Centro de Investigación Científica y de Educación Superior de Ensenada, Baja California

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Doctorado en Ciencias en Ecología Marina

Distribution and abundance of cetaceans in Mexican waters of the Gulf of Mexico

Tesis
para cubrir parcialmente los requisitos necesarios para obtener el grado de
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Presenta:

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Resumen de la tesis que presenta **Mario Rafael Ramírez León** como requisito parcial para la obtención del grado de Doctor en Ciencias en Ecología Marina.

Distribución y abundancia de cetáceos en aguas mexicanas del golfo de México

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En el golfo de México hay 21 especies de cetáceos: un misticeto (ballenas barbadas) y 20 odontocetos (cetáceos dentados). La mayor parte del conocimiento sobre este grupo proviene de la Zona Económica Exclusiva de Estados Unidos; en contraste, su ecología ha sido poco estudiada en las aguas mexicanas. Esta falta de información básica limita la evaluación del estado de sus poblaciones en el golfo de México. El objetivo principal de este trabajo fue crear la línea de base sobre la distribución y abundancia de los cetáceos en aguas mexicanas del golfo de México. En primer lugar, se determinó el estado actual del conocimiento de los cetáceos en aguas mexicanas, para lo cual se hizo una búsqueda bibliográfica de los registros históricos de avistamientos y varamientos, y otra sobre publicaciones científicas para conocer cuáles son las especies y temáticas más estudiadas. Se recopilaron registros de 16 especies de cetáceos en aguas mexicanas del golfo, añadiéndose cuatro especies a las reportadas previamente, y ~91% de estos registros fueron tursiones. Además, se encontró que en México existe un retraso importante en relación a los estudios hechos en aguas de Estados Unidos. Asimismo, se encontró que el tursión ha sido la especie más estudiada en el golfo de México. En segundo lugar, se modeló la idoneidad ambiental de 12 especies de cetáceos, para lo cual se utilizó el algoritmo de máxima entropía (MaxEnt) y para identificar aquellas regiones geográficas capaces de soportar una alta diversidad de cetáceos se utilizó un enfoque espacial. En general, la profundidad, la temperatura mínima de la superficie del mar y la pendiente del fondo fueron los predictores que más contribuyeron a los modelos. Igualmente, se encontró que áreas de alta idoneidad para 10 especies se localizaron en el talud continental y se identificaron cuatro regiones idóneas: (1) el cañón del Mississippi y el talud de Luisiana-Texas en el norte del golfo, (2) la terraza occidental de Florida en el este-noreste, (3) el talud del Río Bravo en el oeste-noroeste, y (4) el talud de Tamaulipas-Veracruz en el oeste-suroeste. Finalmente, se estimó la densidad poblacional y abundancia de delfínidos en el suroeste del golfo. Cuatro muestreos aéreos se llevaron a cabo entre agosto 2015 y febrero 2017, utilizando protocolos de muestreo de distancias y los datos se analizaron mediante un modelo jerárquico bayesiano. Se encontró que la abundancia de los delfínidos en el suroeste del golfo de México estuvo en el orden de los cientos de animales (N= 668; 95 %-CI: 340 – 1,179), con una densidad global de 1.91 individuos 100 km^{-2} (95 %-CI: 0.97 – 3.38). Los resultados reportados en esta tesis son una primera aproximación para entender la distribución y abundancia de los cetáceos en aguas mexicanas del golfo de México, y se pueden considerar como una línea de base para estudios futuros.

Palabras clave: modelos de distribución de especies, MaxEnt, muestreo de distancias, inferencia bayesiana

Abstract of the thesis presented **by Mario Rafael Ramírez León** as a partial requirement to obtain the Doctor of Science degree in Marine Ecology.

Distribution and abundance of cetaceans in Mexican waters of the Gulf of Mexico

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There are 21 species of cetaceans in the Gulf of Mexico: one baleen whale and 20 odontocetes (toothed whales). Most of the knowledge about this group comes from the U.S. Exclusive Economic Zone; in contrast, their ecology has been poorly studied in the Mexican waters. This lack of basic information limits the assessments of the population status of cetacean in the Gulf of Mexico. The main objective of this study was to create a baseline on the distribution and abundance of cetaceans in Mexican waters of the Gulf of Mexico. First, the current knowledge on cetaceans was determined, conducting a bibliographic search of historical records of sightings and strandings, and another search one on peer-review papers to identify the most studied species and subjects. Records of 16 species of cetaceans were compiled in Mexican waters of the Gulf, adding four species than those previously reported, and ~90% of these records were common bottlenose dolphins. Moreover, in Mexico a substantial delay was found in relation to the studies made in the U.S. waters. Likewise, the common bottlenose dolphin has been the most studied species in the Gulf of Mexico. Secondly, the habitat suitability of 12 species was modeled using the maximum entropy algorithm (MaxEnt), and a spatial approach was used to identify those geographic regions capable of supporting a high diversity of cetaceans. Overall, depth, minimum sea surface temperature, and bottom slope were the most contributing predictors in the models. Similarly, high suitability areas of 10 species were located on the continental slope, and four suitable regions were identified: (1) the Mississippi Canyon and the Louisiana-Texas slope in the northern Gulf, (2) the west Florida slope in the east-northeastern, (3) the Rio Grande slope in the west-northwestern, and (4) Tamaulipas-Veracruz in the west-southwestern. Finally, the population density and abundance of delphinids was estimated in the southwestern Gulf of Mexico. Four aerial surveys were conducted between August 2015 and February 2017, using distance sampling protocols, and the data were analyzed using hierarchical Bayesian approach. Delphinids abundance in the southwestern Gulf of Mexico was in the order of the hundreds of animals (N= 668; 95 %-CI: 340 – 1,179), with a global density of 1.91 individuals 100 km^{-2} (95 %-CI: 0.97 – 3.38). The results reported are a first approximation to understand the distribution and abundance of cetaceans in Mexican waters of the Gulf of Mexico and can be considered as a baseline for future studies.

Keywords: distributions species models, MaxEnt, distance sampling, Bayesian inference

Dedication

Para los que se quedaron en el camino, pero siguen muy presentes.
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Para Alessandra y Aimie

"Have a good time. Enjoy life. Life is too short to get bogged down and be discouraged. You have to keep moving. You have to keep going. Put one foot in front of the other, smile just keep on rolling."

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Chapter 1. Introduction

1.1 Background

The Gulf of Mexico (GOM) is a semi-enclosed marine ecosystem connected to the Atlantic Ocean by the Florida Straits, and to the Caribbean Sea by the Yucatan Channel (Kumpf et al., 1999; De la Lanza-Espino & Gómez-Rojas, 2004). It is bounded to the north and northwest by the United States of America (U.S.), to the south and southwest by Mexico, and to the east by Cuba, covering the Economic Exclusive Zones (EEZ) of these countries (Fig. 1). The bathymetry is heterogeneous, from broad continental shelves, such as those off the Florida and Yucatan peninsulas (>200 km of extension), to regions with narrow continental shelves, such as the coast of Tamaulipas and Veracruz (~2 km). The continental slope (between 200 and 2,800 m depth) presents vast canyons, as the Mississippi Canyon, and the central basin's average depth is 3,500 m (Bouma & Roberts, 1990; Monreal-Gómez et al., 2004).

The Loop Current dominates the oceanographic dynamics of the GOM to the east and the anticyclone circulation cell to the west (Elliott, 1982). Overall, it is an ecosystem of moderate productivity, which varies from eutrophic conditions on the coast due to the input from rivers discharges (Biggs, 1992; Lohrenz et al., 1999), to oligotrophic deep waters (Muller-Karger et al., 2015). These characteristics allow the GOM to hosts a significant marine biodiversity, with more than 15,400 recorded species; of these, ~10% are endemic (Felder & Camp, 2009).

The GOM is an important source of exploitable natural resources for Cuba, the U.S., and Mexico (Cato & Adams, 1999). Several human activities are carried out in its waters, such as hydrocarbon exploration and extraction, tourism, artisanal fisheries in the coast, and industrial and sport fishing in oceanic waters (Sturges et al., 2005). Moreover, every year large amounts of pollutants and sediments are transported by rivers to the GOM (Davis et al., 2002), thus human disturbances are not only limited to activities in the marine environment but extend to the continent. Due to the increase in the human population on the coast, these activities have intensified (Cato & Adams, 1999), directly or indirectly impacting the GOM ecosystem's health and disturbing the mega-fauna populations.

Cetaceans are part of this GOM's mega-fauna, and they are a key group for assessing the health of marine ecosystems because changes in their populations reflect ecological variations at large spatial and temporal scales (Moore, 2008). The primary disturbances to which the cetaceans of the GOM are exposed, and which could potentially negatively impact their populations, are those related to the hydrocarbon industry, pollution, marine traffic, and interactions with fisheries (Ortega-Ortiz et al., 2004; Read et al., 2006; Lane et al., 2015).

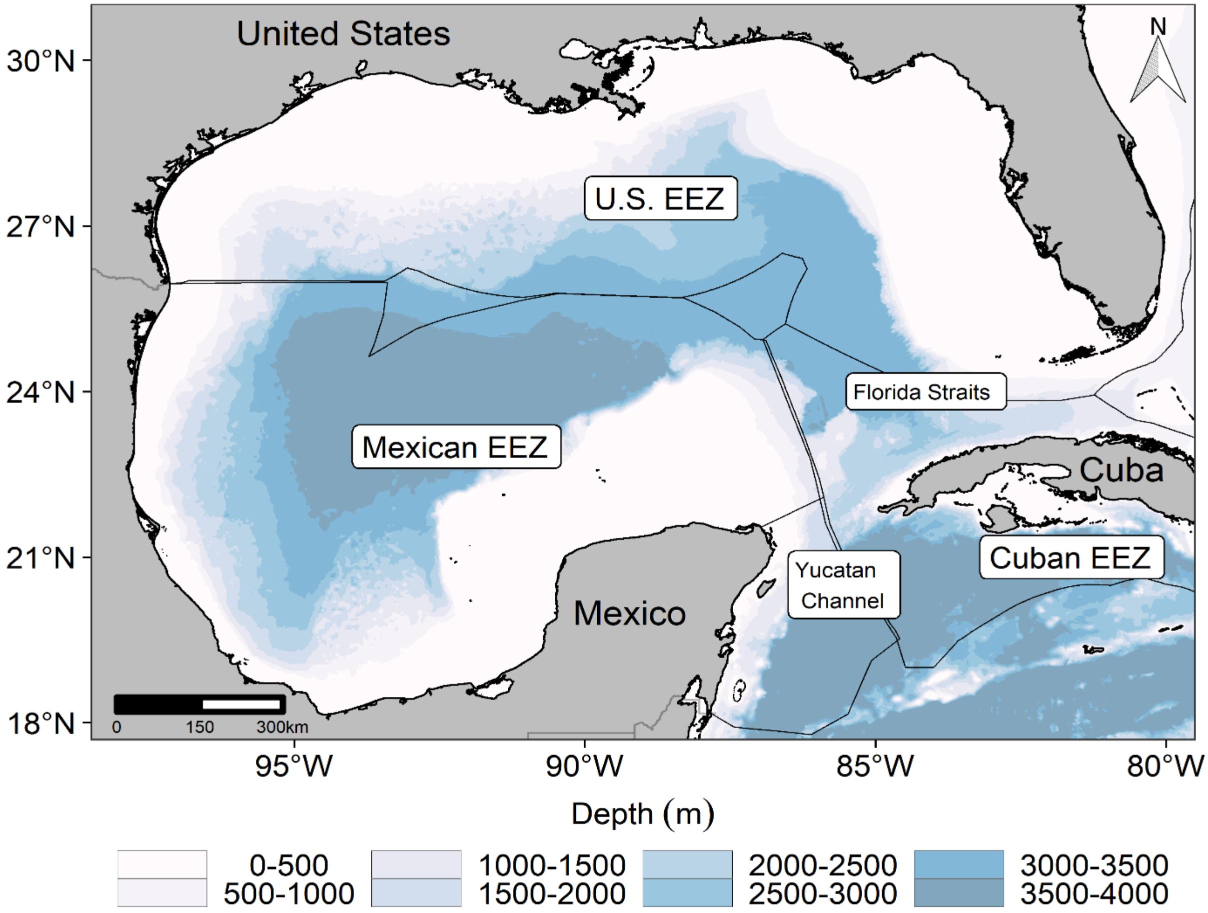

Figure 1. The Gulf of Mexico showing the Exclusive Economic Zone of the United States, Mexico, and Cuba.

Currently, 82% of Mexico's oil production occurs in the waters of the GOM, where more than 75% of the country's proven oil reserves are located (CNIH, 2019). Under this scenario, following the 2010 Deepwater Horizon oil spill in the northern GOM, the Mexican government promoted a large-scale research initiative in 2015, to generate a baseline for biota in Mexican waters of the GOM. Such baseline is intended to serve as a guide in the development of management plans and mitigation measures for potential impacts related to the hydrocarbon industry. This study is part of that initiative, and the main objective is to estimate of distribution and abundance of the cetacean species that inhabit the Mexican waters of the GOM.

1.2 Justification

Research on cetaceans in Mexico has focused mainly on the west coast of the Baja California Peninsula and the Gulf of California with 66% of the studies in last two decades, while the knowledge of cetaceans' ecology in Mexican GOM is extremely poor (Torres et al., 1995; Escobar-Lazcano, 2015). The lack of basic ecological information of this group has limited reliable assessments on the status of their populations in the whole GOM. Hence, given that cetaceans are an important component of the mega-fauna that inhabits it, understanding their ecological dynamics and processes will help better management actions, which will allow the establishment of improved conservation tools and policies for the ecosystem and their populations.

1.3 Objectives

1.3.1 General objective

To establish a baseline analysis on the distribution and abundance of cetaceans in the Mexican waters of the Gulf of Mexico.

1.3.2 Specific objectives

1. To determine the state of knowledge on cetaceans in the Mexican waters of the Gulf of Mexico (Chapter 2).

2. To analyze the habitat suitability of cetaceans and to identify suitable regions capable for supporting high cetacean diversity (Chapter 3).

3. To estimate the abundance of cetaceans in the southwestern Gulf of Mexico (Chapter 4).

Chapter 2. Review of the state of knowledge of cetaceans in the Gulf of Mexico

2.1 Introduction

The GOM portraits a relatively high diversity of cetaceans, with 21 common species in the U.S. EZZ (Table 1) (Jefferson & Schiro, 1997; Hildebrand et al., 2015; Würsig, 2017), which represent ~21% of the global cetacean species diversity (Burgin et al., 2018). The Bryde's whale (*Balaenoptera edeni*) is the only mysticete (i.e., baleen whales), and it is distributed exclusively in the northwestern GOM (Soldevilla et al., 2017). The remaining 20 species are odontocetes (i.e., toothed cetaceans), with the most diverse being the Family Delphinidae with 14 species. Sightings and strandings of five species of baleen whales, as well as the Sowerby's beaked whale (*Mesoplodon bidens*), have been reported occasionally (Waring et al., 2016; Würsig, 2017).

Table 1. List of cetacean species in the Gulf of Mexico. Scientific and common names were taken from Jefferson et al. (2015). *Listed by Ortega-Ortiz (2002).

Family	Scientific name	Common name
Balaenopteridae	*Balaenoptera edeni*	Bryde's whale
Physeteridae	*Physeter macrocephalus**	Sperm whale
Kogiidae	*Kogia breviceps*	Pygmy sperm whale
	Kogia sima	Dwarf sperm whale
Ziphiidae	*Mesoplodon densirostris*	Blainville's beaked whale
	Mesoplodon europaeus	Gervais's beaked whale
	Ziphius cavirostris	Cuvier's beaked whale
Delphinidae	*Orcinus orca**	Killer whale
	*Globicephala macrorhynchus**	Short-finned pilot whale
	Peponocephala electra	Melon-headed whale
	Feresa attenuata	Pygmy killer whale
	Grampus griseus	Risso's dolphin
	*Pseudorca crassidens**	False killer whale
	*Steno bredanensis**	Rough-toothed dolphin
	Lagenodelphis hosei	Fraser's dolphin
	*Stenella attenuata**	Pantropical spotted dolphin
	Stenella clymene	Clymene dolphin
	*Stenella coeruleoalba**	Striped dolphin
	*Stenella frontalis**	Atlantic spotted dolphin
	*Stenella longirostris**	Spinner dolphin
	*Tursiops truncatus**	Common bottlenose dolphin

The ecology of cetaceans in the GOM was poorly studied before the 1980s, but the establishment of the Southeastern United States Marine Mammal Stranding Network in 1977 marked the beginning of systematic research (Schmidly & Würsig, 2009). Large-scale surveys started in the 1980s, and starting the 1990s, the National Marine Fisheries Services and the U.S. Fish and Wildlife Service have published annual the U.S. Atlantic and Gulf of Mexico marine mammal stocks assessments (NOAA, 2020). In contrast, knowledge seems to be very limited inside the Mexican EEZ, which comprises about 50% of the total area of the GOM. Ortega-Ortiz (2002) presented the most extensive compilation of sightings, confirming the presence of ten commonly sighted species (Table 1); however, until the beginning of the 21st century, the information on basic ecology, including cetacean distribution and abundance, was practically non-existent (Ortega-Ortiz et al., 2004).

Besides its biological diversity, the GOM is an important economic area where fishing, tourism, and the hydrocarbon industry generate billions of dollars annually (Karnauskas et al., 2013). These activities place the GOM ecosystem under increasing anthropogenic pressure, but the development of regional management plans for cetaceans has been difficult by the lack of ecological data inside the Mexican EEZ. In this chapter, the state of knowledge of cetaceans in Mexican waters of the GOM was reviewed.

2.2 Objectives

1. To update the database of records of cetaceans within the Mexican waters of the GOM.

2. To review the state of knowledge of cetaceans within the Mexican EEZ in order to evaluate research patterns and identify knowledge gaps.

2.3 Materials and methods

2.3.1 Study area

The GOM is one of Mexico's marine eco-regions (Fig. 2a), each with unique oceanographic features that influence the species distribution and richness (CONABIO et al., 2007; Niño-Torres et al., 2015). The

Mexican EEZ of the GOM extends from Cabo Catoche, Quintana Roo (21° 36'N and 87°06'W), on the oceanographic border between the GOM and the Mexican Caribbean (Fig. 2b), to the U.S.-Mexico border (25° 57'N and 97°07'W) (De la Lanza-Espino, 1991).

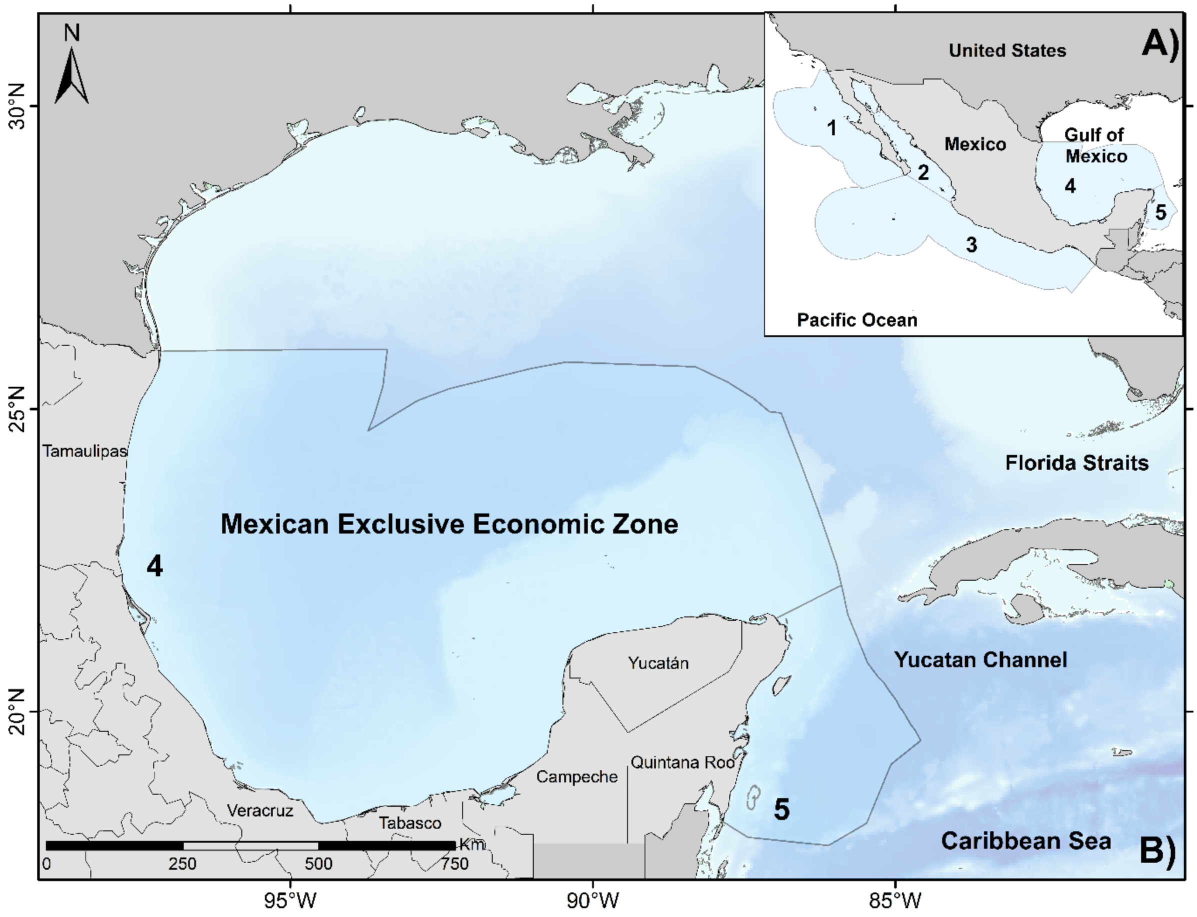

Figure 2. (A) Marine eco-regions of Mexico: 1. North occidental Pacific, 2. The Gulf of California, 3. Tropical Pacific, 4. The Gulf of Mexico, 5. The Caribbean Sea. (B) Study area, the Mexican Exclusive Economic Zone of the Gulf of México.

2.3.2 Review of historical records

Sighting and stranding records until to 2018 were compiled from specialized literature. The criteria of Jefferson & Schiro (1997) and Ortega-Ortiz (2002) were followed to avoid using misidentified records, and only those sightings for which there was proven evidence of correct identification based on diagnostics characteristics were included. Verified records were mapped (when the geographic coordinates were available), using the package ggplot2 (Wickham, 2010) for the R software (R Core Team, 2018).

