1998 and 2021. a) Delphinidae; b) Balaenopteridae; c) Otariidae; and d) Trichechidae (n = 1,931).

Topic

Only in 2004 all the topics considered here were covered (n = 13), followed by the years 2001-2003, 2008, and 2012 with 12 topics (92.3%). Conversely, the years 2017 (n = 2), 2019 (n = 2), and 2020 (n = 1) had fewer topics. Population ecology was the most consistent in all years (1998-2021), followed by conservation (covered in 20 of the 24 years). Conversely, reproduction and physiology were less studied overall (only in seven and eight years, respectively).

Population ecology (n = 619; 32.1%), conservation (n = 321; 16.6%), and animal health (n = 200; 10.4%) were recurrent across the study period; also, topics such as sampling techniques (n = 120; 6.2%), behavior (n = 141; 7.3%), and feeding (n = 132; 6.8%) had a similar number of records throughout the sampling period. Within these topics, the studies were mainly focused on the development of methodology and bioacoustics. As stated earlier, reproduction (n = 13; 0.9%) and physiology (n = 11; 0.6%) had the fewest number of records. Similarly, most of the records came from the first decade of the 2000s, with a slight decrease observed between 2011 and 2021, except for the conservation topic, which had an increase over the last decade (Fig. 8).

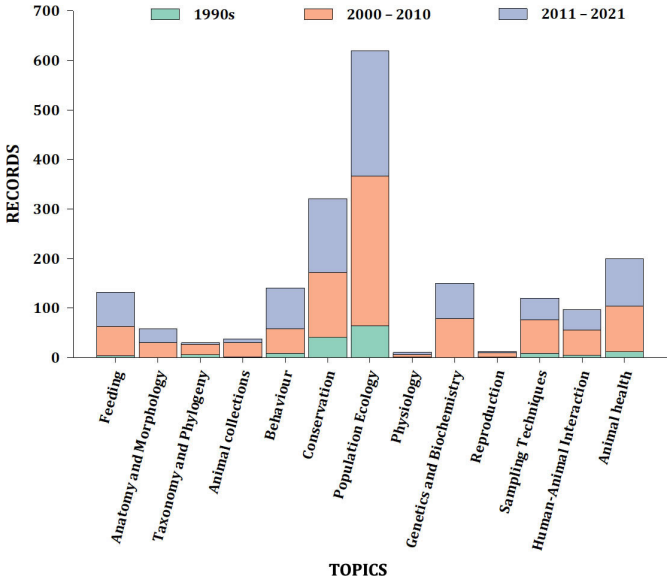

Figure 8. Topics on marine mammal studies per decade in Mexico during 1998-2021 (n = 1,931).

The topics studied for most marine mammal families were population ecology (14 families: 100%), anatomy and morphology, behavior, and conservation (10 families, or 83.3% for each topic). On the other hand, Balaenopteridae and Otariidae had the highest number of studied topics (n = 13; 100%), followed by Delphinidae and Phocidae (n = 12; 92.3%). These three families also presented the largest number of records within the most studied topics, except Conservation, where the Trichechidae family is also represented (Fig. 9).

Regarding the geographical distribution of topics, population ecology was the most frequent in both sides of Mexican waters (Pacific, n = 467; GoM and CS, n = 129). The least studied topics in the Pacific referred to animal collections (n = 5) and physiology (n = 4); for the GoM and CS, physiology (n = 3), taxonomy, and

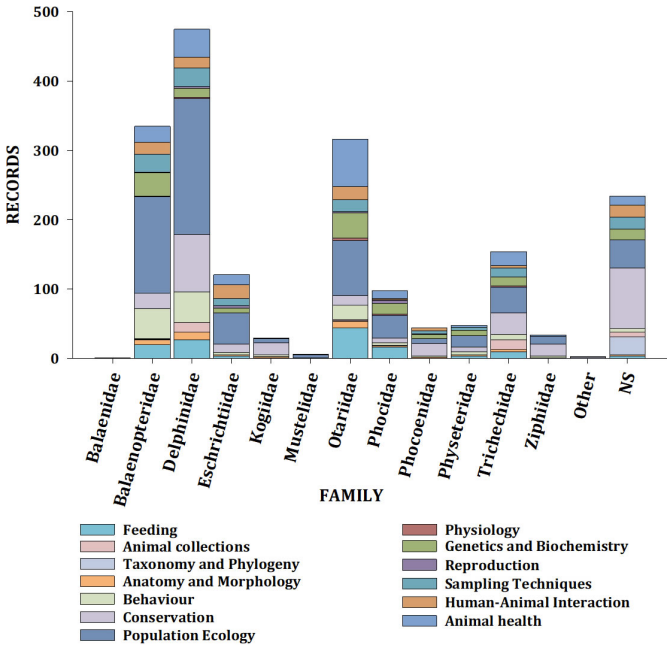

Figure 9. Records of topics studied by families of marine mammals in Mexico during 1998-2021 (n = 1,931). NS = not specified

phylogeny were infrequent topics (n = 2). The latter regions had no studies on reproduction.