2.3.3 State of knowledge

The state of knowledge was evaluated based on the number of papers, which is a good indicator of the research investment, assuming that a published work meets scientific quality standards (Wilson et al., 2016). An exhaustive bibliographic review of peer-reviewed scientific papers was conducted using the Elsevier, JSTOR, Web of Science, Wiley, and Redalyc databases. However, given the low number of papers found for the Mexican EEZ, another query was done in the abstracts of the Reunión Internacional para el Estudio de los Mamíferos Marinos, of the Sociedad Mexicana de Mastozoología Marina (SOMEMMA).

The production trend (number of papers over time) was evaluated using time series, but because trends can vary in time, the freely available software *SegReg* (https://www.waterlog.info) was used to determine if there was a break-point; that is, to detect if the trend changed abruptly. Subsequently, the nonparametric Mann-Kendall test (MK) was used to assess whether the production trend (slope) was statistically different from zero, and if so, to determine its direction (increasing or decreasing) (Libiseller & Grimvall, 2002). Study topics were divided into ten classes based on the SOMEMMA criteria (Table 2, Escobar-Lazcano, 2015).

Table 2. Topic classification of the study of cetaceans. Modified from Escobar-Lazcano (2015).

Principal topics	**Sub-topics**
Feeding and foraging	Feeding habits, food webs, foraging ecology.
Anatomy and morphology	Anatomy, allometry, morphometry.
Evolution and phylogeny	Evolution, systematics.
Strandings	Stranding events.
Socio-sexual behavior	Behavioral ecology, diving behavior, predator-prey relationships, reproductive behavior, social structure, acoustic studies.
Management and conservation	Legislation, wildlife management, conservation status, threats for species, interaction with fisheries and vessels, bycatch, zoonosis, tourism, effect of acoustic pollution.
Population ecology	Distribution, abundance, diversity, demography, migration, habitat, home range, movements.
Genetics and biochemistry	Metabolism, Stable isotopes. DNA/RNA analysis
Sampling technics	Telemetry, computer programs, and databases, acoustic methods, photo-identification, satellite imagery, capture, and management.
Animal health	Animal injuries, body condition, toxicology, clinical monitoring, pathology.

To evaluate if there were changes both in the research lines and in the species studied between periods (see below) the method of *m* proportions (Fleiss, 1981) was used, which allows the carry out hypothesis test on the equality of proportions of independent samples.

2.4 Results

2.4.1 Review of historical records

The oldest cetacean sighting record in Mexican waters dates back to 1952; since then and until 2018, a total of 3,941 records of 16 species were found (Table 3; Appendix 1). The sources of information were theses (64% of the total records), conference proceedings and abstracts (15%), scientific papers (15%), and technical reports (6%) (Appendix 1). Almost all sightings were recorded opportunistically, except for the records of the common bottlenose dolphin (*Tursiops truncatus*), although some were collected in 14 surveys carried out by Mexican researchers in the 1980s (A. Aguayo-Lobo, unpub. data), six in the late 1990s (Ortega-Ortiz, 2002), three in the mid-2000s (Galindo et al., 2009; Vázquez-Castán et al., 2009), and four in the late 2010s (present study). However, only six surveys were specifically designed for cetacean data collection (Galindo et al., 2009; present study), while the remaining 21 were opportunistic surveys conducted during oceanographic cruises. Only 805 sightings of 13 species were georeferenced (see below), and more than 95% of them were recorded on the continental shelf (< 200 m depth) and the inner slope (200 to 1,000 m depth).

Sightings

Ninety-one percent of the records were of common bottlenose dolphins (Table 3). Excluding these records, the most commonly sighted species in the Mexican EEZ were the Atlantic spotted dolphin (*Stenella frontalis*, 42% of the remaining 372 sightings), pantropical spotted dolphin (*S. attenuata*, 20%), short-finned pilot whale (*Globicephala macrorhynchus*, 13%), rough-toothed dolphin (*Steno bredanensis*, 10%), and sperm whale (*Physeter macrocephalus*, 8%). Sightings of killer whales (*Orcinus orca*), false killer whales (*Pseudorca crassidens*), and spinner dolphins (*Stenella longirostris*) were scarce (< 10 each), while only one record was found for the Fraser's dolphin (*Lagenodelphis hosei*). There were also some sightings of fin whales (*Balaenoptera physalus*) and humpback whales (*Megaptera novaeangliae*). Records of four species not previously reported by Ortega-Ortiz (2002) were found: the dwarf sperm whale (*Kogia sima*), pygmy killer whale (*Feresa attenuata*), Clymene dolphin (*Stenella clymene*), and Risso's dolphin (*Grampus griseus*) (see below).

Family Balaenopteridae

Rorquals have a cosmopolitan distribution, and six species have been reported in the GOM, but five are occasional visitors (Jefferson & Schiro, 1997; Würsig, 2017). Only two confirmed sightings were found for this Family in the Mexican EEZ of the Gulf (Table 3; Fig. 3).

Table 3. Historical records of cetaceans in the Mexican Exclusive Economic Zone of the Gulf of Mexico, period 1915 – 2018. *First confirmed record after 2002.

Family	**Specie**	**Sightings**	**Strandings**
Balaenopteridae	*Balaenoptera acutorostrata*	0	1
	Balaenoptera borealis	0	1
	Balaenoptera musculus	0	2
	Balaenoptera physalus	1	2
	Megaptera novaeangliae	1	1
Physeteridae	*Physeter macrocephalus*	28	9
Kogiidae	*Kogia breviceps*	0	17
	Kogia sima	1*	6
Ziphiidae	*Mesoplodon densirostris*	0	1
	Mesoplodon europaeus	0	3
	Ziphius cavirostris	0	3
Delphinidae	*Orcinus orca*	2	3
	Globicephala macrorhynchus	50	13
	Peponocephala electra	0	2
	Feresa attenuata	1*	3
	Grampus griseus	3*	3
	Pseudorca crassidens	5	5
	Steno bredanensis	39	6
	Lagenodelphis hosei	1	0
	Stenella attenuata	75	0
	Stenella clymene	1*	0
	Stenella coeruleoalba	0	2
	Stenella frontalis	155	2
	Stenella longirostris	9	3
	Tursiops truncatus	3569	231
Total		3941	319

The first corresponds to a fin whale observed near the bay of Campeche (Ortega-Ortiz, 2002), and the second to a humpback whale recorded in northern Veracruz (Ortega-Ortiz et al., 1998).

Family Physeteridae

The only member of this family is the sperm whale, which has a cosmopolitan distribution and is commonly sighted in the GOM (Waring et al., 2016; Würsig, 2017). There were 27 sightings in the Mexican EEZ (Table 3, Fig. 3).

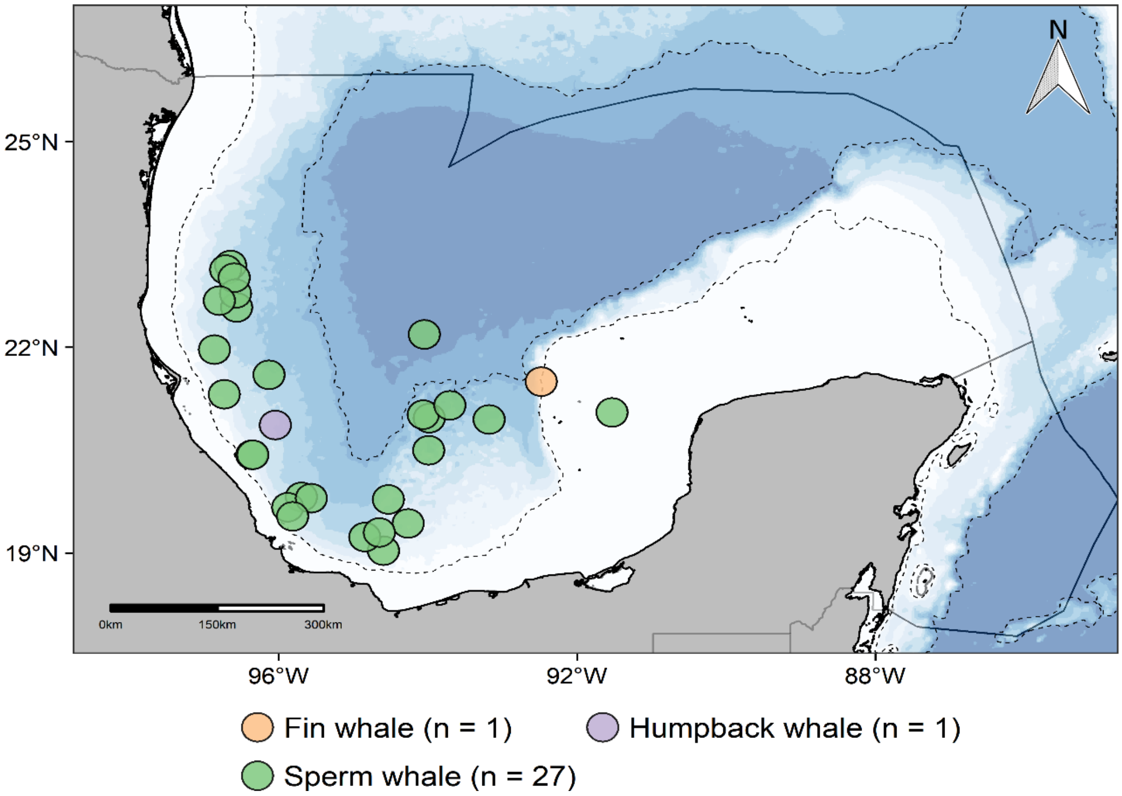

Figure 3. Sightings records of Balaenopteridae and Physeteridae families in the Mexican Exclusive Economic Zone (solid line). The dotted lines represent the 200 m and 2,800 m isobaths, respectively.

Family Kogiidae

The two species of this family, the pygmy sperm whale (*Kogia breviceps*) and the dwarf sperm whale are distributed in tropical and sub-tropical waters of almost all oceans; several records suggested that both species are resident in the Gulf of Mexico (Würsig, 2017). The only reported sighting of the dwarf sperm whale (not georeferenced and without group size data) occurred in the southern GOM (off the Yucatan platform) in the period 2002-2003 (Table 3, Antochiw-Alonzo & Manzano-Kantún, 2004). No sightings of the pygmy sperm whale were found.

Family Delphinidae

Delphinids have a cosmopolitan distribution, and 14 species have been reported from the GOM (Table 1, Würsig, 2017). However, until 2018 there are not sighting records for melon-headed whales (*Peponocephala electra*) and striped dolphins (*Stenella coeruleoalba*) in the Mexican EEZ (Table 3).

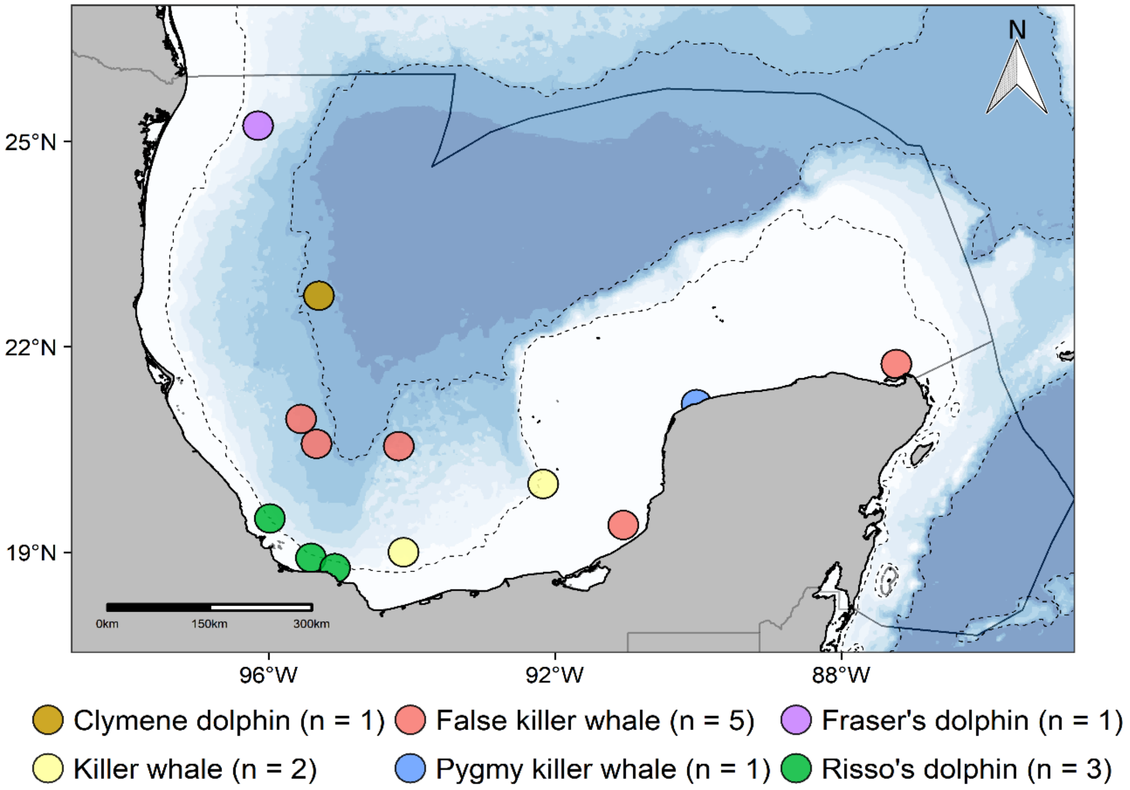

Figure 4. Sightings records of Clymene dolphins, false killer whales, Fraser's dolphins, killer whales, pygmy killer whales, and Risso's dolphins in the Mexican Exclusive Economic Zone (solid line). The dotted lines represent the 200 m and 2,800 m isobaths, respectively.

Sightings of killer whales, pygmy killer whales, false killer whales, Fraser's dolphins, Clymene dolphins, and Risso's dolphins are rare (Table 3, Fig. 4). Only one sighting of the pygmy killer whale, Fraser's dolphins, and Clymene dolphins have been reported; for killer whales, there are two records, five of pygmy killer whales, and three of Risso's dolphins. The only sighting of the pygmy killer whale corresponds to a group of 13 animals sighted on waters off the Yucatan coast (Díaz-Gamboa, 2015), a group of ~30 Clymene dolphins in deep waters (~1,000-m deep) of the western GOM (Vázquez-Castán et al., 2009), and the Fraser's dolphin near the U.S.-Mexico border (~200 individuals) (Leatherwood et al., 1993). Killer whale sightings were near the bay of Campeche (O'Sullivan & Mullin, 1997) and in oceanic waters (Ortega-Ortiz et al., 1998). False killer whales have been observed both in the continental slope of Yucatan (two records) and in oceanic waters (three records) (Zacarías et al., 1987; Fuentes-Allen & Aguayo-Lobo, 1992; Ortega-Ortiz et al., 1998). There was one sighting of Risso's dolphins in 2015 (group size of ~40 individuals) and two in 2016 (group size of 4 and 3 individuals), all of them in the southwestern continental shelf-break (Castro-Proal, 2018).

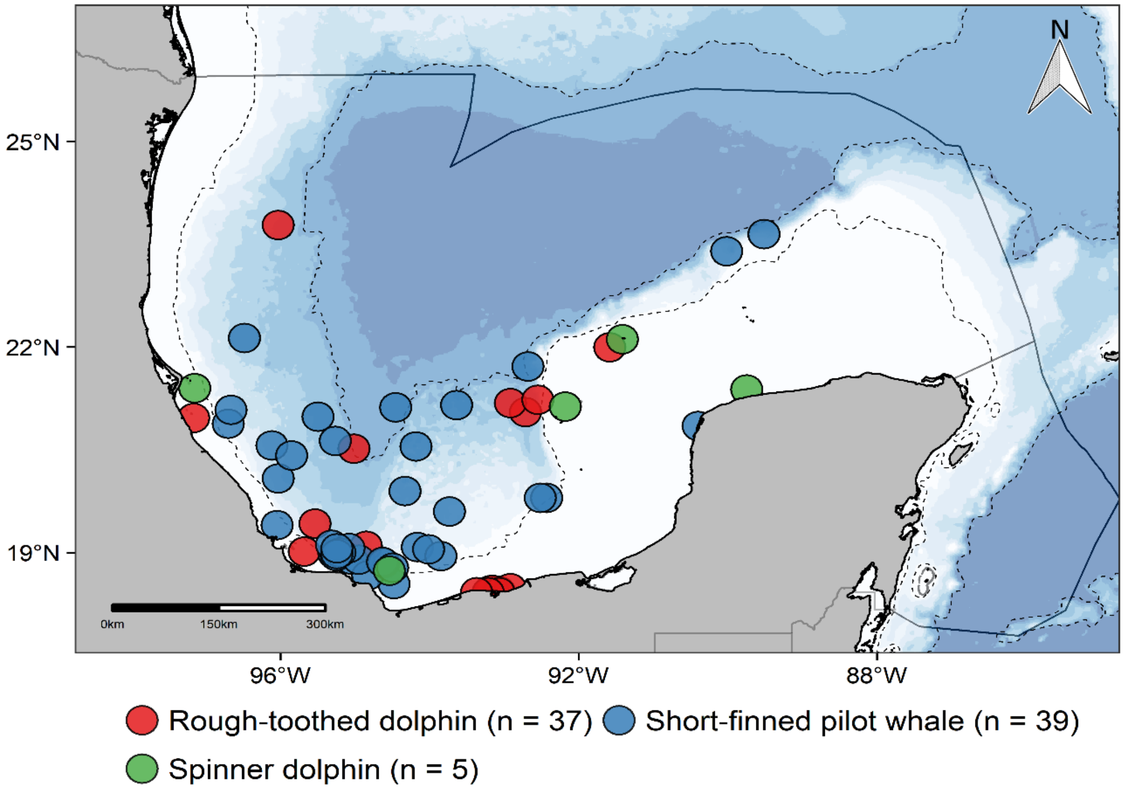

Figure 5. Sightings records of rough-toothed dolphins, short-finned pilot whales, and spinner dolphins in the Mexican Exclusive Economic Zone (solid line). The dotted lines represent the 200 m and 2,800 m isobaths, respectively.

The remaining six species are commonly seen in Mexican waters (Table 3). Short-finned pilot whales have been sighted on the continental slope and oceanic waters off Veracruz (Ortega-Ortiz, 2002; Galindo et al., 2009), the bay of Campeche, and the Yucatan shelf (Fuentes-Allen & Aguayo-Lobo, 1992; Ortega-Ortiz et al., 1998) (Fig. 5). Sightings of rough-toothed dolphins have occurred on the continental shelf of

Veracruz (Galindo et al., 2009), Tabasco (López-Hernández, 1997), and Yucatan (Sauz-Sánchez & Díaz-Gamboa, 2016), as well as in oceanic waters (Ortega-Ortiz, 2002) (Fig. 5). Sightings of spinner dolphins have been reported in oceanic waters off Veracruz and Yucatan (Urbán & Aguayo-Lobo, 1983; Salinas-Zacarías et al., 1984; Padilla et al., 1985; Antochiw-Alonso & Manzano-Kantún, 2004; Galindo et al., 2009) (Fig. 5).

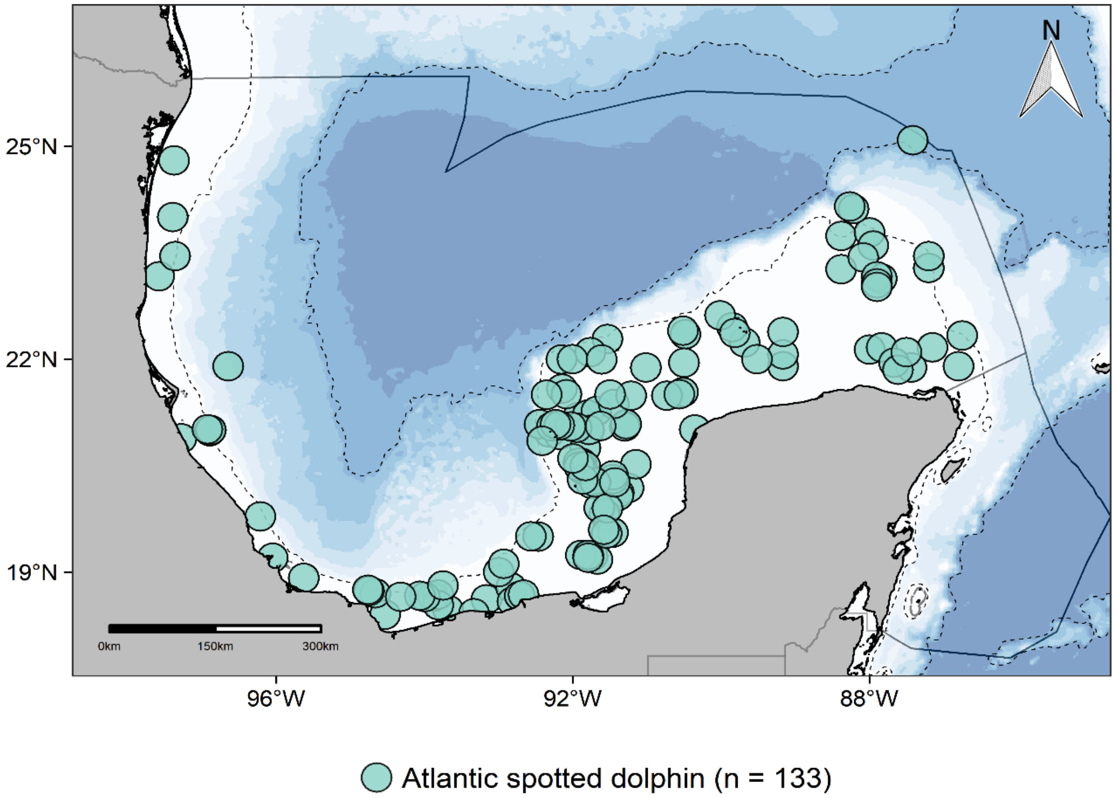

Figure 6. Sightings records of Atlantic spotted dolphins in the Mexican Exclusive Economic Zone (solid line). The dotted lines represent the 200 m and 2,800 m isobaths, respectively.

The second and the third species with more records were the Atlantic spotted dolphins and pantropical spotted dolphins (Table 3). The first has been sighted mainly on the continental shelf of Veracruz, Tabasco, Campeche, and Yucatan (e.g., Delgado-Estrella, 1997; Ortega-Ortiz, 2002) (Fig. 6), whereas the second on the continental slope and oceanic waters (e.g., Ortega-Ortiz et al., 1998) (Fig. 7).

The common bottlenose dolphin was the species with the highest number of sightings, with over ~90% of the records. Most sightings have been recorded in the coastal waters off Veracruz (e.g., Martínez-Serrano et al., 2011; Valdes-Arellanes et al., 2011; Hernández-Candelario et al., 2015; Morteo et al., 2017), the bay of Campeche and the Yucatan Peninsula (Urbán & Aguayo-Lobo, 1983; Salinas-Zacarías et al., 1984; Perdomo et al., 1985; Delgado-Estrella, 1997) (Fig. 8).

Strandings

Stranding records (n = 327) were found for most of the species listed in Table 3, except for fin whales, Fraser's dolphins, pantropical spotted dolphins, and Clymene dolphins. Most of these reports involved a single animal, although four mass stranding events (≥ 2 animals) were found.

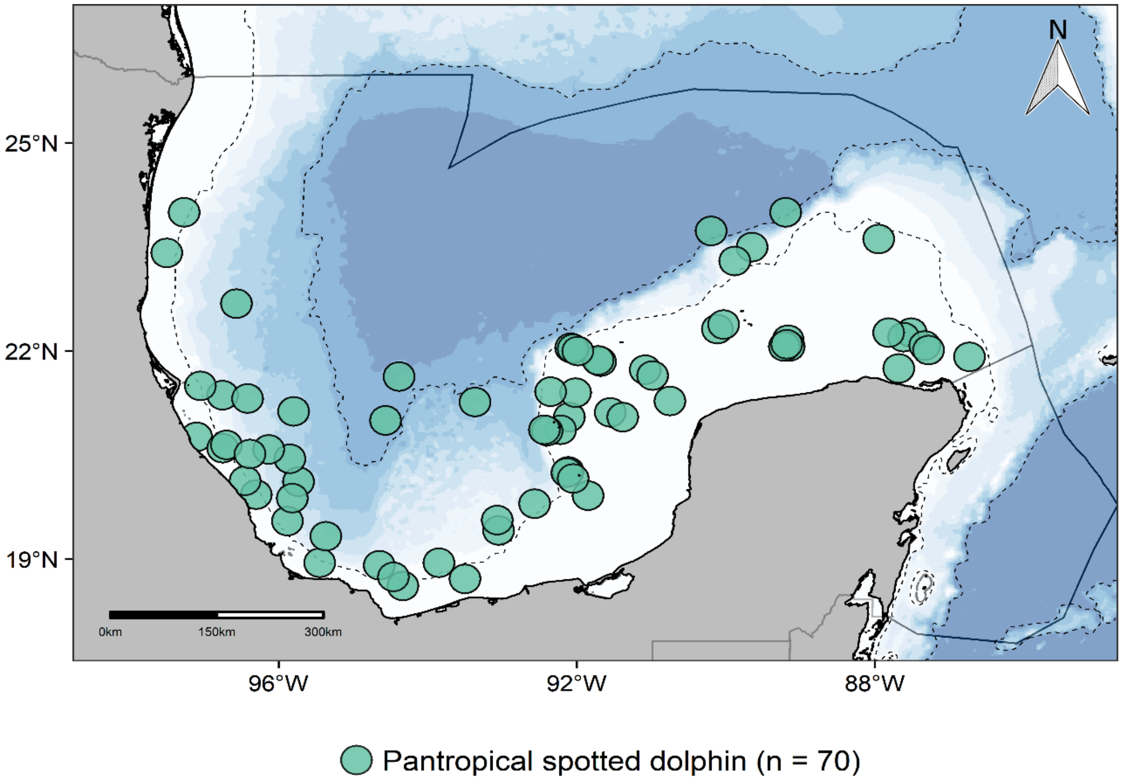

Figure 7. Sightings records of pantropical spotted dolphins in the Mexican Exclusive Economic Zone (solid line). The dotted lines represent the 200 m and 2,800 m isobaths, respectively.

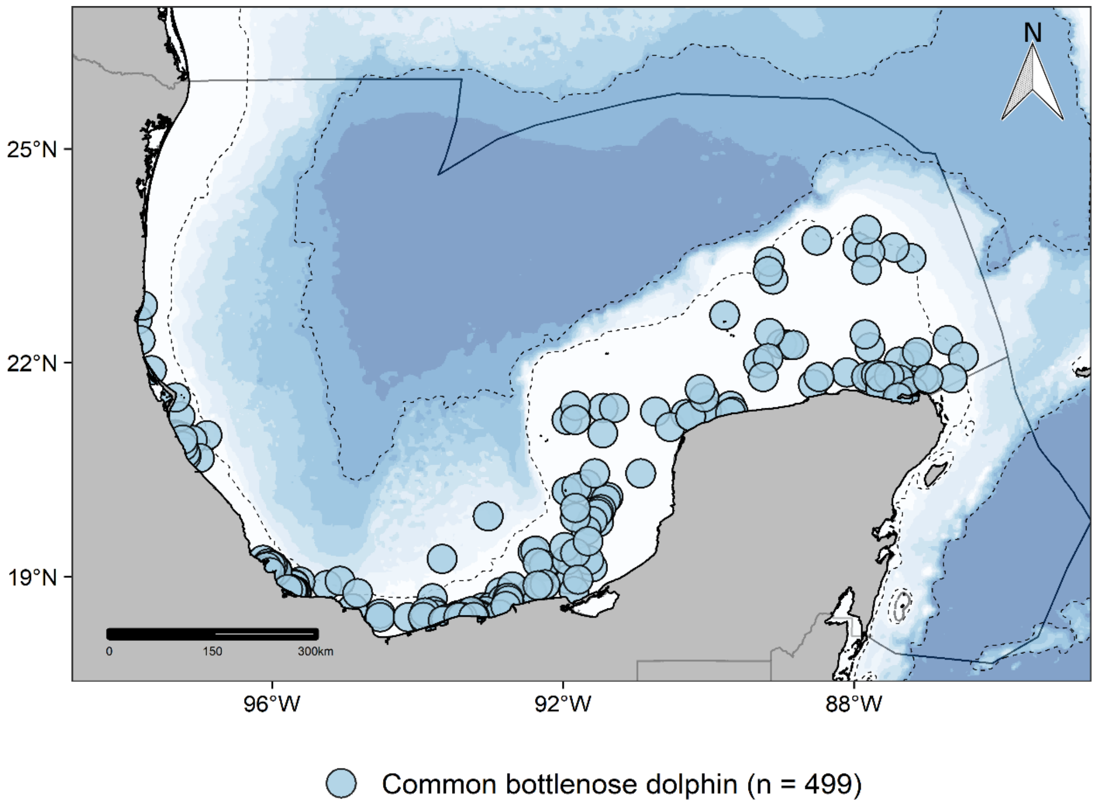

Figure 8. Sightings records of common bottlenose dolphins in the Mexican Exclusive Economic Zone (solid line). The dotted lines represent the 200 m and 2,800 m isobaths, respectively.

Family Balaenopteridae

Seven stranding events of five species of baleen whales have been reported (Table 3). The common minke whale (*Balaenoptera acutorostrata*), sei whale (*Balaenoptera borealis*), and humpback whale strandings were of a single individual in each. The stranding of the common minke whale occurred in the Yucatan Peninsula in December 1997 (Delgado-Estrella et al., 1998a), and that of the humpback whale in northern Veracruz in 2006 (Galindo et al., 2009). The sei whale's only record was a skeleton found in 1928 in Campeche (Miller, 1928). For both the blue whale (*Balaenoptera musculus*) and the fin whale, there were two records. The first blue whale stranding corresponded to an individual stranded in Veracruz (Jefferson & Schiro, 1997), and of the second, the only evidence is photographs of vertebrae found in Tamaulipas (NMNH, 2017). Fin whale strandings occurred in the Yucatan Peninsula in February 2016 (Díaz-Gamboa, 2016), and in southern Veracruz in January 2017.

Family Physeteridae

There were eight records of sperm whale strandings, all from a single animal (Table 3). Seven occurred along the coast of Veracruz (e.g., Villa-Ramírez, 1969; Mead, 1977; Ortega-Argueta et al., 2005; Galindo et al., 2009), and one in the Yucatan Peninsula (Antochiw-Alonso & Membrillo-Venegas, 1998).

Family Kogiidae

Pygmy sperm whales strandings have been recorded in Yucatan (one event; González-Solis et al., 2006), Veracruz (five; Delgado-Estrella et al., 1998b; Ortega-Argueta et al., 2005), Campeche (two, Reyes-Gómez et al., 2006; Rivas & Vidal-Martínez, 2006), and Tabasco (one, Martínez-López et al., 2003). Dwarf sperm whales strandings have been reported in Veracruz (one; Delgado-Estrella et al., 1998b), Campeche (one; Rivas & Vidal-Martínez, 2006), and the Yucatan Peninsula (three, Antochiw-Alonso & Membrillo-Venegas, 1998).

Family Ziphiidae

There were three records of strandings of Gervais' beaked whales (*Mesoplodon europaeus*) (Table 3). The first was in Campeche in May 1986 (Gallo & Pimienta, 1989), and the other two in Yucatan in 1995 (Solís-Ramírez, 1995), and 1998 (Antochiw-Alonso & Membrillo-Venegas, 1998). Cuvier's beaked whales (*Ziphius cavirostris*) had two records (Table 3); one was from a single animal stranded in Campeche in 1996 (Delgado-Estrella et al., 1998a), and the second a female and her calf stranded in Yucatan in 2016. Also, one Blainville's beaked whale (*Mesoplodon densirostris*) was found stranded in Yucatan in March 1999 (Antochiw-Alonso et al., 2000).

Family Delphinidae

Stranding events have been reported for almost all delphinid species, except for Cymene dolphins, pantropical spotted dolphins, and Fraser's dolphins (Table 3). There are three records of killer whales, all on the Yucatan coast (Antochiw-Alonso & Membrillo-Venegas, 1998), two of melon-headed whales, both in Veracruz (Ortega-Ortiz, 2002; Ortega-Argueta et al., 2004), two of pygmy killer whales, one in Tamaulipas (Villa-Ramírez & Hoz-Zavala, 1997), and another in northern Veracruz (Delgado-Estrella et al., 1998a), and three of Risso's dolphins, one in Veracruz (Vanoye et al., 2000), and the other two in Yucatan (Antochiw-Alonso & Membrillo-Venegas, 1998; Díaz-Gamboa, 2016). Each these strandings were of a single animal. Five false killer whale strandings have been reported, one in Veracruz (Jefferson, 1995), one in Campeche (NMNH, 2017), and three in the Yucatan coast, two of them mass stranding events of 72 and 82 animals (Antochiw-Alonso & Membrillo-Venegas, 1998; Antochiw-Alonso, 2001).

Most common bottlenose dolphin strandings have been reported along the Veracruz coast (Delgado-Estrella et al., 1998a; Ortega-Argueta et al., 2005; CONABIO, 2016; NMNH, 2017), although in the last two years, some animals have stranded in the Yucatan Peninsula. There are records of two strandings of Atlantic spotted dolphins in Veracruz (Ortega-Argueta et al., 2005), and two of striped dolphins, one in Veracruz (Jefferson, 1995), and another in the Yucatan coast (Antochiw-Alonso & Membrillo-Venegas, 1998). Most of the short-finned pilot whales strandings (13 in total) occurred in the Yucatan Peninsula (Aguayo-Lobo et al., 1986; Navarro, 1988; Vidal, 1991; Antochiw-Alonso & Membrillo-Venegas, 1998), and only one in northern Veracruz (Galindo et al., 2009). Spinner dolphins have stranded three times on the Yucatan coast (Frazier, 1996; Antochiw-Alonso & Membrillo-Venegas, 1998; CONABIO, 2016), one of them a mass stranding of 24 animals (Frazier, 1996). Three strandings have been reported for rough-toothed dolphins, two in the Yucatan Peninsula (Antochiw-Alonso & Membrillo-Venegas, 1998; Delgado-Estrella et al., 2001), and one massive event of 24 animals in Campeche (Sánchez-Ríos et al., 1996).

2.4.2 State of knowledge

Scientific production

Up until 2017, 281 scientific papers were found. Two hundred and fifty-two papers were written within U.S. institutions (both government and academic), of which four extended to Mexican waters; the remaining 29 were carried out by Mexican institutions in Mexican waters. The oldest paper dates back to 1910, but no publications were found for the 1920s and 1930s; therefore, the trend analysis covered the period 1940-2017. The optimal break-point was found in year 1982 (Figure 9), thus the study of cetaceans of the GOM was divided into two periods: 1940-1982 (n = 41 papers) and 1983-2017 (n = 240 papers).

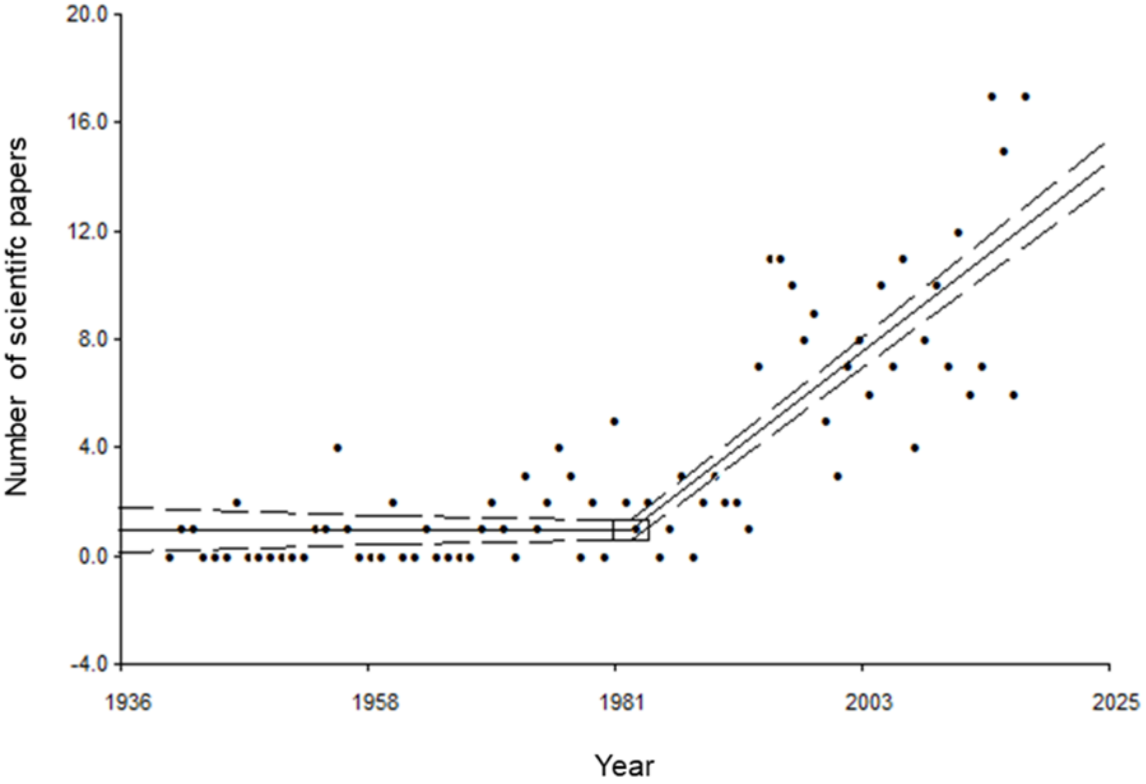

Figure 9. Scientific production on cetaceans of the Gulf of Mexico from 1940 to 2017. Solid rectangle represents the 90% confidence interval of break-point (1982). Dashed lines represent the 90% confidence interval of the two regressions: the first when X (year) is smaller or equal than the break-point, and the second when X is higher than the break-point.

The MK test revealed positive and significant trends in both periods for U.S. scientific production, although production increased notably faster during the second period than in the first (Table 4). Regarding Mexican production, during the first period, only one paper was produced, whereas 28 papers were produced in the second period; however, there was no statistical evidence that the trend was different from zero between 1983 and 2017 (Table 4), suggesting that there has been no major developments in this research over the last 35 years.

Overall, the topics of study have changed over time (Fig 10a). During the first period, strandings and population ecology were the central topics with ~71% of total studies (Fig. 10a). In the second period, the topics were diversified, being animal health, population ecology, socio-sexual behavior, and management and conservation the main topics (Fig. 10a). Between the first and second period (41 and 240 papers, respectively) there was a significant reduction in the proportion of papers on strandings (from 39.0 to

5.0%; $\chi^2 = 15.22$, $P < 0.01$), while the proportion of animal health studies increased (from 9.8% to 26.9%; $\chi^2 = 4.97$, $P = 0.03$).

Table 4. Number of peer-reviewed papers (*n*) by country, Mann-Kendall test results (*Z* and *P*-values), and the magnitude of the slope (*b*; papers per year) for the periods 1940-1982 and 1983-2017.

	Period	***n***	***Z***	***p***	**b**
United States	1940-1982	40	2.34	0.02	0.04
	1983-2017	211	4.03	< 0.01	0.28
Mexico	1940-1982	1	---	---	---
	1983-2017	28	1.91	0.06	---

The species studied also varied between periods (Fig. 10b). The proportion of studies on common bottlenose increased significantly (from 24.4 to 61.1%; $\chi^2 = 5.78$, $P = 0.02$), whereas the proportions of multi-species studies remained constant (~20%). In contrast, the proportions of papers on baleen whales (*Balaenoptera* sp.), dwarf and pygmy sperm whales (*Kogia* sp.), false killer whales, short-finned pilot whales, pantropical spotted dolphins, and rough-toothed dolphins were reduced, although the change was not significant.

Considering exclusively Mexican production (n= 29), the oldest reference dates from 1969, and it was the only paper found in the first period. Scientific production in the second period (1983 – 2017) was poor, with less than one article per year on average, and the main topics were reports of strandings and population ecology, both with ~30% of the production (Fig. 11). Studies of seven species were published: dwarf sperm whale, Gervais' beaked whale, pygmy killer whale, short-finned pilot whale, rough-toothed dolphin, Atlantic spotted dolphin, and common bottlenose dolphin; however, more than half of the papers focused on the latter (Fig. 11).

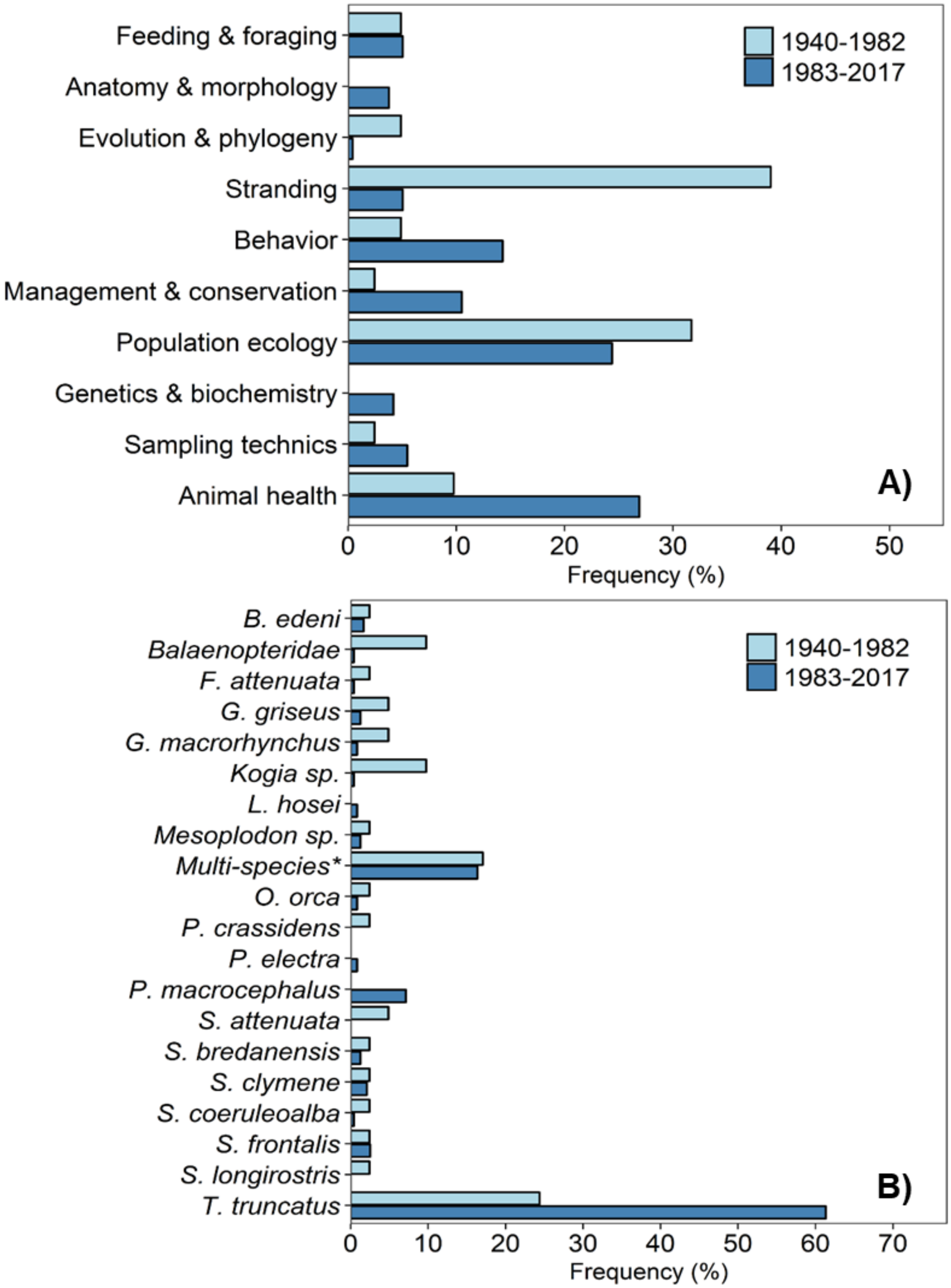

Figure 10. Comparison between periods of the proportions of scientific papers produced by (A) topic and by (B) species. *Studies that include two or more species.

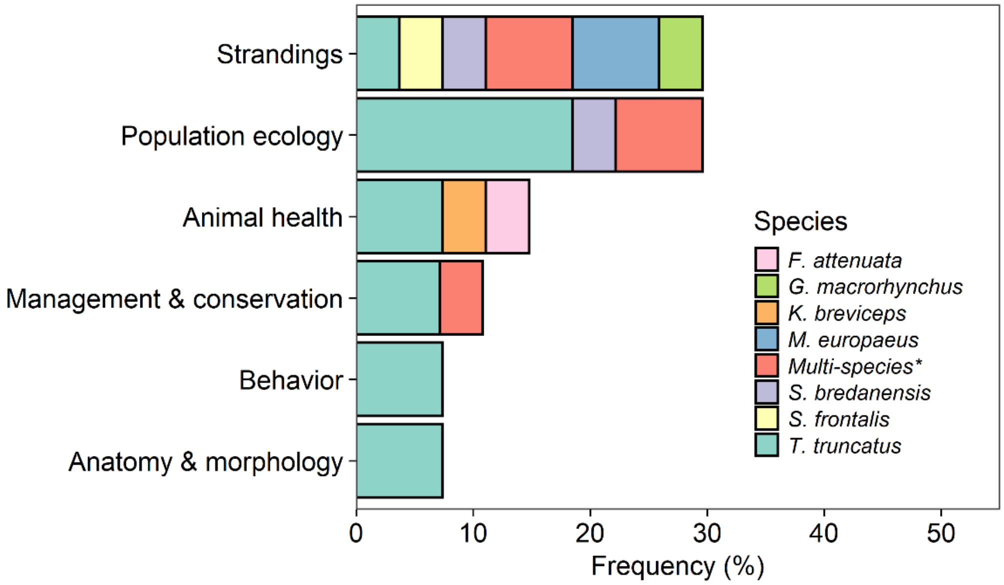

Figure 11. Proportion of scientific papers produced by Mexican institutions by topic and species during the period 1983-2017. *Indicates studies that include two or more species.