Population ecology was also the most studied topic in four of the five marine regions: GC (n = 215), NP (n = 133), TP (n = 111), GoM (n = 103); whereas conservation had the highest number in the CS (n = 46) records. Physiology and reproduction were the topics with the least number of studies in all marine regions.

Again, population ecology was the only topic studied in all coastal states with marine mammal research records in Mexico (n = 17), followed by sampling techniques (in 15 states each), conservation (n = 12), and human-animal interactions (n = 12). The topics with the least coverage were reproduction (n = 4), and physiology (n = 2). In addition, five studies on animal health were recorded for captive facilities in the capital of the country (Ciudad de Mexico), a non-coastal state of Mexico.

Discussion

Periodic publications in international journals are often easier to find than proceedings and conference abstracts, which commonly facilitates and allows easy access to information (Adell, 1997). However, this has changed in recent years due to different search engines, online academic platforms such as ResearchGate, Academia.edu, and bibliographic software such as Mendeley. It is commonly accepted that information in papers by international peer-reviewed journals is more reliable since they mostly use stringent editorial standards and present more detailed information than conference proceedings or other non-periodical publications. However, as the quality of the research is improving, this trend is changing, and the intrinsic value of non-published information is growing. This is because most of these are also subject to (faster and often lighter) peer-review processes before being accepted and presented (Aurioles-Gamboa, 2009), but also because many of these abstracts are already - or eventually become - peer-reviewed literature.

On average, only 16.2% of the 44 marine mammal species present in Mexican waters are studied every year; specifically, the families Delphinidae, Balaenopteridae, Otariidae, and Trichechidae (Fig. 2). However, most of the records are represented by only a handful of species such as the bottlenose dolphin, the humpback whale, the California sea lion, and the manatee, respectively (Fig. 3). The latter is consistent with the trends reported by Urbán & Rojas (1999) and Aurioles-Gamboa (2009), who carried out similar studies considering periods of 19 (1979 – 1998) and 22 (1982 – 2004) years, respectively. Both used the data available in the abstracts of the meetings organized by SOMEMMA and considered the marine regions as the main characteristic for the geographical distribution of the studies, as well as the species and topics, although neither focused on scientific publications in periodic peer-reviewed journals (Fig. 1). Other recent bibliometric analyses have shown similar geographic and taxonomic patterns both in South (Szteren & Lercari, 2022) and Latin (Palacios et al., 2011; Huesca-Domínguez et al., 2023), (Stewart et al., 2002) America, pointing toward similar academic goals and research strategies, but also to well-known logistic and economic limitations.

The geographic and taxonomic patterns found here are likely due to the coastal distribution of the studied species, which are also somewhat common within Mexican waters. As their distribution and habits facilitate access to their study, some dolphin species are prone to interact with boats, which increases the chances of finding them during any type of marine endeavor (García-Vital et al., 2015). Whales can also be commonly observed from the beach during their migrations to their reproduction areas in Mexico (Urbán et al., 2021); for instance, in the Pacific these species are also the focus of the ever-growing touristic activities and the whale-watching industry, attracting the public attention and the government to get involved in conservation programs, as they also serve as indicators of environmental change (Isasi-Catalá, 2001). Pinnipeds spend much of their time resting on land and only enter the water to feed (Riedman, 1990). In coastal lagoons and shallow waters, sirenians are frequently detected by boat observers or with he use of sonars (Rodas-Trejo et al., 2008; Gonzalez-Socoloske et al., 2009; Aragones et al., 2012; Gonzalez-Socoloske & Olivera-Gómez, 2023) where they have easy access to food (Stewart et al., 2002).

As expected, the geographic patterns (Figs 5-7) and the studied topics also followed the trends reported by Aurioles-Gamboa (2009), where population ecology is one of the most recurrent. However, we found a gradual increase in the number of studies aimed at conservation and environmental education. Interestingly, there was a clear pattern in specific topics for particular areas and species (*e.g.* humpback whale, gray whale, bottlenose dolphin, and manatee), that has not diversified over time, which leaves a clear gap in the basic information currently available for many species.