Abstracts of SOMEMMA meetings

Between 1976 and 2016, there were 25 SOMEMMA meetings. The conferences were annual from 1976 to 2003, and bi-annual since 2004. During the first ten meetings, between 1976 and 1984, there was no single work on cetaceans in the GOM. Between 1985 and 2016, there were 1,201 abstracts, of which 108 were on GOM cetaceans (Fig. 12). In general, the proportion of abstracts on cetaceans in the GOM has been low, with the XXIII meeting (Xcaret, Quintana Roo, 1998) being the one that had the highest (28%).

Fifty-three percent of the abstracts were on common bottlenose dolphins, followed by multi-species studies (31%) and rough-toothed dolphins (6%). The main topics were population ecology (39%), followed by strandings (28%), and behavior (9%). Most of the studies were carried out in Yucatan (31%), Veracruz (30%), and Campeche (25%), whereas Tabasco and Tamaulipas contributed the least (10 and 4% respectively).

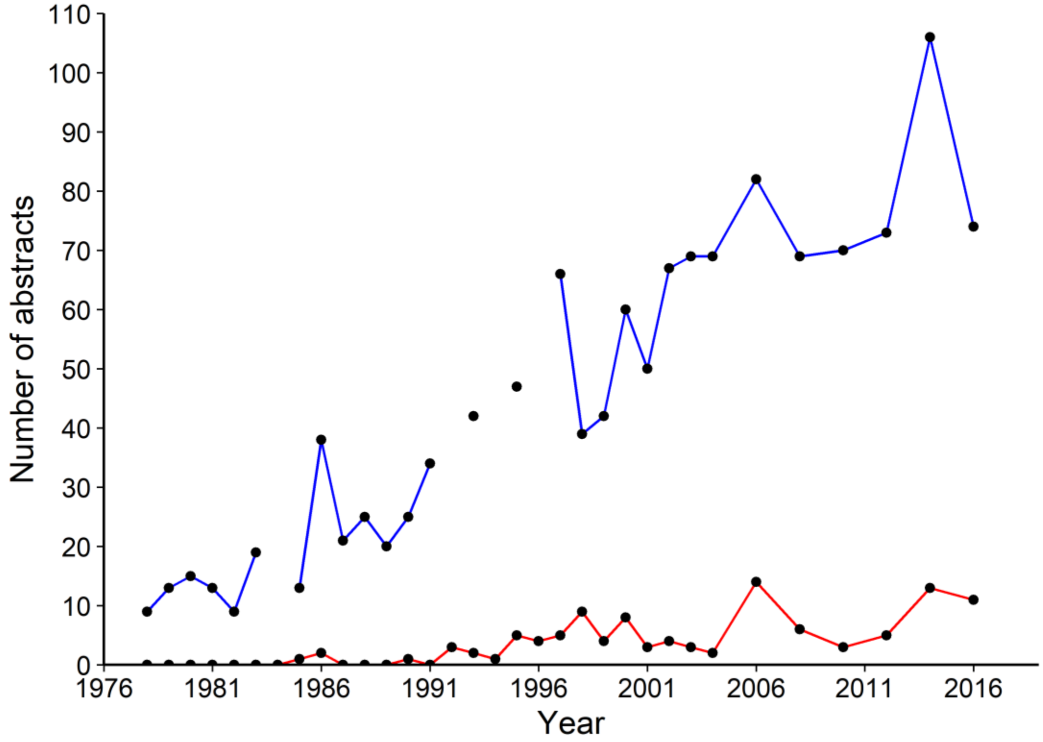

Figure 12. Number of abstracts of the SOMEMMA meeting, 1976 – 2016. The blue line shows the total number of abstracts and the red line the abstracts on cetaceans of the Gulf of Mexico.

2.5 Discussion

Our chances of success to minimize the negative impacts of human activities in particular areas depend primarily on our knowledge of how many species are present, and how they are distributed in space and time (Kaschner et al., 2012). Research on the diversity, distribution, and abundance of cetaceans in the GOM began decades ago; however, our current knowledge about the state of their populations remains limited because the effort in Mexican waters has been poor compared to the number of surveys and studies in the U.S. EEZ. There are no comparative studies on the diversity of cetaceans along the latitudinal axis of the GOM, but it can be assumed that the number of species of odontocetes in the south (i.e., Mexican EEZ) should be the same as in the north (i.e., U.S. EEZ) and that stocks are likely transboundary (Waring et al., 2016). Observations by Ortega-Ortiz (2002), as well as from this study, support this idea, since of the 20 species commonly sighted in the U.S. EEZ, 14 were confirmed by records in the Mexican EEZ.

No records of the pygmy sperm whale (*Kogia breviceps*), Blainville's beaked whale (*Mesoplodon densirostris*), striped dolphin (*Stenella coeruleoalba*), Cuvier's beaked whale (*Ziphius cavirostris*), and melon-headed whale (*Peponocephala electra*) were found. Nevertheless, this does not imply that these species are not distributed in Mexican waters, but rather there is a lack of survey effort, particularly in deep waters (> 1,000 m depth), which is their preferred habitat (Maze-Foley & Mullin, 2006; Würsig, 2017). This statement is supported by the fact that almost all georeferenced sightings compiled in this study were of common bottlenose dolphins recorded in the continental shelf and the inner slope. The few sightings of the other species (even offshore bottlenose dolphins) have been recorded through isolated surveys conducted by different institutions, and mostly in a non-systematic way. Hence, both data archival and availability are minimal (i.e., existence and access to the data), which complicates their compilation and analysis.

On the other hand, common bottlenose dolphins had the highest stranding reports, suggesting that it is an abundant species in the coastal zone. This species is frequently found in coastal zones across the northern GOM (Waring et al., 2016) and it also appear in most strandings records (Pitchford et al., 2013). Moreover, since information from strandings records helps increase knowledge of cetaceans in regions where information is limited (Norman et al., 2004; Maldini et al., 2005), the presence of nine cetaceans species was only documented with stranding data on the Mexican coast of the Gulf, although only four species are commonly sighted in the GOM: dwarf sperm whales, the Cuvier's beaked whales, melon-headed whales, and striped dolphins (Würsig, 2017).

The study of cetaceans in the U.S. EEZ began in the 1940s and initially had a descriptive approach, represented mainly by publications on sightings and stranding reports (e.g., Gunter, 1946; Moore, 1953; Caldwell, 1955; Schmidly et al., 1972). In the last few decades, research has not only accelerated but also diversified, and the current interest is aimed at identifying potential threats associated with anthropogenic activities (e.g., the effect of oil spills or noise pollution). A clear example is the increase in studies on animal health, mainly after the Deepwater Horizon oil spill in 2010 (e.g., Schwacke et al., 2017; Smith et al., 2017; Wallace et al., 2017). On the other hand, Mexican research began in the 1980s, and its development has been extremely slow: average annual production has not increased, and in the 2010s it was still similar to that of the U.S. in the 1980s (1.6 papers per year). Furthermore, until a few years ago, most publications were reports of strandings (e.g., Delgado-Estrella et al., 1998; Ortega-Argueta et al., 2005). Although the study topics seem to have diversified recently (e.g., González-Solís et al., 2006; Morteo et al., 2014), it is striking that all Mexican production in the 2010s was exclusively focused on a few coastal populations of common bottlenose dolphins (e.g. Valdés-Arellanes et al., 2011; Vázquez-Castán et al., 2014; Morteo et al., 2017).

The low number of Mexican publications, as well as the few works presented at the SOMEMMA meetings, reflects the lack of logistical, financial, and technical resources, expertise and security to face the conditions in offshore waters. In the national context, investment in research infrastructure and human resources in the GOM is notably lower compared to other regions, such as the Gulf of California and the western coast of the Baja California Peninsula (Escobar-Lazcano, 2015), where there is a greater diversity of marine mammals (Torres et al., 1995). In the local context, the research of the academic institutions located in the GOM is focused on coastal populations of the common bottlenose dolphin, ignoring offshore cetacean populations; and marine mammal conservation efforts promoted by government agencies have been directed exclusively to the endangered manatee (*Trichechus manatus*) (Muzquiz-Villalobos & Pompa-Mansilla, 2018).

Globally, cetaceans are affected by a wide range of threats, including the immediate and direct impacts of bycatch and, in some places, hunting, as well as the long-term impacts associated with habitat degradation, climate change, and loss of genetic diversity (Reeves et al., 2003). However, it is essential to know their distribution, abundance, and population trends, to determine the extent to which a particular threat impacts a population (Royle et al., 2014). Currently, cetaceans of the GOM face different threats associated with human activities, mainly those related to the hydrocarbon industry, marine traffic, and fisheries. Although population traits of several species are known in the U.S. EEZ, the lack of data in the Mexican EEZ prevents the detection of changes in populations at the regional level because of their transboundary distribution. Therefore, it is necessary to invest in Mexican research capabilities, and establish large-scale and long-term binational monitoring and research programs, to improve the knowledge about the status of cetacean populations in the GOM.

2.6 Summary

- Sighting records of 16 cetacean species in Mexican waters of the GOM were found, adding four species to those previously reported.

- Ninety-one percent of the records were of common bottlenose dolphins. Excluding these records, the most commonly sighted species in the Mexican EEZ were the Atlantic spotted dolphin, followed by pantropical spotted dolphins and short-finned pilot whales.

- The study of cetaceans in Mexican waters of the GOM has been very poor: there is a 40 year delay compared to the U.S. EEZ research.

- The Mexican research effort is focused on a few coastal populations of a single species, the common bottlenose dolphin, whereas oceanic cetaceans have been systematically ignored possibly for the lack of interest and/or funding.

Chapter 3. Habitat suitability and potential distribution of cetaceans in the Gulf of Mexico

3.1 Introduction

Understanding species' geographic distribution patterns and their related environmental factors is a central topic of population ecology (Guisan & Zimmermann, 2000). Environmental factors include both abiotic conditions that influence the physiological response (e.g., temperature) determined, in turn, by the species' adaptive response and also the interspecific interactions (e.g., prey availability) (Soberón & Peterson, 2005; Peterson et al., 2011). Cetaceans are a group of fully aquatic mammals whose anatomical, morphological, and physiological adaptations have allowed them to colonize a wide variety of aquatic habitats (Katona & Whitehead, 1988). Nevertheless, their distribution is usually explained in terms of the abundance of prey, primarily controlled by dynamic oceanographic conditions (e.g., sea surface temperature and mesoscale processes), as well as by physiographic features (e.g., bottom depth and slope) (Kenney et al., 1997; Forcada, 2018).

The distribution of cetaceans in the northern GOM (i.e., the U.S. EEZ) has been extensively studied. Based on sighting records, Maze-Foley & Mullin (2006) divided the cetaceans into two communities: (1) the continental shelf community, which includes the common bottlenose dolphin, the Atlantic spotted dolphin, and Bryde's whale, and (2) the continental slope community, which comprises the remaining species, although the rough-toothed dolphin can be found in both. More recently, using density surface models, Roberts et al. (2016) described the spatial distribution of cetaceans in the northern GOM. Overall, their results are consistent with those of Maze-Foley & Mullin (2006), although they highlight the importance of the continental slope and submarine canyons, such as the Mississippi Canyon areas as of high density of cetaceans. In contrast, the distribution of cetaceans in the southern GOM (i.e., the EEZs of Mexico and Cuba) is poorly understood. In fact, the only one study has covered this region, but it was conducted by extrapolating data from the northern GOM (Mannocci et al., 2017).

Besides the ecological relevance of the GOM, it is an important economic area where fishing, tourism, and the hydrocarbon industry generate billions of dollars annually (Karnauskas et al., 2013), but it is also a key region for transportation and marine cargo (Shepard et al., 2013). Given its economic importance, the GOM ecosystem is under increasing anthropogenic pressure, activities such as vessel strikes, noise pollution, entanglement with debris and fishing gears, and contamination from oil spills threaten cetacean populations (Roberts et al., 2016; Fraiser et al., 2020). To determine the extent and impact of these hazards and to optimize threat mitigation and conservation measures, it is necessary to have accurate predictions of their distribution on a broader scale; that is, at the ecosystem level. However, their limited data at the southern GOM makes it difficult, but one way to achieve this is with the use of ecological niche models (ENM).

ENM are statistical tools that define the distribution of suitable habitats of a species based on their ecological requirements (Peterson et al., 2011). The rationale is that the records, which are discontinuous in nature, are related to environmental and/or spatial characteristics (environmental predictors) such that these may predict the suitable areas for the species in unsampled locations; therefore, the maps produced are spatially continuous, showing the regions where the greater aggregation is expected (Franklin, 2010). Thus, areas of high habitat suitability are defined as those sites where ideal (or favorable) conditions exist for a species' long-term subsistence (Peterson & Soberón, 2012).

This chapter aimed at estimating habitat suitability for the odontocetes of the GOM to identify geographical regions that could support a high diversity of these cetaceans. The analysis included historical datasets of georeferenced sightings (presence-only data) recorded in both the south and north of the GOM. The maximum entropy (MaxEnt) modeling approach was used (Phillips et al., 2006) to find the ideal combination between the presence records and those environmental predictors that define the niche of the species.

3.2 Objectives

1. To model the habitat suitability of odontocetes in the GOM.

2. To evaluate the importance of environmental predictors that determine habitat suitability in each model.

3. To identify high-suitable regions capable of supporting high cetacean diversity.

3.3 Materials and methods

3.3.1 Study and modeling area

Given the high movement capacity of cetaceans, and because there are no physicals barriers for them in the marine environment, the modeling area was not restricted to the GOM. The area was extended to include the warm-temperate and tropical oceanic provinces of the northwest Atlantic Ocean (Fig. 13a; Spalding et al., 2007).

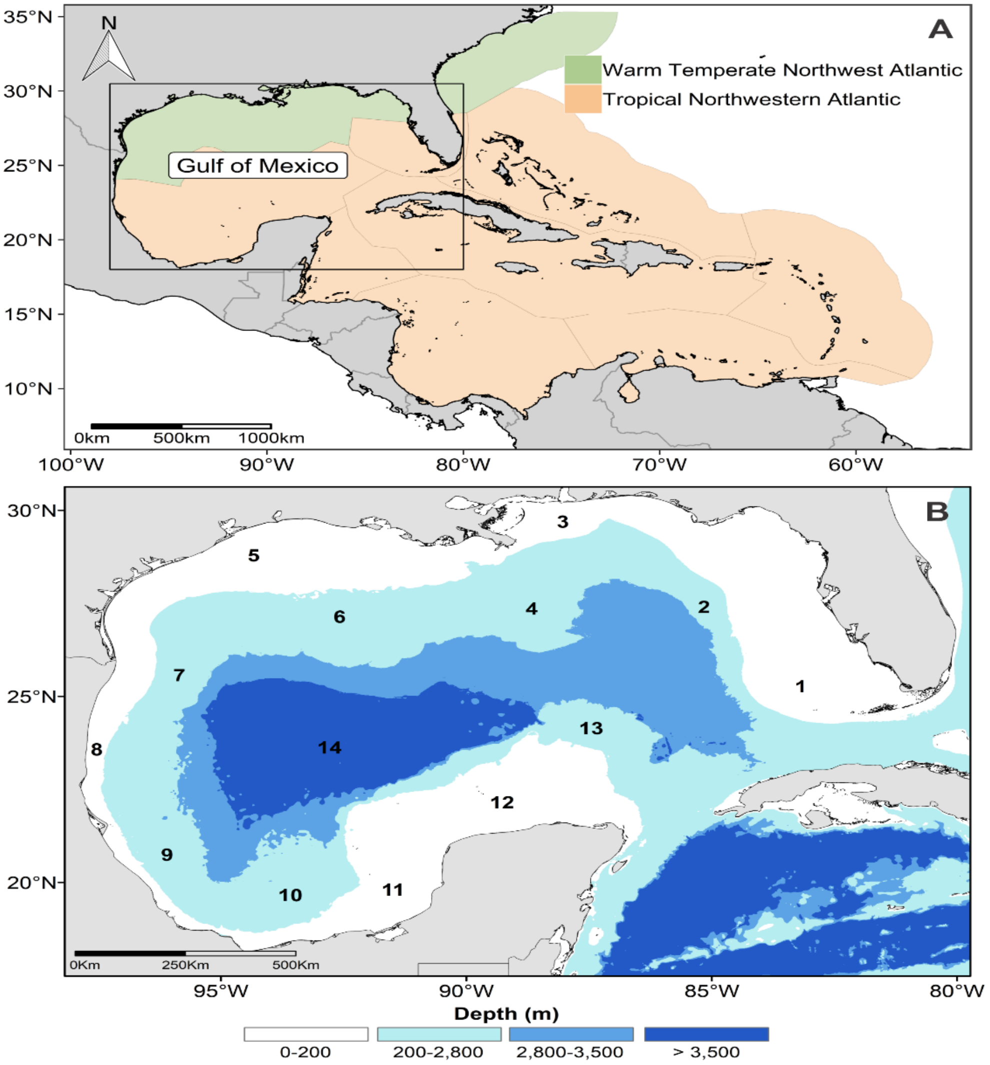

Figure 13. (A) Geographic extension of the modeling area limited to the oceanic provinces: Warm-Temperate Northwest Atlantic and Tropical Northwest Atlantic. The black polygon delimits the Gulf of Mexico. (B) Physiographic provinces of the Gulf of Mexico: 1. West Florida shelf, 2. West Florida slope, 3. Mississippi-Alabama shelf, 4. Mississippi Canyon, 5. Louisiana-Texas shelf, 6. Louisiana-Texas slope, 7. Rio Grande slope, 8. Tamaulipas-Veracruz shelf, 9. Tamaulipas-Veracruz slope, 10. The bay of Campeche, 11. Campeche Bank, 12. Yucatan shelf, 13. Campeche terrace, 14. Sigsbee plain.

The physiography of the GOM is complex and consists of 13 physiographic sub-provinces (Fig 13b). The continental shelf (≤ 200 m deep) can be very narrow, as the Tamaulipas-Veracruz shelf, or extensive, like the Yucatan and Florida shelves. The continental slope extends from the 200 m continental shelf break to 2,800 m depth, and there are vast canyons, such as the Mississippi Canyon. The oceanic zone extends beyond the slope up to the abyssal plain, where it reaches depths > 3,500 m (Bouma & Roberts, 1990; Monreal-Gómez et al., 2004). The GOM oceanic waters have oligotrophic conditions that contrast with the eutrophic coastal regions, which receive a high nutrient input by river discharges, mainly in the northern GOM (Biggs, 1992; Lohrenz et al., 1999; Muller-Karger et al., 2015).

3.3.2 Presence-only data

Historical georeferenced sightings (presence-only data) of odontocetes were compiled. The Blainville's and Gervais' beaked whales, the killer whale, and Fraser's dolphin were discarded because these species' sightings are infrequent (Würsing, 2017). The presence-only of the remaining 16 species (Table 5) were collected from the literature (e.g., peer-reviewed articles, thesis, and technical reports), and digital databases of the Sistema Nacional de Información Sobre la Biodiversidad (SNIB; http://www.snib.mx/; CONABIO, 2016) and Ocean Biogeographic Information System Spatial Ecological Analysis of Megavertebrate Populations (OBIS-SEAMAP; http://seamap.env.duke.edu/; Halpin et al., 2006). Databases were filtered (one per species) using the spThin package (Aiello-Lammens et al., 2015) in the R software (R Core Team, 2018), to reduce the sampling bias (the north of the GOM is oversampled relative to the south) and the spatial autocorrelation that negatively affect model performance (Boria et al., 2014; Varela et al., 2014). The *thin* function uses a random approach to return a dataset with the maximum number of records for a given distance restriction (Aiello-Lammens et al., 2015), which in this study was defined by the average daily movement of each species (Table 5).

3.3.1 Environmental predictors

Five environmental predictors were selected based on previous knowledge about the environmental factors that influence cetaceans' occurrence (e.g., Praca et al., 2009; Fernandez et al., 2018; Pace et al., 2018). The selected predictors included both oceanographic and bathymetric variables. Used oceanographic predictors were the sea surface temperature (SST, °C), and chlorophyll-*a* concentration (Chl-*a*, mg/m^3), and these included in three metrics: mean, minimum, and maximum values. Data of both variables were downloaded from the Ocean Color portal (https://oceancolor.gsfc.nasa.gov/; NASA, 2018) of the MODIS-Aqua sensor for the period July 2002–December 2018. The data are at an L3 processing level with a spatial resolution of 0.041° (~4 km). Weekly values (8-d composite) were downloaded and averaged across the 16 years with the available data. Bathymetric predictors were: depth (D, m), bottom slope (S, degrees), and distance to the 200-m isobath (D_{200}, m). The first was acquired from the General Bathymetric Chart of the Ocean (GEBCO; https://www.gebco.net/; IOC y IHO, 2018) with a spatial resolution of 0.008° (~1 km); the other two were calculated from the depth using the raster package (Hijmans et al., 2013) in R software. These bathymetric predictors were re-projected at a spatial resolution of 0.041° to match oceanographic predictors.

The co-linearity among environmental predictors was evaluated using the Pearson correlation coefficient (ρ) (Dormann et al., 2012; Cruz-Cárdenas et al., 2014). If $\rho \geq 0.70$ (Dormann et al., 2013), a principal component analysis was then performed to determine which of the correlated predictors need to be discarded.

3.3.3 Habitat suitability modeling

The MaxEnt algorithm was used (Phillips et al., 2006) to predict the habitat suitability of odontocetes in the GOM. MaxEnt assumes that the species are distributed uniformly (i.e., the maximum entropy distribution) over the modeling area, and the environmental values constrain this distribution at the presence of records locations (Phillips et al., 2006, 2017).

Habitat suitability modeling for each species was conducted using the ENMeval package (Muscarella et al., 2014, 2016) in R. Models were built with a random sample of 10,000 background points (i.e., points not registered as occurrence records in the modeling area that are contrasted with the occurrence positions) and selected the *Linear*, *Quadratic*, and *Hinge* features of the MaxEnt algorithm. The cross-validation of the models was done using the block method that split the presence data into four bins, three as training data, and one as test data, based on the latitude and longitude lines that divided the occurrence localities (Muscarella et al., 2014).

The performance of each model was evaluated using the area under the receiver-operator curve (AUC), which measures the discriminatory ability of each model, and the omission rate (OR), which indicates the proportion of test localities that fall into cells not predicted as suitable (Philips et al., 2006). An AUC of 1 indicates perfect discrimination between sites where the species is present or absent, and an AUC < 0.5 indicates that the model performance is less capable than the random assumption (Elith et al., 2006). The 10 percentile training omission rate (OR_{10}) was used because it is less sensitive to outlier presence locations (Radosavljevic & Anderson, 2014). Omission rates greater than the expected value of 0.1 (or 10%) suggest model overfitting (Peterson et al., 2011; Radosavljevic & Anderson, 2014). Finally, the contribution percentages returned by each MaxEnt model was used, to evaluate the contribution of each environmental predictor (Phillips et al., 2006).

The logistic output was selected and obtained the habitat suitability for each 0.041° x 0.041° cell of the modeling area, and it was expressed in an interval between 0 (unsuitable conditions) and 1 (highly suitable conditions). In this study, high habitat suitability areas were defined as those sites (cells) with habitat suitability values ≥ 0.6 (Kaschner et al., 2011).

3.3.3 Suitability regions for cetaceans

A spatial approach based on habitat suitability maps was used to identify suitable regions for cetaceans; that is, the geographical regions capable of supporting a high diversity of cetacean. These regions were defined as those sites were high suitability areas (suitability values ≥ 0.6) of at least seven species overlap.

3.4 Results

A total of 8,523 sightings records for 16 odontocetes species of the GOM were found. After the spatial filtering, 1,020 records were retained (Table 5; Fig. 14), representing only ~12% of the presence records. More than half of the records belonged to four species: the sperm whale (7%), the pantropical spotted dolphin (9%), the Atlantic spotted dolphin (13%), and the common bottlenose dolphin (30%). Habitat suitability was modeled for only twelve species, which were those that after filtering had the minimum required sample (≥ 30 presence records; Wisz et al., 2008). The pygmy sperm whale, pygmy killer whale, false killer whale, and melon-headed whale were excluded due to small sample size (Table 5).

The models showed a good degree of discriminatory ability based on the AUC scores, which ranged from 0.74 (the pantropical spotted dolphin model) to 0.91 (the common bottlenose dolphin model) (Table 6). On the other hand, the OR_{10} values was close to the expected values in some models, such as the rough-toothed dolphin, but in other it was higher, as in the spinner dolphin model (Table 6), suggesting some degree of overfitting.

Table 5. Total number of georeferenced sightings of 16 odontocetes in the Gulf of Mexico, period of the presence data, filtering distance (average daily movement in km), and number of sightings used in the modeling (sample size). Modeled species are marked with*.

Specie	Period	Total sightings	Filtering distance	Used sightings (n)
Sperm whale*	1978 – 2017	810	90[1]	70
Pygmy sperm whale	1992 – 2011	51	75[2]	17
Dwarf sperm whale*	1990 – 2011	319	75[2]	37
Cuvier's beaked whale*	1990 – 2017	88	25[3]	39
Pygmy killer whale	1990 – 2008	24	70[4]	16
Melon-headed whale	1992 – 2011	70	70[5]	25
False killer whale	1986 - 2017	96	70[6]	25
Short-finned pilot whale*	1984 – 2017	200	80[7]	61
Rough-toothed dolphin*	1983 – 2017	90	90[8]	37
Risso's dolphin*	1990 – 2017	330	80[9]	54
Atlantic spotted dolphin*	1979 – 2015	1,557	70[10]	128
Pantropical spotted dolphin*	1983 – 2012	800	90[11]	93
Striped dolphin*	1992 – 2005	76	90[12]	35
Spinner dolphin*	1983 – 2012	126	80[13]	41
Clymene dolphin*	1990 – 1998	108	70[12]	37
Common bottlenose dolphin*	1971 – 2017	3,778	35[14]	305
Sum		8,523		1,020

Sources: [1]Whitehead (2018), [2]McAlpine, (2018), [3]Baird et al. (2009), [4]Baird et al. (2011), [5]Baird et al. (2012), [6]Baird et al. (2010), [7]Olson (2018), [8]Wells et al. (2008), [9]Wells et al. (2009), [10]Davis et al. (1996), [11]Scott and Chivers (2009), [12]Gannier (1999), [13]Perrin (2018), [14]Irvine et al. (1981)

The environmental predictors used in each model differ (Table 6). The common bottlenose dolphin models had the fewest predictors, whereas the pantropical spotted dolphin and the spinner dolphin models had the most. Slope was included in 11 models, whereas both depth and minimum-SST in 10 (Table 6). However, in terms of contribution, depth was the most important environmental predictor, with a contribution of > 25% in seven models, followed by the minimum-SST, which had an important contribution in five models.

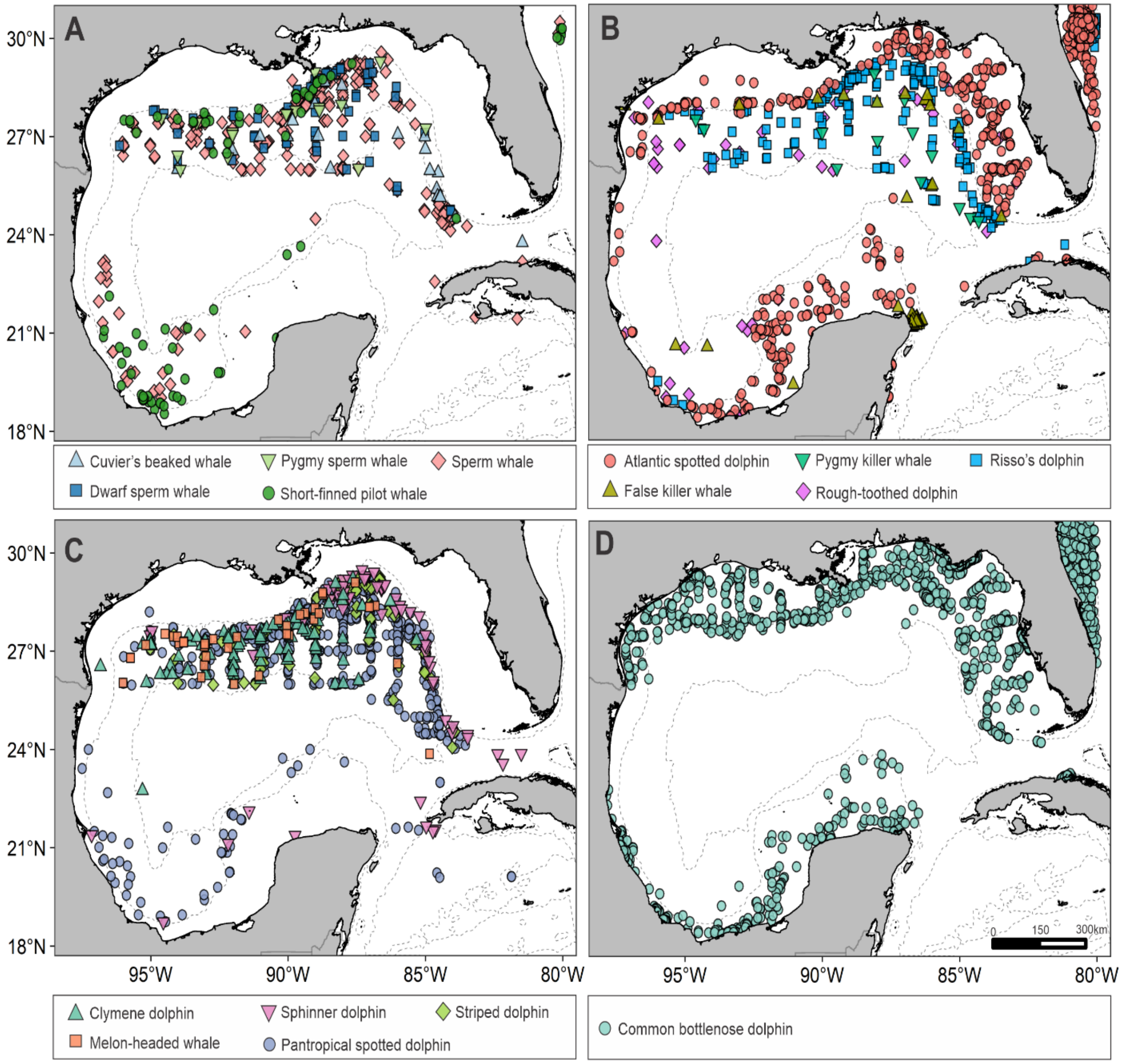

Figure 14. Total georeferenced sightings in the Gulf of Mexico: (A) Cuvier's beaked whale, dwarf sperm whale, pygmy sperm whale, short-finned pilot whale, and sperm whale. (B) Atlantic spotted dolphin, false killer whale, pygmy killer whale, rough-toothed dolphin, and Risso's dolphin. (C) Clymene dolphin, melon-headed whale, spinner dolphin, pantropical spotted dolphin, and striped dolphin, and (D) common bottlenose dolphin. The dotted lines indicated the 200 y 2,800 m isobaths, respectively.

Table 6. Values of the area under the receiver-operator curve (AUC) and of the 10-percentile training omission rate (OR_{10}), and percent of contribution of the environmental predictors in each model. Environmental predictors: SST_m = mean sea surface temperature, SST_{min} = minimum sea surface temperature, SST_{max} = maximum sea surface temperature, Chl-a_m = mean chlorophyll-*a* concentration, Chl-a_{min} = minimum chlorophyll-*a* concentration, Chl-a_{max} = maximum chlorophyll-*a* concentration, D = depth, S = slope, D_{200} = distance to the 200-m isobath.

			Environmental predictors								
Species	**AUC**	**OR_{10}**	**SST_m**	**SST_{min}**	**SST_{max}**	**Chl-a_m**	**Chl-a_{min}**	**Chl-a_{max}**	***D***	***S***	**D_{200}**
Sperm whale	0.83	0.21		17.34				7.23	38.25	9.47	27.71
Dwarf sperm whale	0.86	0.28		45.57	14.59			7.96	28.81	3.06	
Cuvier's beaked whale	0.85	0.24		35.77	1.34				41.51	4.92	16.46
Short-finned pilot whale	0.83	0.18		15.25		5.47			18.00	18.76	42.53
Rough-toothed dolphin	0.83	0.13		57.93	1.10	25.45				7.45	8.07
Risso's dolphin	0.87	0.27		39.06	1.23	12.86			29.60	17.25	
Atlantic spotted dolphin	0.83	0.20		6.95		4.33			74.38	1.54	12.80
Pantropical spotted dolphin	0.74	0.25		24.87	7.60	24.83			27.68	8.59	6.44
Striped dolphin	0.81	0.25	21.28		13.91	37.04			16.85	10.91	
Spinner dolphin	0.80	0.38		8.88	4.75	28.27			10.04	15.44	32.62
Clymene dolphin	0.88	0.16	44.88		18.27			18.37		14.44	4.03
Common bottlenose dolphin	0.91	0.16		20.18	1.07	2.91			75.84		

3.4.1 Sperm whale

Depth and distance to the 200-m isobath contributed for 66% in total to the sperm whale model (Table 6; Figs. 15a and 15b). Areas with high suitability values are located on the inner continental slope (~200 and 800 m deep) in almost the entire GOM, except the inner west Florida slope, and some areas of the bay and terrace of Campeche (Fig. 15c).

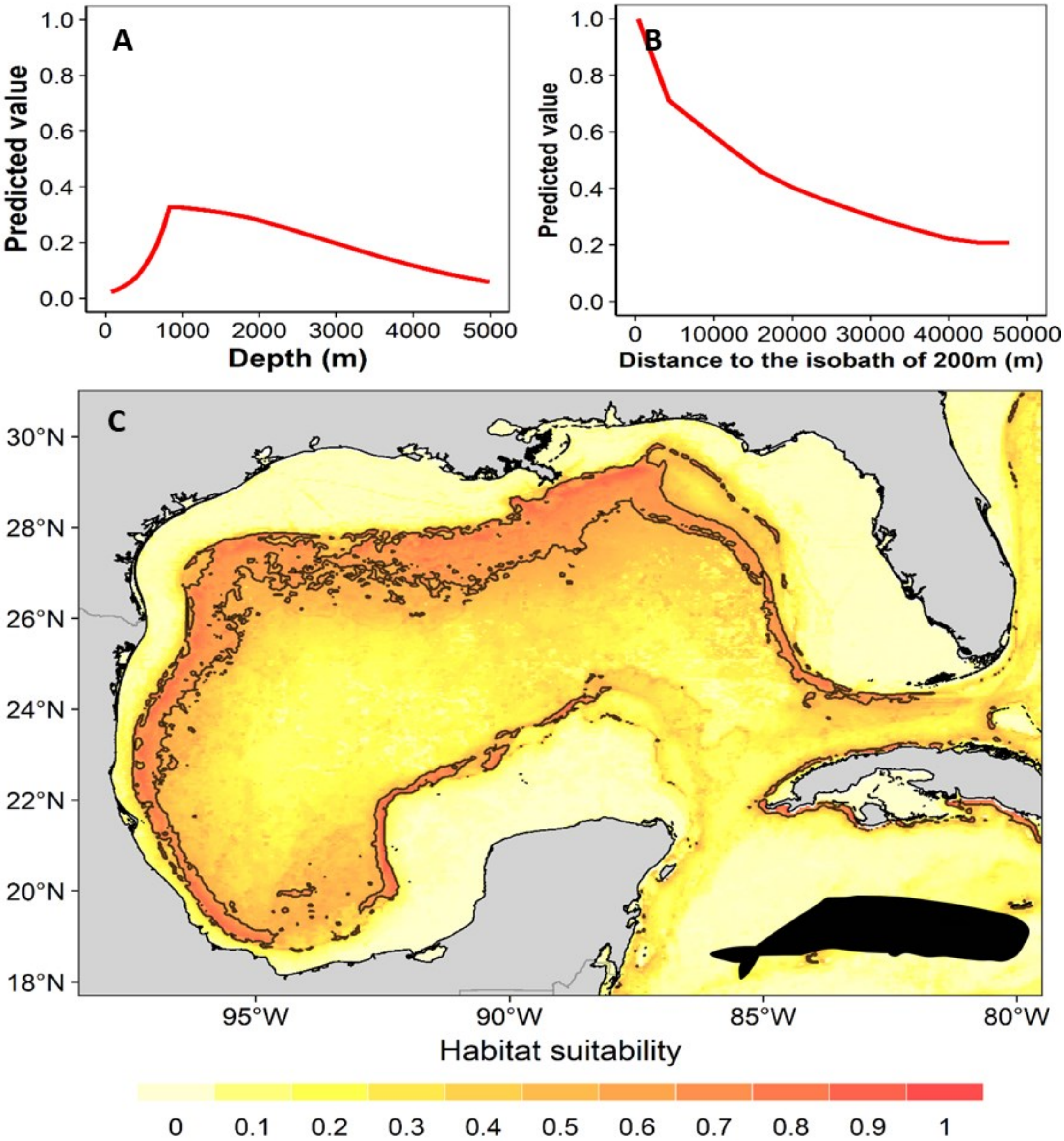

Figure 15. Response curves for the environmental predictors that best explain the data (A) depth and (B) distance to the isobath of 200 m, and (C) habitat suitability of the sperm whale in the Gulf of Mexico. The solid lines indicated areas with high suitability values ≥ 0.6.

3.4.2 Dwarf sperm whale

SST_{min} and depth were the most important predictors in the dwarf sperm whale model, contributing to 74% in total (Table 2; Figs. 16a and 16b). High-suitability areas were located mainly on the entire continental slope in the northern GOM, from the west Florida slope to the Louisiana-Texas slope. Besides, highly suitable areas were found in the inner part of the Rio Grande and Tamaulipas-Veracruz slopes and some patches of the bay and terrace of Campeche (Fig. 16c).

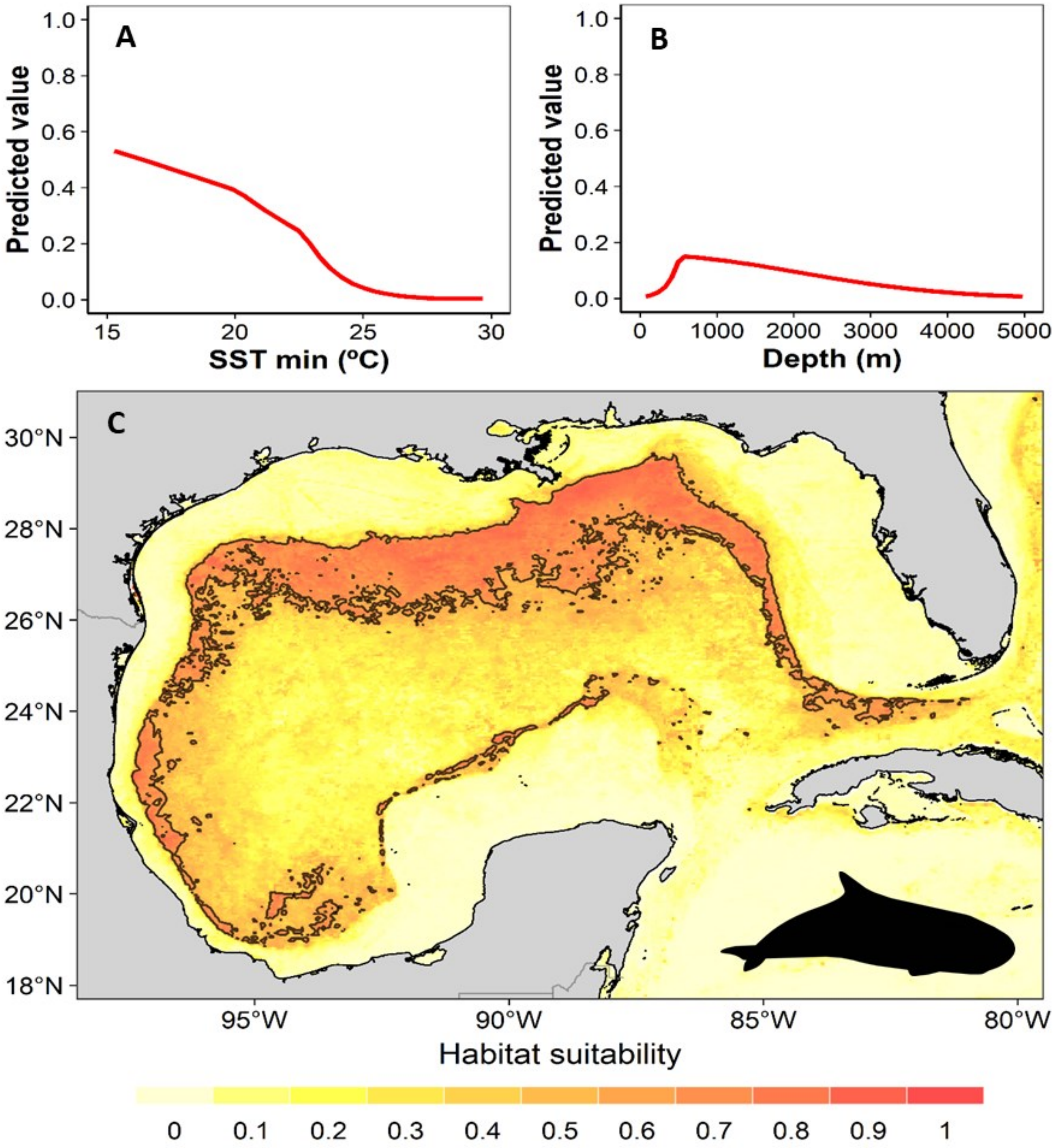

Figure 16. Response curves for the environmental predictors that best explain the data (A) SST_{min} and (B) depth, and (C) habitat suitability of the dwarf sperm whale in the Gulf of Mexico. The solid lines indicated areas with high suitability values ≥ 0.6.

3.4.3 Cuvier's beaked whale

Depth and SST_{min} contributed 77% to the Cuvier's beaked whale model (Table 6; Figs. 17a and 17b). High-suitability areas were located on the entire GOM's continental slope, except for the inner part of the west Florida slope and the bay of Campeche (Fig. 17c).

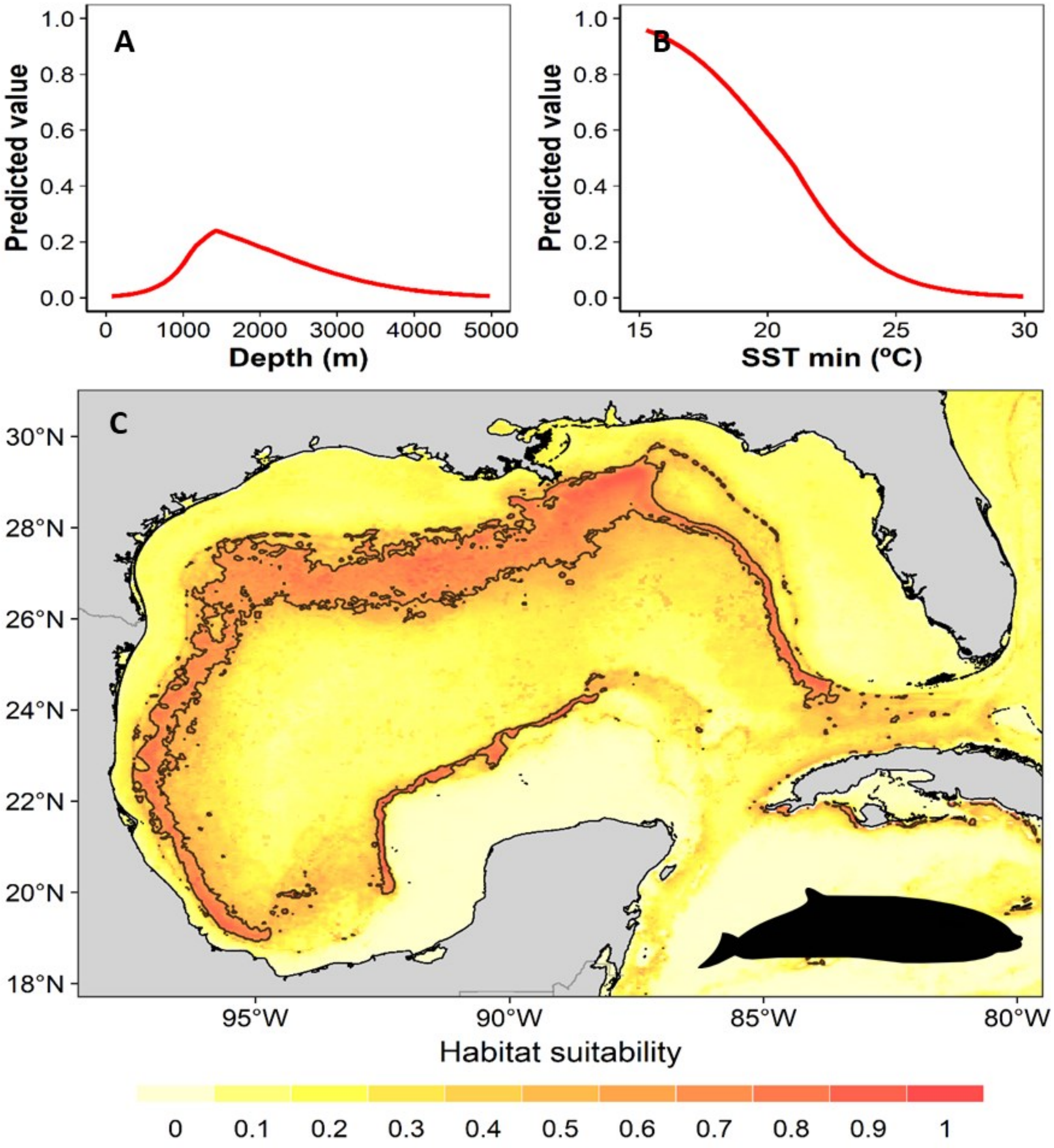

Figure 17. Response curves for the environmental predictors that best explain the data (A) depth and (B) SST_{min}, and (C) habitat suitability of the Cuvier's beaked whale in the Gulf of Mexico. The solid lines encompassed areas with high suitability values ≥ 0.6.