It is important to consider that not all marine mammals are distributed homogeneously in Mexican seas (Fig. 7, Suppl. Material 1). For the east side (*i.e.* GoM and CS), 29 species can be found; however, only two (bottlenose dolphin and manatee) are frequently studied, leaving aside species such as the Clymene dolphin (*Stenella clymene*), the Atlantic spotted dolphin (*S. frontalis*), and the Gervais' beaked whale which are exclusive of this region. As stated earlier, the lack of studies on these species is likely due to the logistic challenges imposed by their offshore distribution, given their habitat and food preferences, and as they are rarely seen in waters near the coast (Stewart et al., 2002). On the other hand, in the Pacific, there are 39 species, and in this case research is mainly dominated by pinnipeds and baleen whales. In the same way, as on the east coast, this is mostly due to easier access, thus being traditionally common study subjects among researchers. However, little or no information still exists for taxa such as the Ziphiidae family, because of their deeper water habits and diving behavior, which also makes them difficult to spot. The scarce information on these species has been mostly obtained from strandings, with the notable exception of research on Cuvier's beaked whales (*Ziphius cavirostris*) in Guadalupe Island, especially between 2006 and 2009 (Cárdenas-Hinojosa et al., 2012).

In general, our results showed that, excepting the Tropical Pacific, the number of species studied over time decreased in all marine areas, which can be interpreted as a lack of diversification by the scientific community. Most of the research was generally carried out in a single location, and studies in more than one site were uncommon. The latter were mostly studies on strandings and a handful of long-term studies, where individuals or populations were monitored. Also, most of the records from conference abstracts lacked detailed geographic references, whereas research papers did contain precise geographical locations.

Overall, the Pacific had more records compared with the GoM and CS, consistent with a longer presence of academic institutions in the region (Fig. 6). Also, based on our data within the NP and the GC, research has remained relatively stable over the past 24 years (Urbán & Rojas, 1999; Aurioles-Gamboa, 2009). On the other hand, particularly in the TP, there has been an increase in the number of records throughout the sampling period, which prompts growing interest from the scientific community to expand their work in the states of Jalisco, Colima, and Oaxaca (Suppl. Material 2). However, for the southern states such as MIC, CHI, and Guerrero, the number of studies is still minimal. As stated originally by Aurioles-Gamboa (2009), this may be partially explained by the lack of academic institutions specifically focused on marine studies in these states; however, there is also the possibility that persistent and well-known issues on public safety due to drug traffic and paramilitary activities discourage academics, companies, and the general public to conduct marine surveys or even report the presence of marine mammals in some of these areas (Boyd et al., 2020; Calderón et al., 2020).

Turning to the east coast of Mexico, there was a general increase in the studies of marine mammals over time, mainly within the GoM (Figs 5-6). Interestingly, although there was a broader range of topics, no variation occurred in the taxa involved in these studies, since these were focused on bottlenose dolphins and manatee, specifically in the states of VER and QROO, respectively. Also, most of the records for uncommon species were composed of stranded individuals, as occurred in the Pacific. It is noteworthy that the lack of information on marine mammals within the waters of the state of TAM may very well have the same academic and security issues as in the Pacific.

The importance of collaboration to enhance the quantity and the quality of marine mammal research in America has been pointed out in recent studies (Palacios et al., 2011; Szteren

& Lecari, 2023; Huesca-Domínguez et al., 2023). Increasing collaboration and interest in marine mammal studies is not only attributed to researchers (Suppl. Material 1 and 2), but also to the higher number of students, who have pressed the scientific community to respond and create opportunities for the future (Hoyos et al., 1996; CONACYT, 2010). However, such growth has not translated into larger support for developing marine studies in Mexico; actually, only 0.4% of the gross domestic product has been available for all research activities over the last 23 years, placing Mexico among the countries with the least investment, along with Chile, Vietnam, and Saudi Arabia (BM, 2022).