3.4.4 Short-finned pilot whale

Distance to the 200-m isobath and bottom slope contributed 61% to the short-finned pilot whale model (Table 6; Figs. 18a and 18b). High-suitability areas were located continuously on the inner continental slope in almost the entire GOM, except for some parts of the west Florida slope and the terrace of Campeche (Fig. 18c).

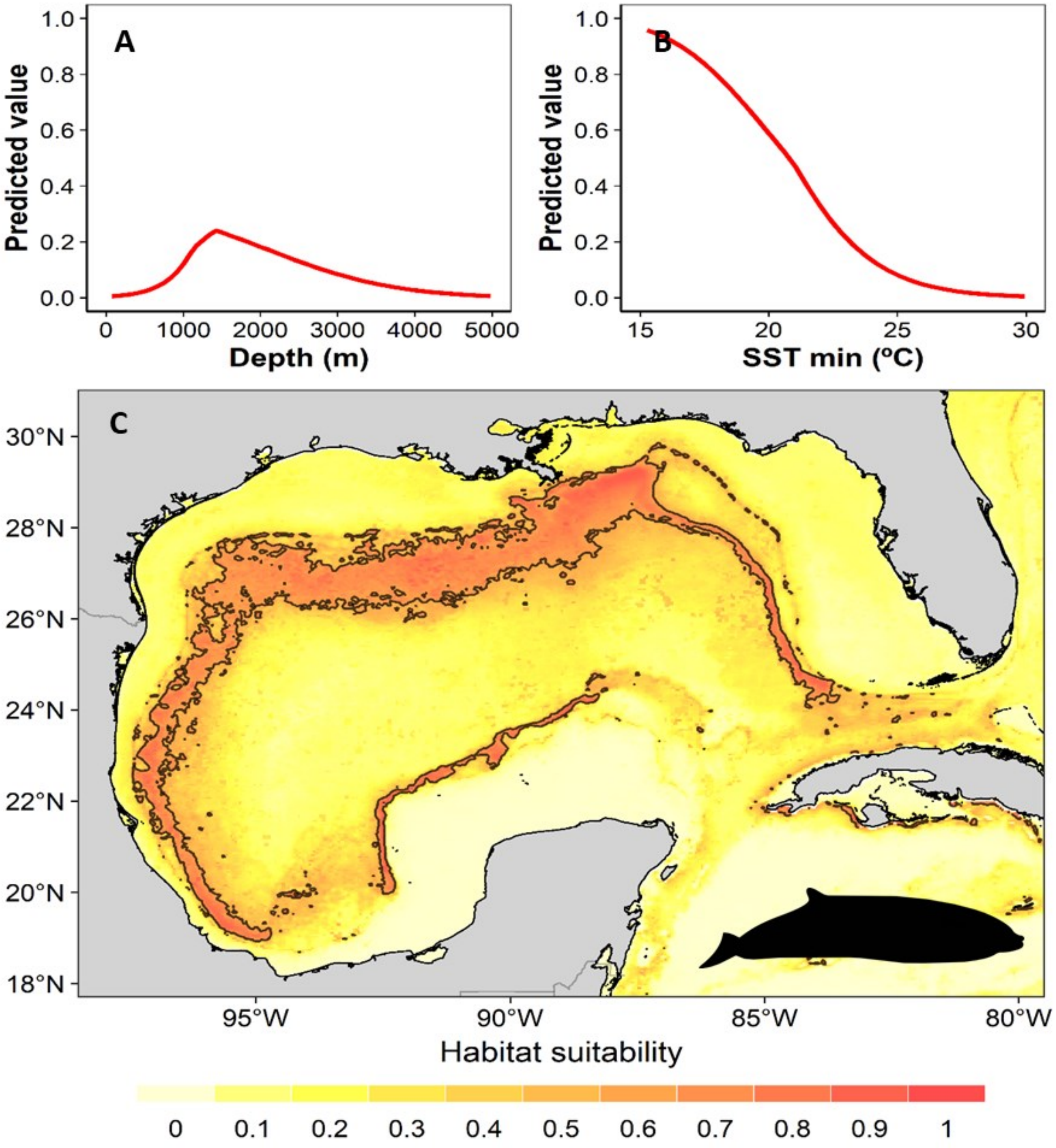

Figure 18. Response curves for the environmental predictors that best explain the data (A) distance to the isobath of 200 m and (B) bottom slope, and (C) habitat suitability of the short-finned pilot whale in the Gulf of Mexico. The solid lines indicated areas with high suitability values ≥ 0.6.

3.4.5 Rough-toothed dolphin

SST_{min} contributed for over half (58%) to the rough-toothed dolphin model (Table 6; Fig. 19a). High-suitability areas were located on both the outer shelf and on the continental slope in almost the entire GOM from the west Florida slope to the Tamaulipas-Veracruz slope. However, they are also in discontinuous patches on the bay and terrace of Campeche (Fig. 19b).

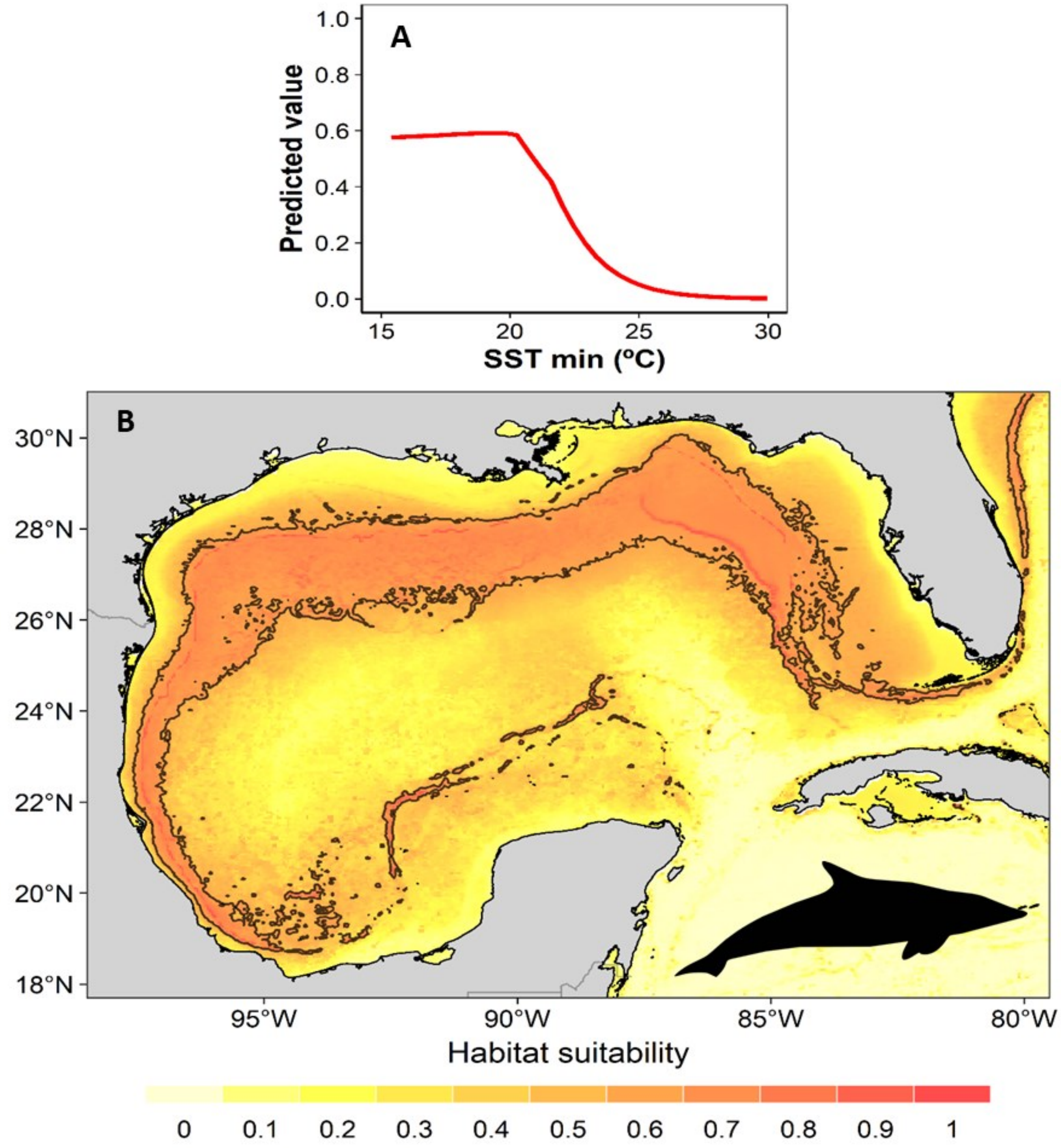

Figure 19. Response curve for the environmental predictor that best explain the data (A) SST_{min}, and (B) habitat suitability of the rough-toothed dolphin in the Gulf of Mexico. The solid lines indicated areas with high suitability values ≥ 0.6.

3.4.6 Risso's dolphin

SST$_{min}$ and depth contributed for 69% of this model (Table 6; Figs. 20a and 20b). High-suitability areas were located on the almost entire continental slope in the north GOM, except for some parts of the west Florida slope. High-suitability areas were also located in the inner part of the Rio Grande and Tamaulipas-Veracruz slopes and on some patches of the bay and terrace of Campeche (Fig. 20c).

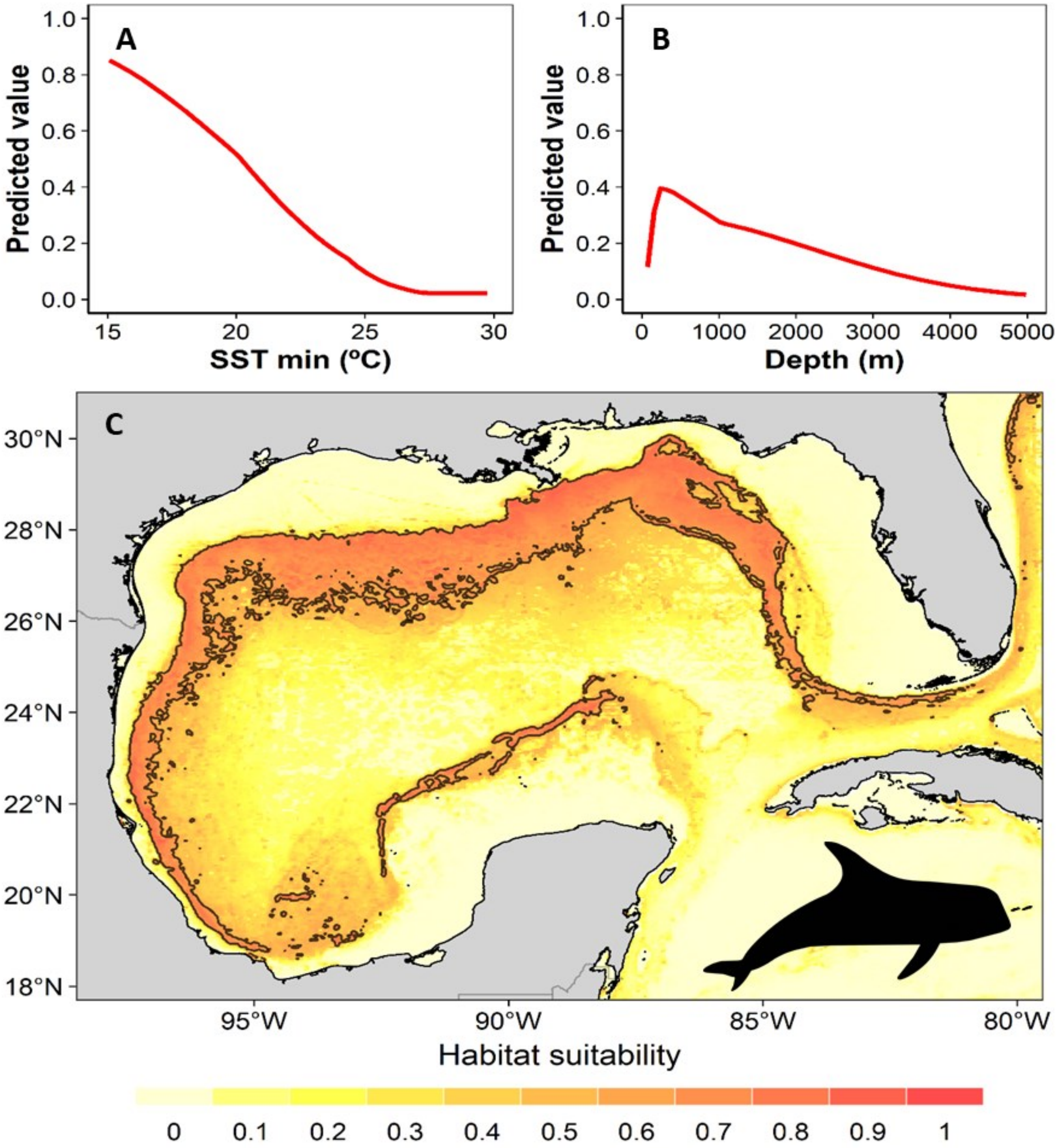

Figure 20. Response curves for the environmental predictors that best explain the data (A) SST$_{min}$ and (B) depth, and (C) habitat suitability of the Risso's dolphin in the Gulf of Mexico. The solid lines indicated areas with high suitability values ≥ 0.6.

3.4.7 Atlantic spotted dolphin

Depth contributed to 74% of the Atlantic spotted dolphin model (Table 6; Fig. 21a). High-suitability areas were located continuously from the outer continental shelf to the entire GOM's upper continental slope, extending to a large part of west Florida, Mississippi-Alabama, Louisiana-Texas, and Tamaulipas-Veracruz shelves (Fig. 21b).

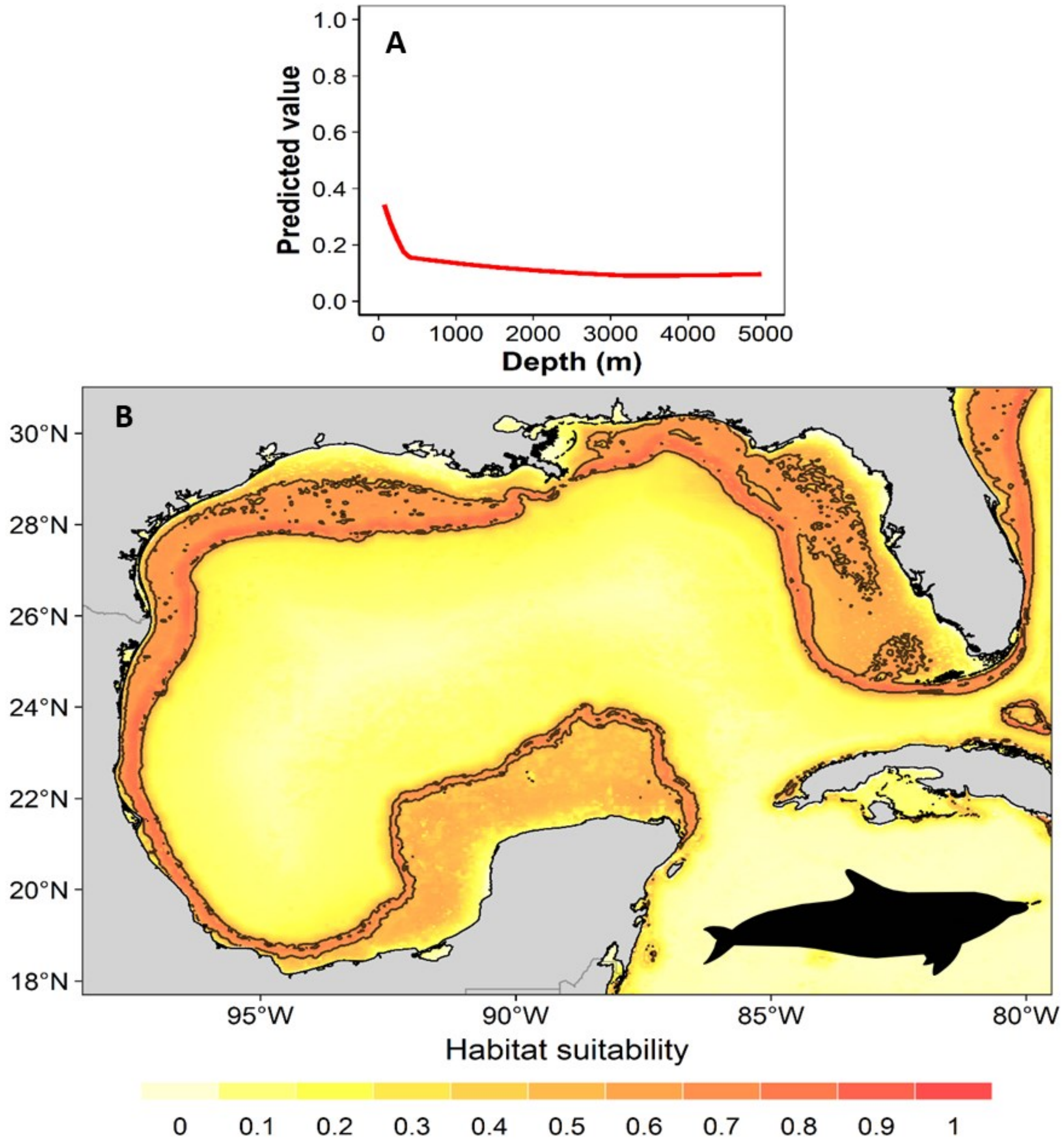

Figure 21. Response curve for the environmental predictor that best explain the data (A) depth, and (B) habitat suitability of the Atlantic spotted dolphin in the Gulf of Mexico. The solid lines indicated areas with high suitability values ≥ 0.6.

3.4.8 Pantropical spotted dolphin

SST_{min} and depth were the most important predictors, contributing for 53% to of the model (Table 6; Figs. 22a and 22b). It suggests that habitat suitability for the pantropical spotted dolphin could extend widely in the entire continental slope of the GOM, except for some parts of the terrace of Campeche (Fig. 22c).

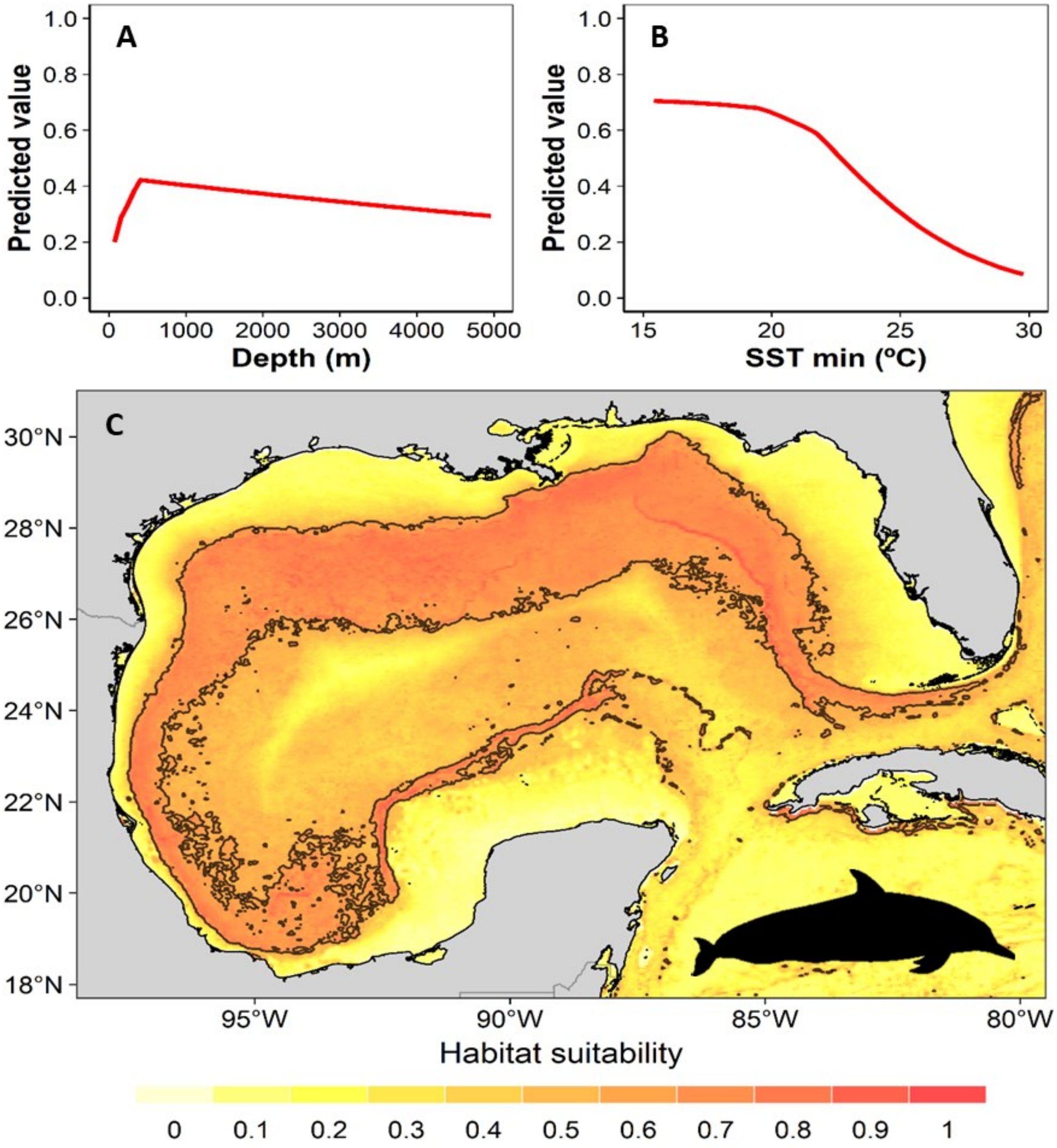

Figure 22. Response curves for the environmental predictors that best explain the data (A) SST_{min} and (B) depth, and (C) habitat suitability of the pantropical spotted dolphin in the Gulf of Mexico. The solid lines indicated areas with high suitability values ≥ 0.6.

3.4.9 Striped dolphin

Chl-a_{m} and SST$_{\mathrm{m}}$ contributed for 58% of the striped dolphin model (Table 6; Figs. 23a and 23b). High-suitability areas were located mainly on the continental slope of the northern GOM. Some patches of the Tamaulipas-Veracruz slope and the bay of Campeche were also identified as high suitability areas (Fig. 23c).

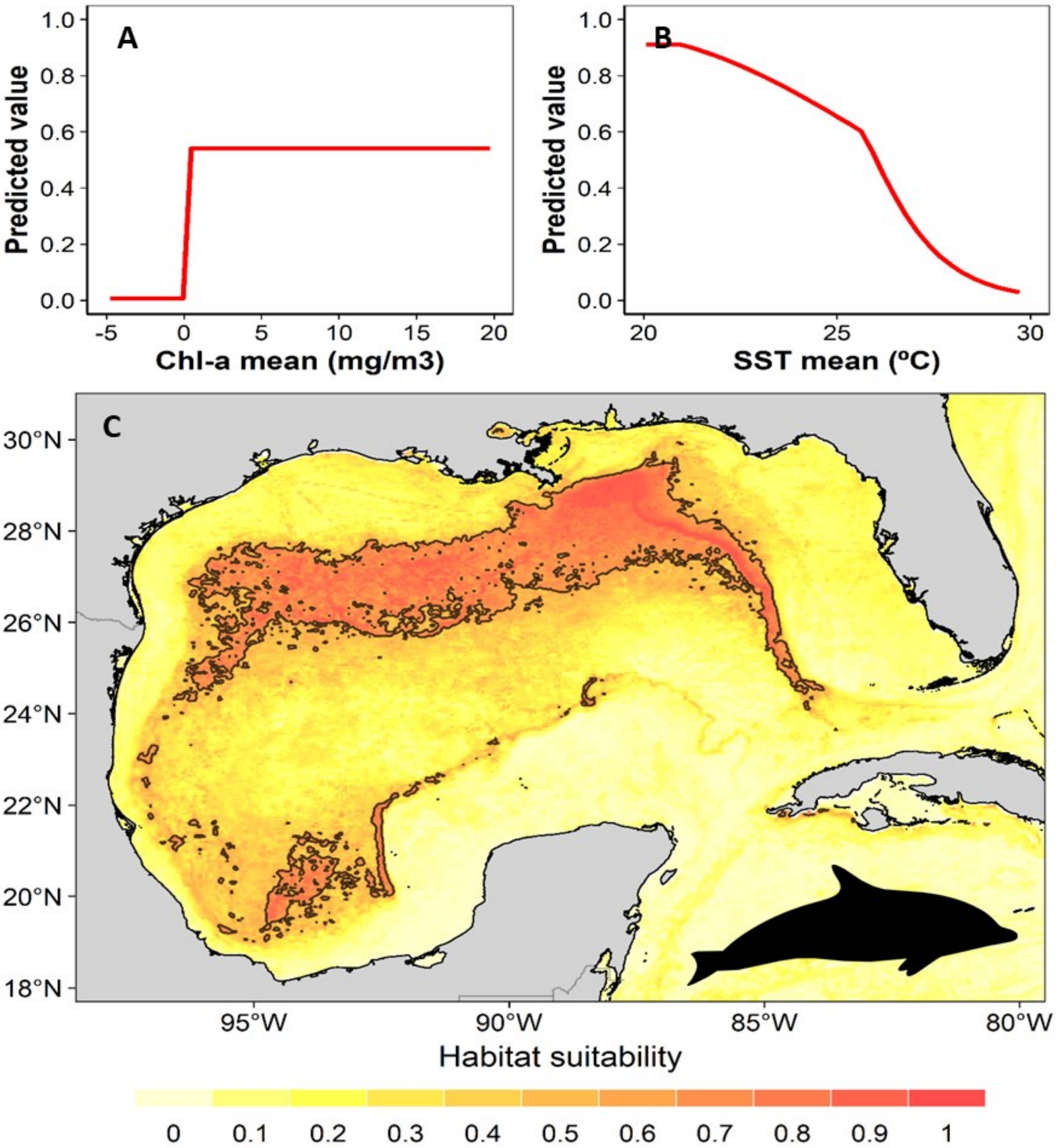

Figure 23. Response curves for the environmental predictors that best explain the data (A) Chl-a_{m} and (B) SST$_{\mathrm{m}}$, and (C) habitat suitability of the striped dolphin in the Gulf of Mexico. The solid lines indicated areas with high suitability values ≥ 0.6.

3.4.10 Spinner dolphin

Distance to the 200-m isobath and Chl-a_m were the strongest contributors to the model, accounting for 61% (Table 6; Figs. 24a and 24b). High-suitability areas extend along with the continental shelf break of almost the entire GOM, except for some parts of the west Florida slope and the terrace of Campeche (Fig. 24c).

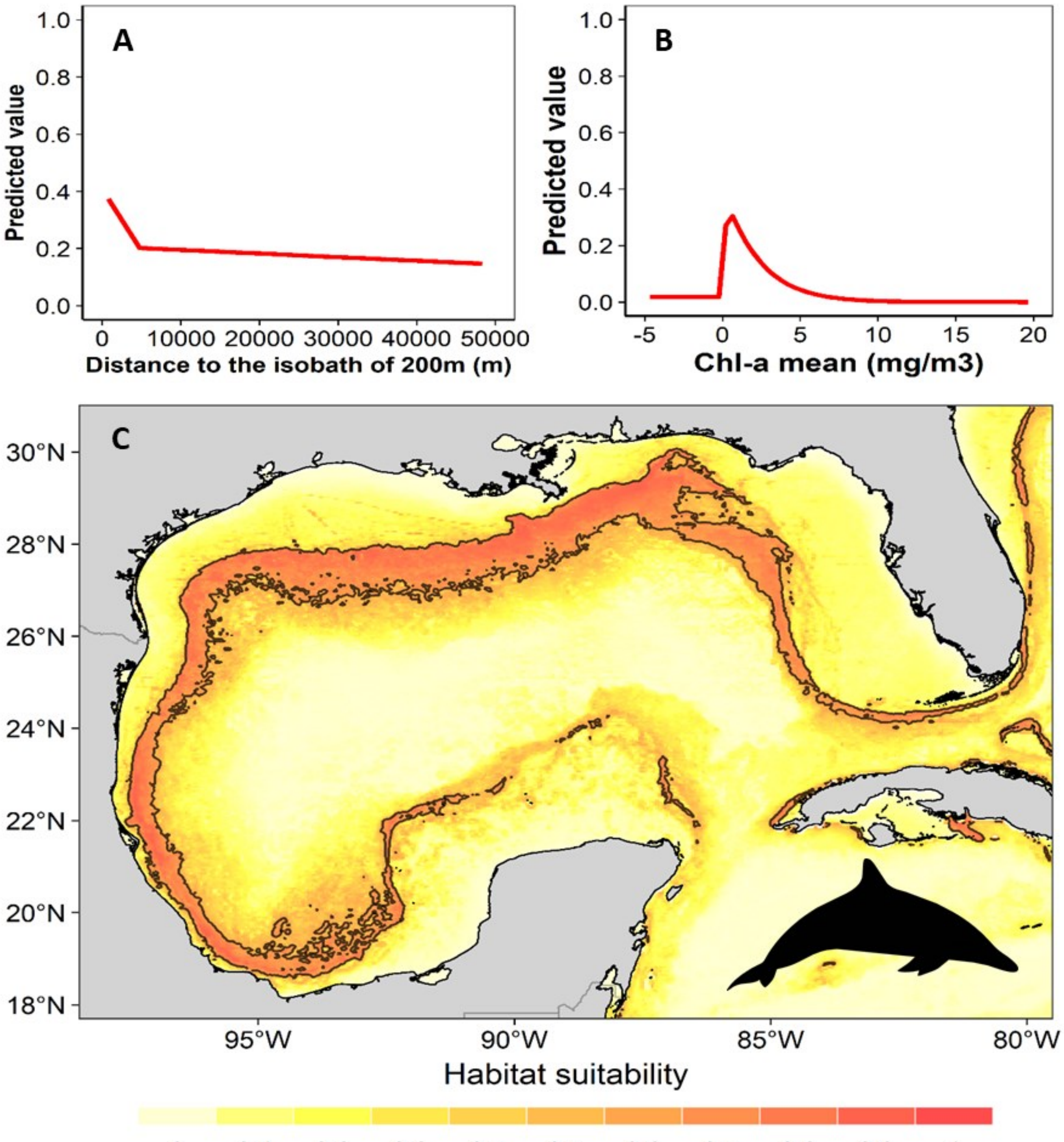

Figure 24. Response curves for the environmental predictors that best explain the data (A) distance to the isobath of 200 m and (B) Chl-a_m, and (C) habitat suitability of the spinner dolphin in the Gulf of Mexico. The solid lines indicated areas with high suitability values ≥ 0.6.

3.4.11 Clymene dolphin

SST_{mean} and Chl-a_{max} contributed to 65.6% of the Clymene dolphin model (Table 6; Figs. 25a and 25b). High-suitability areas were located on the northern GOM's continental slope, mainly in the western Florida slope, the Mississippi Canyon, and the Louisiana-Texas and the Rio Grande slopes. Also, small patches on the Tamaulipas-Veracruz slope were identified as high-suitable areas (Fig. 25c).

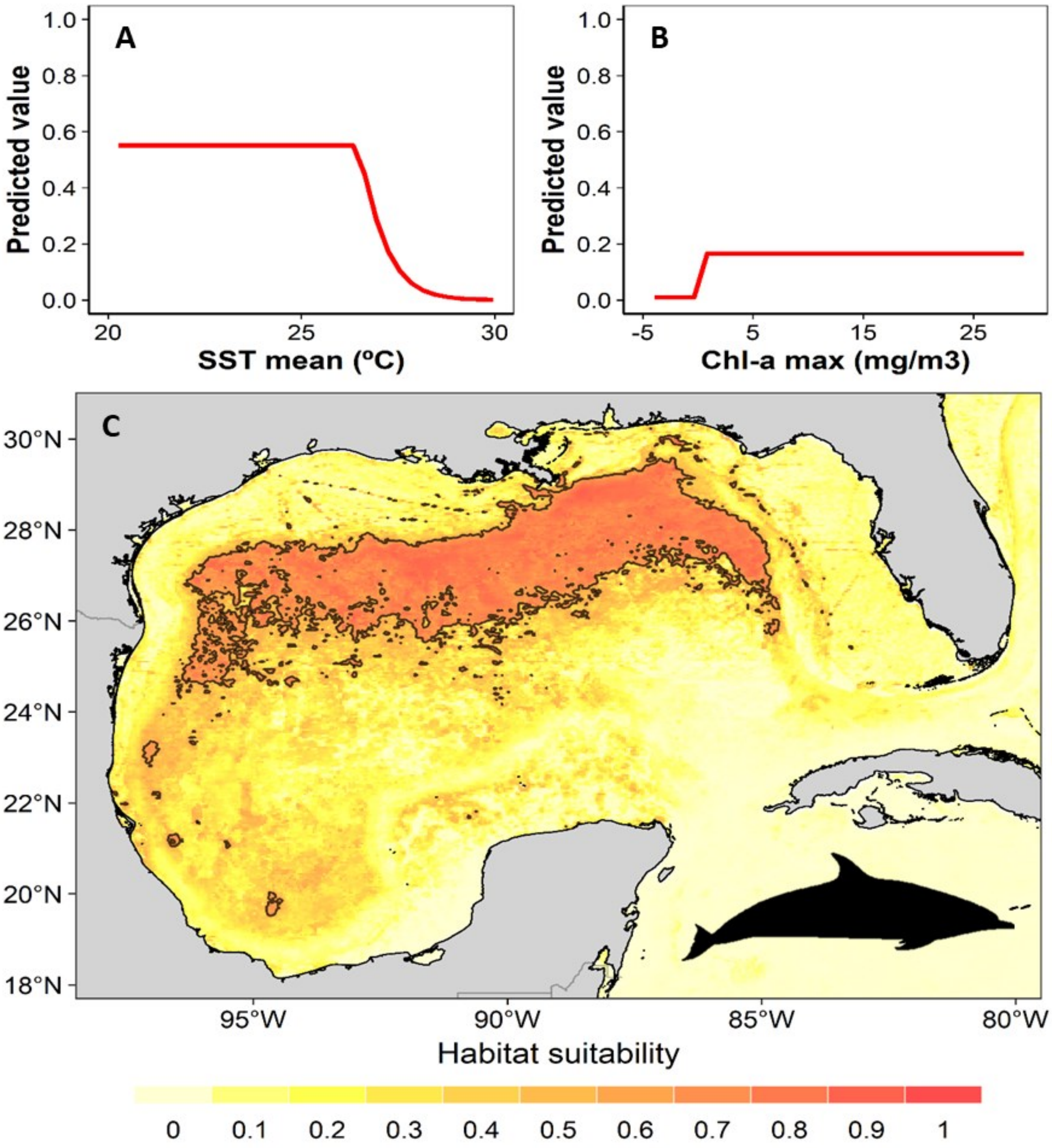

Figure 25. Response curves for the environmental predictors that best explain the data (A) SST_{max} and (B) Chl-$a_{max,}$ and (C) habitat suitability of the Clymene dolphin in the Gulf of Mexico. The solid lines indicated areas with high suitability values ≥ 0.6.

3.4.12 Common bottlenose dolphin

Depth contributed to 76% of the common bottlenose dolphin model (Table 6; Fig. 26a). Highly suitability areas were found mainly on the eastern part of the Florida shelf, Mississippi-Alabama, and Texas-Louisiana continental shelves. Besides, the northern part of the Tamaulipas-Veracruz shelf and other patches to the south identified as highly suitable areas (Fig. 26b).

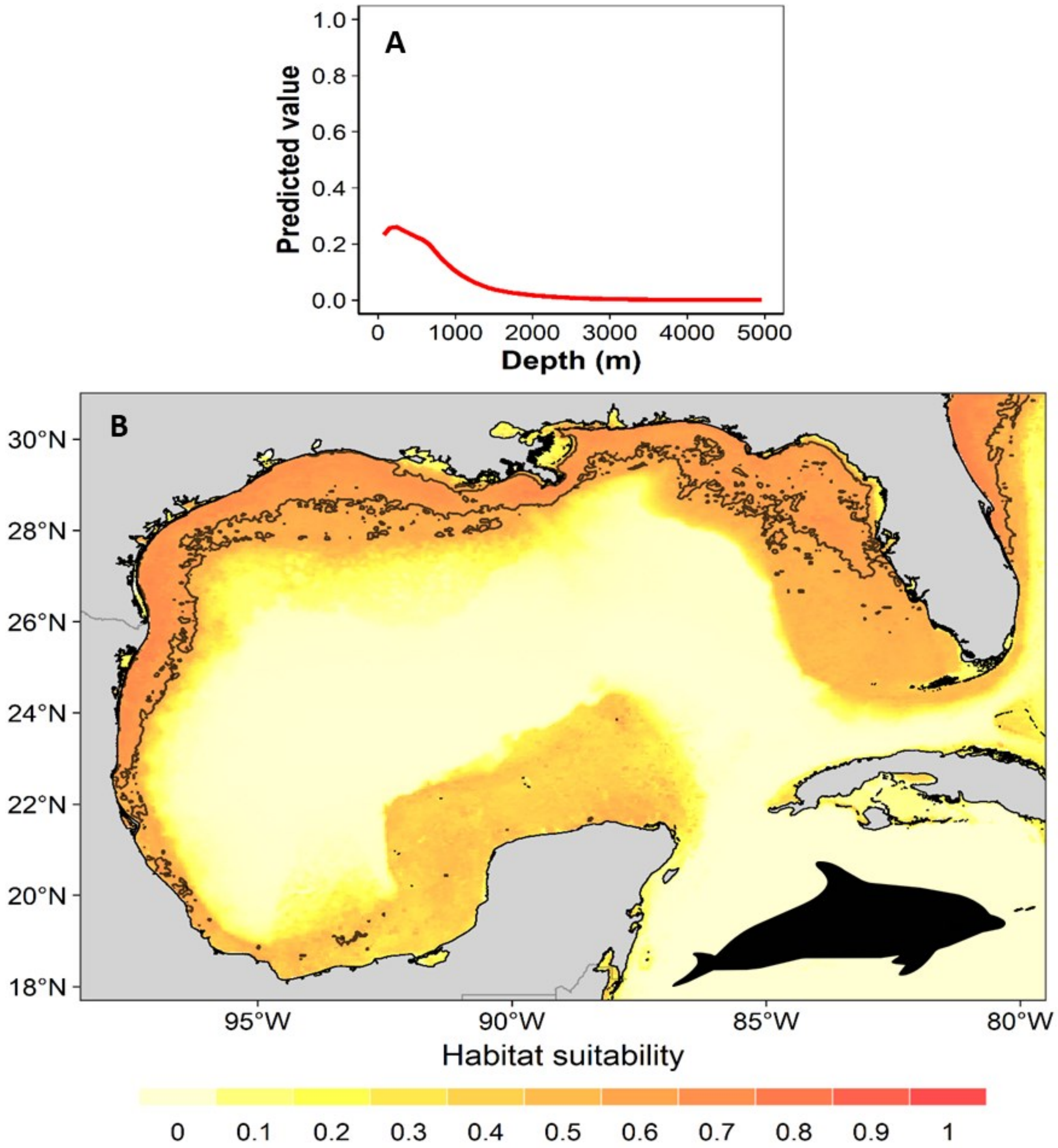

Figure 26. Response curve for the environmental predictor that best explain the data (A) depth, and (B) habitat suitability of the common bottlenose dolphin in the Gulf of Mexico. The solid lines indicated areas with high suitability values ≥ 0.6.

3.4.13 Suitability regions for cetaceans

The main region of high diversity of odontocetes was located between the Mississippi Canyon and the Louisiana-Texas slope (Fig. 27). Other suitable regions were identified on the west Florida slope and on the western continental slope, between the Rio Grande and Tamaulipas-Veracruz slopes

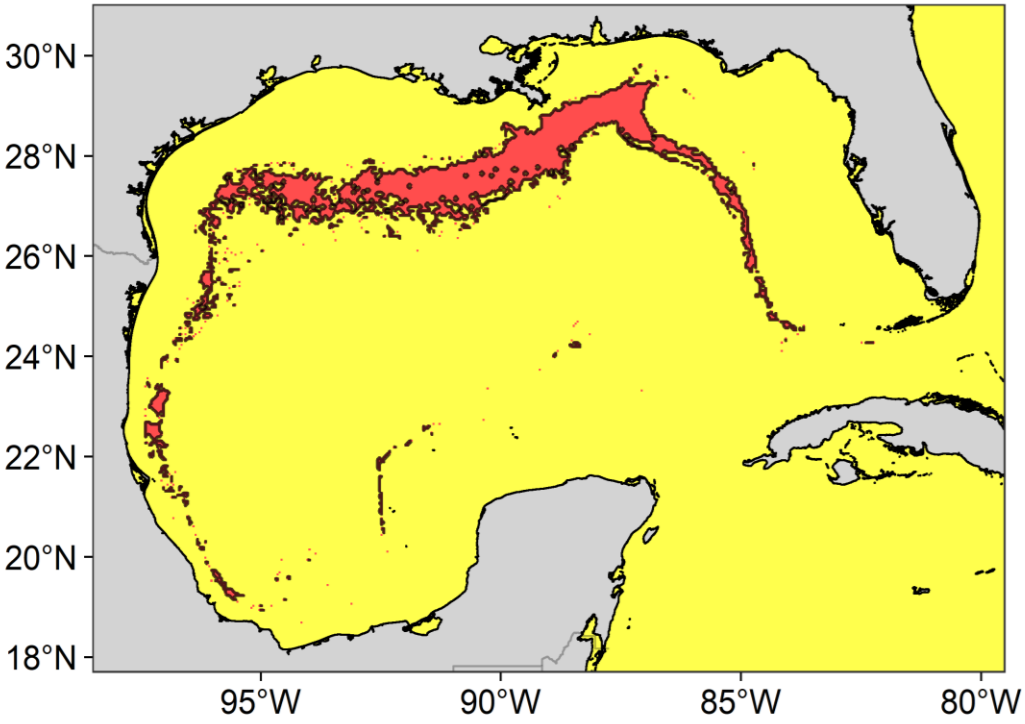

Figure 27. Map of the overlap of the suitable habitat of cetaceans in the Gulf of Mexico. The solid line delimits the highly suitable regions with a high diversity of cetaceans ≥ 7 species.

3.5 Discussion

ENM are powerful tools for generating spatially explicit maps of species' habitat suitability. The MaxEnt approach was used to model the habitat suitability of the GOM odontocetes, using data from both the north and south, and managed to identify regions where high diversity can be expected. This approach was used because it allows the development of reliable models the potential distribution based on presence-only data, although it is important to emphasize that these models do not represent the probability of the presence of a species. However, only 12 of the 20 species present in the GOM were able to model, due to the paucity of data. Furthermore, the resulting maps are integrated images that show no temporal variations, because the use of historical sighting records.