According to our data, special attention must be drawn to species that have little or no information on their basic ecology, demography, and health status, which correspond to underrepresented taxa such as Kogiidae and Ziphiidae families, rarely studied in the wild (Fig. 9). On the other hand, a review of the reported marine mammals for Mexican waters is necessary, since species such as Fraser's dolphin (*Lagenodelphis hosei*), northern right whale dolphin (*Lissodelphis borealis*), Dall's porpoise (*Phocoenoides dalli*) and ginkgo-toothed beaked whale (*Mesoplodon ginkgodens*) have not been reported since 1998. This warrants updating their status under the current federal regulations to prioritize their research and generate basic data for management and conservation purposes (NOM-059-SEMARNAT-2010). This is also true for the new whale species reported in the GoM, the Rice's whale (*Balaenoptera ricei*) (Rosel et al., 2020), which may potentially reach Mexican territorial waters.

At the same time, starting and continuing systematic research on Endangered (EN) species like the sea otter, Critically Endangered (CR) like the North Atlantic right whale, Least Concern (LC) like the Gervais' beaked whale, and Vulnerable (VU) like the manatee, should provide a better understanding of their actual status and threats, potential distribution, population size, and health. In this sense, federal and state funds should prioritize the creation of research projects for these species, such as the one for the vaquita, before their abundances reach a threshold where conservation measures and technical actions become ineffective to restore their populations (NOAA, 2015).

The scarce knowledge about the biology and ecology of protected species such as the melon-headed dolphin (*Peponocephala electra*), Blainville's beaked whale (*Mesoplodon densirostris*), sei whale (*Balaenoptera borealis*), Clymene dolphin (*Stenella clymene*), and Risso's dolphin (*Grampus griseus*) prevents assessments on their state of conservation, and the risks for these species, due to natural and human-induced changes in their environment (Felix et al., 2007; Garcá-Godos, 2007; Morteo, 2011).

It is noteworthy that the new and more affordable tools may provide valuable information on animal health, including physiology and anatomy for all marine mammal species and their populations (Gálvez et al., 2022). However, the participation of experts in veterinary medicine for marine wildlife research in Mexico is minimal, and most of this research occurs in captive animals, with the notable exception of a handful of studies (Rangel-Martínez, 2014; Hurtado-Mejorada, 2015).

Based on our findings, there is a great need for public policies on conserving these species to include planning future research based on the priorities determined by the knowledge gaps identified here. However, these policies must also include the assessment of potential and actual risks derived from the development of human activities and the perspectives and perceptions of stakeholders and users of marine resources toward these issues (Morteo et al., 2022). These measurements will require several steps, which will be challenging because monitoring marine mammal populations is not mandatory in Mexico. Estimates of mortality rates and/or potential risks are scarce, scattered and very localized such that, excepting the commercial fleet for yellowfin (*Thunnus albacares*) and bluefin tuna (*Thunnus thynnus*), there are no systematic monitoring of incidental captures for any type of fishery, despite regulations by federal institutions such as CONAPESCA (National Commission for Fisheries and Aquaculture) and the National Fisheries Institute (Olivera, 2022). Nevertheless, worldwide, the interaction between fisheries and marine mammals has been documented (Perrin et al., 1973; Joseph, 1994; Soede et al., 2019; Kiszka et al., 2021). In Mexico, this interaction also has been recorded and studied (Joseph, 1994; Noguez-Fuentes et al., 2007; Chávez-Martínez et al., 2022). Although political and commercial agreements have been established in Mexico to exploit the tuna fishery while minimizing the effects on marine mammal populations (Diario Oficial de la Federación, 2014 - NOM-023-SAG/PESC-2014), information on these interactions remains scarce (Morales-Rincon et al., 2019). The latter may have economic implications in the upcoming years, not only for Mexico; this is due to the moratorium of the United States for the importation of marine products that must comply with their welfare regulations according to the Marine Mammal Protection Act.

Finally, we call upon implementing planned and direct actions for the dissemination of knowledge (and the lack thereof) about marine mammals in Mexico to increase awareness and interest of the public, private institutions, and politicians, such that they promote the collaboration required to achieve the several steps necessary to conduct scientific research on these species in multi-, trans, and inter-disciplinary studies. The latter must involve active and assertive participation from all these actors, not only within Mexico, but also to reach across our borders for much needed international collaboration.

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Supplementary material

Supplementary Material 1 - Location of scientific studies in Mexican waters (1998 – 2021) by study period (*i.e.* every four years). The map shows how marine mammal research in the North Pacific developed earlier than in the South Pacific and the Gulf of Mexico.

Supplementary Material 2 - Number of scientific studies in Mexican waters (1998 – 2021) by marine region. The map shows how the Gulf of California (Cortezian) is the most studied area, followed by the Gulf of Mexico and the North Pacific (Southern California Bight).

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