Among the used environmental predictors, depth was the most important, followed by minimum-SST and bottom slope. These results are not surprising since it is well known that these variables influence the occurrence of cetaceans directly, for example, some species display relatively persistent bathymetric associations (Yen et al., 2004; Harvey et al., 2017); but mainly indirectly by playing a determine role in the availability, distribution and abundance of their prey (Davis et al., 2002; MacLeod, 2009; Forcada, 2018). Since steep benthic relief promotes water movements and water column mixing (Harvey et al., 2017), such as upwelling which displace cold (i.e., low temperatures) and nutrients-enriched deep waters towards to upper layers, promoting high primary productivity and biomass (Bakun, 2006; Damien et al., 2018). Consequently, secondary producers concentrate on these patches, where consumers, such as cetaceans, exploit them (Ballance et al., 2006; Palacios et al., 2006, 2013). In fact, previous studies have shown that the distribution of several species of cetaceans of the GOM is strongly related to depth (e.g., Baumgartner, 1997; Davis et al., 1998; Baumgartner et al., 2001).

The results are consistent with the segregated distribution of cetaceans in the GOM proposed by Maze-Foley & Mullin (2006) for the northern GOM. The two dolphin species of the shelf community, the Atlantic spotted dolphins and the common bottlenose dolphins, use different habitats. High suitability areas of the Atlantic spotted dolphins were located on the outer continental shelf and the inner slope, whereas the common bottlenose dolphin has coastal habitats, occupying shallower waters; actually, it is the only species that inhabits lagoons, estuaries, and bays (e.g., Mullin et al., 1990; Griffin & Griffin, 2003; Martínez-Serrano et al., 2011). The continental slope community is composed by the rest species (Maze-Foley & Mullin 2006; present study), although their densities can vary seasonally, at least in the northern GOM (Roberts et al., 2016; Mannocci et al., 2017).

The aggregation of multiple species reveal important biological regions capable of supporting a high cetacean diversity (Harvey et al., 2017). Ten of the 12 species modeled showed habitat suitability areas along the continental slope, consistent with the relatively high diversity of cetaceans observed on the northern GOM continental slope (Davis et al., 2002; Maze-Foley & Mullin, 2006; Roberts et al., 2016). However, the exploitation of different types of habitat (i.e., the use of water column) and prey allow them to co-exist (Bearzi, 2005; Schick et al., 2011). The continental slope of the GOM covers a large area and presents underwater canyons (Bouma & Roberts, 1990), where the main prey (e.g., cephalopods) of the deep-diving species can accumulate (Biggs et al., 2000; O'Hern & Biggs, 2009; Moors-Murphy, 2014). On the other hand, the species that primarily feed on epipelagic prey preferentially use the upper layers of the water column, where mesoscale oceanographic structures occur (Davis et al., 1998, 2002).

Four suitable regions were identified, the most notable was located in the north, encompassing the Mississippi Canyon and the Louisiana-Texas slopes, consistent with that previously reported for the north of the GOM (e.g., Mullin & Fulling, 2006; Roberts et al., 2016). The other regions were located on the west Florida slope (east-northeast of the GOM), the Rio Grande slope (west-northwestern of the GOM), and the Tamaulipas-Veracruz slope (west-southwestern of the GOM). All these regions are characterized by their high primary productivity. In the north, productivity is directly influenced by the input of nutrient from the Mississippi and Atchafalaya rivers (Lohrenz et al., 1999), while in the west by the Grande and Pánuco rivers (Salmerón-García et al., 2011). The plumes of nutrient-rich waters are transported through the continental shelf (Del Castillo et al., 2001; Morey et al., 2003; Zavala-Hidalgo, Morey & O'Brien, 2003), reaching the slope by the interactions of anticyclonic-cyclonic eddies (Toner, 2003; Martínez-López & Zavala-Hidalgo, 2009).

All models had a good discrimination power, with AUC values > 0.70, indicating that the results are reliable, and can be used in planning management and conservation measures (Elith et al., 2006; Raes & Aguirre-Gutiérrez, 2018). On the other hand, the OR_{10} values were higher than the expected value; however, they are within the range reported in other studies (e.g., Kramer-Schadt et al., 2013; Arthur et al., 2019). High OR_{10} values suggest overfitting, which could be due to sampling bias and/or noise in the presence data (Anderson & Gonzalez, 2011; Merow et al., 2014). In the study area, the south of the GOM is under-sampled compared to the north. A spatial filtering was applied to reduce this bias, applied, that allowed it to minimize the omission error, except perhaps in the spinner dolphin model ($OR_{10} > 0.30$).

Areas of high suitability for 12 species of odontocetes were identified in the GOM through the implementation of an ENM. Unfortunately, the paucity of data did not allow modeling all the species, which highlights the importance to establish transboundary research and monitoring programs between the U.S., Cuba and Mexico to improve knowledge on the cetaceans of the GOM. Even so, four geographic regions were detected, where a high diversity of odontocetes is expected, all located on the continental slope. These suitable regions were identified using a spatial overlay, which although it is a very conservative approach (Harvey et al., 2017), it can be useful to detect areas where to focus conservation efforts, such as continuously monitoring programs in these regions (Tolimieri et al., 2015).

3.6 Summary

- This study provides a baseline on the expected distribution patterns of 12 species of cetaceans that inhabit the GOM.

- Environmental predictors varied among species, although depth, minimum sea surface temperature, and bottom slope were the most contributing predictors.

- The continental slope is an important area for cetaceans; ten of the 12 species modeled showed habitat suitability areas along the continental slope.

- Four geographic regions were identified where a high diversity of odontocetes is expected, all located on the continental slope: (1) the Mississippi Canyon and the Louisiana-Texas slope in the northern GOM, (2) the west Florida slope in the east-northeastern GOM, (3) the Rio Grande slope in the west-northwestern GOM, and (4) Tamaulipas-Veracruz in the west-southwestern GOM.

Chapter 4. Abundance estimates of delphinids in the southwestern Gulf of Mexico

4.1 Introduction

The GOM is one of the most economically productive ecosystems in North America (Cato & Adams, 1999), with the extraction of hydrocarbons (gas and oil) as the main activity, although fisheries also generate billions of dollars a year (Karnauskas et al., 2013; Shepard et al., 2013), and it is also a key area for marine traffic (Cato & Adams, 1999). Most of the commercial activities in Mexican waters of the GOM, including hydrocarbon extraction (CNIH, 2019), are carried out in the southwestern region (southward 26°N and westward 91°W). In this area, nine species of delphinids have been reported: the short-finned pilot whale (Ortega-Ortiz, 2002; Galindo et al., 2009), the false killer whale (Vázquez-Castán et al., 2009), the rough-toothed dolphin (Ortega-Ortiz, 2002; Vázquez-Castán et al., 2009), the Risso's dolphin (Castro-Proal, 2018), the common bottlenose dolphin (e.g., Ortega-Ortiz, 2002), and four species of the genus *Stenella*: the pantropical spotted dolphin (Ortega-Ortiz, 2002), the Clymene dolphin (Vázquez-Castán et al., 2009), the Atlantic spotted dolphin (Ortega-Ortiz, 2002), and the spinner dolphin (Galindo et al., 2009).

Abundance estimates are essential in developing management plans to mitigate the potential impacts of anthropogenic activities (Taylor et al., 2007; Kaschner et al., 2012), but knowledge on cetacean ecology in the southwestern GOM is very limited. Almost all studies have focused on coastal populations of the common bottlenose dolphin (e.g., Valdés-Arellanes et al., 2011; Hernández-Candelario et al., 2015; Morteo et al., 2017), and there is only one study on the off-shore delphinid abundance at a large scale (Vázquez-Castán et al., 2009). The latter was based on a single shipboard survey conducted in 2008 using distance sampling methods. The surveyed area extended from the U.S. – Mexico border to southern Veracruz, in waters of 300 to 3,000-m depth. Using six sightings of five species, the overall abundance was estimated at 12,000 individuals (95% confidence interval: 3,506 – 41,646), with a mean density of 61 individuals 100 km^{-2} (95% confidence interval: 18 – 214), which is notably higher than the animal density estimates of regions known for their high cetacean abundances, such as the California Current System, with a mean delphinid density of around 47 individuals 100 km^{-2}, dominated by large schools of common dolphins (*Delphinus delphis* spp.) (Barlow & Forney, 2007).

Ship-based and aerial surveys and distance sampling methods are the standard techniques used to estimate the density and abundance of cetaceans (Hansen et al., 1996; Buckland et al., 2001). Currently, the Bayesian hierarchical scheme is increasingly common to analyze data collected using distance sampling (e.g., Moore & Barlow 2013, 2014). This analytical approach allows incorporating existing information with new data (Ellison, 2004) and including covariates in the estimation process (Marques & Buckland, 2003). The parameters are treated as random variables whose probability distributions are estimated with propagated uncertainty (Ellison, 2004). All these advantages have been shown to result in accurate estimations, with reduced uncertainty compared to frequentist methods (Eguchi & Gerrodette, 2009), and they have proven to be a useful tool for estimating the density and abundance of cetaceans (Moore & Barlow, 2014). In contrast, one of the limitations in traditional (i.e., frequentist) distance sampling analyses is that many sightings are required to fit a robust detection function (Burnham et al., 1980; Buckland et al., 2001).

This chapter aimed to generate animal density and abundance estimates of delphinids in the southwestern GOM, which would serve as a baseline. From 2015 to 2017, four aerial surveys were conducted using distance sampling protocols (Buckland et al., 2001), and data were analyzed in a hierarchical Bayesian modeling framework. This approach allowed the incorporation of different datasets into a single model to fit a robust detection function, and at the same time propagating the uncertainty of the parameters estimated among sub-models (Kéry & Royle, 2015).

4.2 Objectives

1. To estimate the density and abundance of delphinids in the southwestern Gulf of Mexico from aerial surveys.

4.3 Materials and methods

4.3.1 Study area and surveys

The search effort extended from southern Tamaulipas (23°N) to southern Veracruz, (18°05´N), from ~2 to ~60 km off the coast (Fig. 28), covering an area of 34,908 km^2, which was divided into two strata based on their distinct topographic profile, using the 20°30´N parallel as boundary. The northern stratum had an area of 17,662 km^2, with a broad continental shelf (<200-m depth), reaching waters of around 1,000-m depth, whereas the southern stratum had a similar area of 17,246 km^2, but with a narrower continental shelf, reaching depths of >1,500 m, corresponding to the continental slope.

Four aerial surveys were carried out between August 2015 and February 2017, following distance sampling methods (Buckland et al., 2001): from August 18 to 27, 2015, from March 1 to 11 2016, from August 16 to 27 2016, and from February 10 to 19 2017. The flights followed a pre-determined zig-zag design-based method configured in a linear pattern roughly orthogonal to the coastline. Following Mexican aeronautical laws (SENEAM, 2004), flying over four restricted airspaces was avoided: the Tampico airport, the Laguna Verde nuclear power plant, the Veracruz airport the military and naval school located at Anton Lizardo (Fig. 28).

Surveys were conducted aboard high-wing single-engine aircrafts Cessna 177 and 182 with flat windows (i.e., a blind strip bellow the airplane). The average altitude was 339 ± 69 m, at a speed of 195 ± 22 km h^{-1}. The survey team consisted of the pilot, a co-pilot, and two observers located in the cabin's back. The survey effort was carried out in optimum weather conditions, i.e., Beaufort sea state ≤3 and good visibility (without rain or fog). These conditions were recorded at the beginning of the effort, and each time a change was noticed. When a sighting occurred, the altitude h was recorded with a Garmin eTrex 10 GPS, along with the complementary angle to the sighting θ, measured with a manual clinometer Suunto PM-5. The perpendicular distance x from the transect to the group was calculated $x = h / \tan\theta$. Whenever possible, the effort was interrupted while circling over the animals to identify the species and determine the group size.

Linear effort was divided into (5-km length) segments as standard sampling units of the analyses to estimate density (Buckland et al., 2015). After inspection of the effort's frequency distribution, only surveys that summed more than 1,000 km in a stratum were considered for animal density and abundance estimates because the effort was not completed in all surveys (see below).

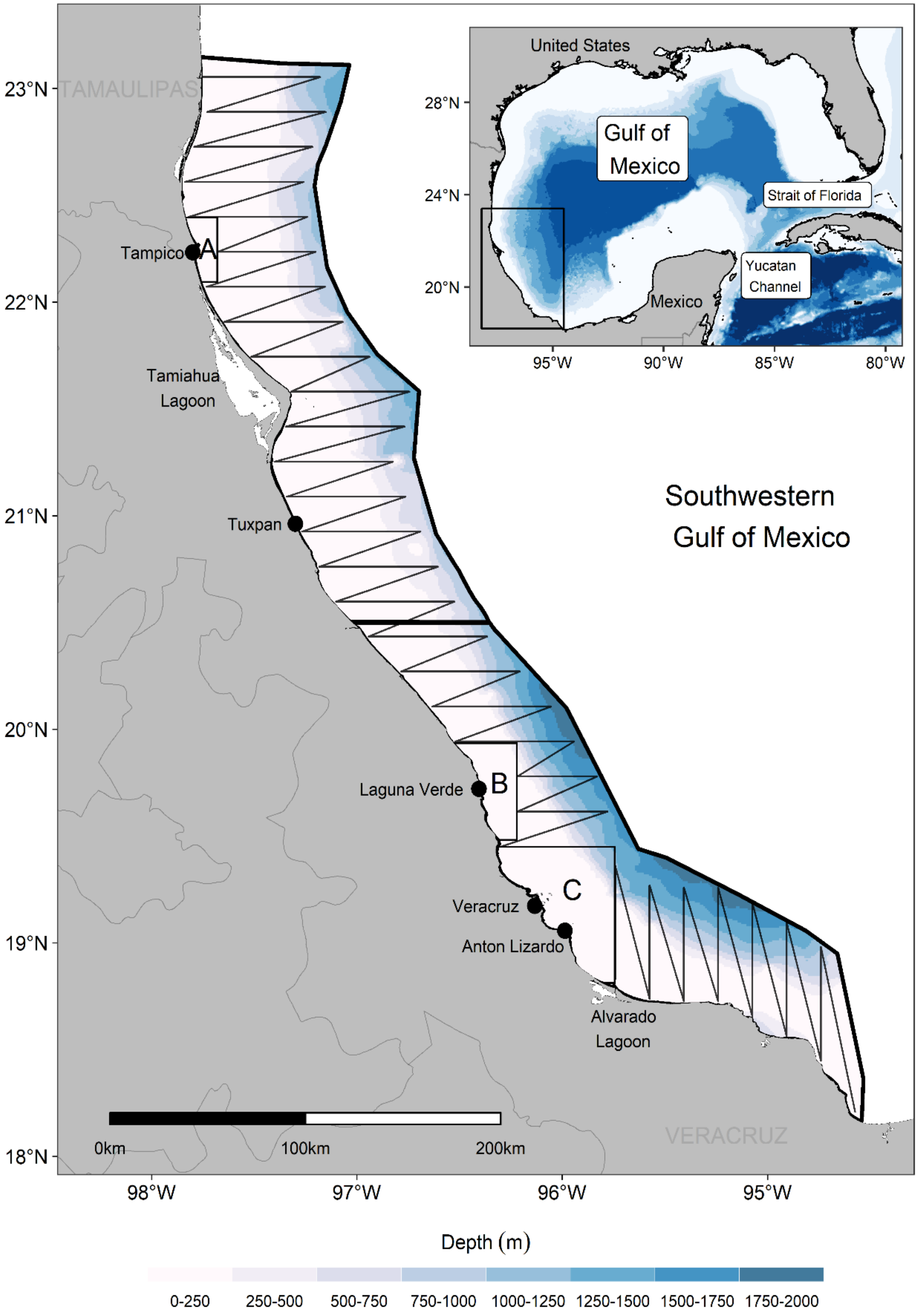

Figure 28. Study area in the southwestern Gulf of Mexico, and the aerial survey design. The polygons correspond to the restricted airspaces: A = Tampico airport, B = Laguna Verde nuclear power plant, and C = Veracruz airport, and the military and naval school at Anton Lizardo.

4.3.2 Model definition

Due to the low number of sightings during the study (see below), density and abundance estimates were made at the family level instead of separately for each species. Since the modeling framework involved different levels and sources of information to estimate the parameters needed to obtain abundance, it was decided to analyze them as sub-models of a single Bayesian hierarchical structure (Ellison, 2004; Kéry & Royle, 2015). The complete model consisted of three sub-models: one to estimate the mean group size, one to estimate the detection function and the effective strip half-width, and another to estimate the animal density at each segment. The model was written in the language Just Another Gibbs Sampler (JAGS) (Su & Yajima, 2012), which implements Bayesian inference by sampling from the posterior distributions of the parameters through a Markov Chain Monte Carlo (MCMC) procedure. All data processing, analyses, and graphical representations were written in R software (R Core Team, 2018). Five MCMC with 1,000,000 iterations for all sub-models were ran, with a burn-in phase of 200,000 samples, and retaining every 20th value, for a final posterior sample size of 200,000.

The first sub-model estimated the mean group size from sightings both on- and off-effort. After inspecting the frequency of distribution of the group sizes *s*, a log-normal likelihood was assumed, with mean μ_s and standard deviation σ_s, both with uninformative priors (Pardo et al., 2015). Then, the mean group size $\tilde{s}$, was estimated as:

$$\tilde{s} = exp\left[\mu_s + \frac{\sigma_s^2}{2}\right] \tag{1}$$

The second sub-model estimated the probability of detecting groups as a function of their distance from the segment. Nevertheless, since the number of on-effort sightings with known perpendicular distance was not enough to fit such model (see below), they were pooled with data collected in surveys conducted in the northeast Pacific Ocean off Mexico and the Gulf of California (M.A. Pardo; unpublished data). These sightings were made following the same protocols described above for the present study in terms of survey conditions, type of plane, flight speed, altitude, type of windows (flat), and the number of experienced observers. Only sightings of the same delphinid species and maximum group sizes comparable to those recorded in this study were used, and only to make feasible the estimation of the detection function, but not for estimating the mean group size or animal densities.

The perpendicular distances *x* at each on-effort sighting *j* followed a half-normal distribution was assumed. Nevertheless, since the airplanes' flat windows prevented any detection along a strip below the aircraft, the perpendicular distances based on a left-truncation point of 0.19 km were rescaled. After inspection of the perpendicular distances' frequency distribution, a right-truncation point was also established at 3 km, and all detections farther from that distance were discarded. The perpendicular distance were modeled as a function of two covariates (Marques & Buckland, 2004) that have proven to affect the detectability: the Beaufort sea state *b* (it is harder to detect groups far away from the track-line when the surface of the ocean is rougher), and the group size *s* (it is easier to miss small groups when they are far from the track-line, compared to larger groups). Thus:

$$\sigma_{x_j} = exp(\alpha_0 + \alpha_1 b_j + \alpha_2 s_j) \qquad [2]$$

The alpha coefficients had uninformative priors, and the effective strip half-width at each sighting w_j was derived from the estimated standard deviations σ_{x_j} , as proposed by Eguchi and Gerrodette (2009):

$$w_j = \frac{1}{(2/\pi\sigma_{x_j}^2)^{1/2}} \qquad [3]$$

The same procedure was used to estimate the effective strip half-width *W* for each segment *k*, using the alpha coefficient estimated in Eq. 2 and the derivation of Eq. 3, but in this case associated with the distance-weighted Beaufort sea state *B* of each segment, and the estimated mean group size $\tilde{s}$ (Eq. 1):

$$W_k = \frac{1}{(2/\pi\left[exp(\alpha_0 + \alpha_1 B_k + \alpha_2 \tilde{s}\right.} \qquad [4]$$

Additional to the results of the two sub-models described above, the estimation of animal density involves the knowledge of *g*(0). Nevertheless, since the estimation of *g*(0) requires special techniques (Thomsen et al., 2005), which were beyond the scope of the present study, as prior distribution the *g*(0) estimated for common bottlenose dolphins and striped dolphins was used of the only available study that followed the same survey protocols (i.e., flat windows, and similar flying altitude and speed) (Gómez de Segura et al., 2006). That study reported a mean *g*(0) of 0.676 and a coefficient of variation *CV* of 0.1632 for both species, from which the parameters *a* and *b* of a Beta prior distribution were calculated (Gelman et al., 2004):

$$a = \mu_{g(0)} \cdot \left(\left[\frac{\mu_{g(0)} \cdot (1 - \mu_{g(0)})}{(CV_{g(0)} \cdot \mu_{g(0)})^2} \right] - 1 \right)$$ [5]

$$b = (1 - \mu_{g(0)}) \cdot \left(\left[\frac{\mu_{g(0)} \cdot (1 - \mu_{g(0)})}{(CV_{g(0)} \cdot \mu_{g(0)})^2} \right] - 1 \right)$$ [6]

Using the results of the parameters described above, the third sub-model was performed, and the animal density *d* at each segment *k* was estimated as (Buckland et al., 2004):

$$d_k = \frac{n_k \tilde{s}}{2W_k l_k} \cdot \frac{}{g(0)}$$ [7]

where n_k is the number of groups sighted on-effort in the *k*th segment, and l_k is the length of *k* in kilometers. Then, the animal density of each stratum at each survey *m* was calculated as:

$$d_m = \frac{\sum N_k}{\sum 2 \cdot W_k \cdot l_k}$$ [8]

where N_k is the estimated number of animals per segment, which equals to the multiplication of the density in *k* by the area effectively sampled. The abundance of each stratum at each survey was the multiplication of d_m by the stratum's total area in km^2. Although the density and abundance were estimated for each stratum in each survey, only those in which the linear effort was ≥ 1,000 km were reported. Finally, the total abundance per survey was obtained as the sum of the two strata' abundances, and the global density and abundance for the study area as the mean of those of surveys with enough effort.

3.4 Results

Total sampling effort was 11,207 km, with 5,403 km in the northern stratum and 5,804 km in the southern (Fig 29). The minimum effort was not achieved during the first survey of 2015; thus, it was not used for the animal density estimates. During the winter surveys (March 2016 and February 2017), weather conditions prevented the aircraft from covering ~10% of the original design.

Table 7. Summary of delphinid sightings during the four aerial surveys in the southwestern Gulf of Mexico, 2015 - 2017.

	Sightings			
Survey	**Species**	**Stratum**	**Group size**	**Type**
August 2015	*T. truncatus*	North	9	Off-effort
	G. griseus	South	40	On-effort
	G. macrorhynchus	South	9	On-effort
		South	24	On-effort
	Unidentified small dolphins	North	38	Off-effort
March 2016	*T. truncatus*	North	8	On-effort
		North	10	Off-effort
		North	4	Off-effort
		North	24	Off-effort
	Stenella spp.	North	90	Off-effort
		South	40	On-effort
August 2016	*T. truncatus*	North	8	Off-effort
		North	10	Off-effort
		South	2	Off-effort
	G. griseus	South	4	On-effort
		South	3	On-effort
	G. macrorhynchus	South	7	On-effort
		South	1	On-effort
	Unidentified small dolphins	South	150	On-effort
February 2017	*T. truncatus*	North	10	Off-effort
		North	1	Off-effort
		South	8	On-effort
		South	3	Off-effort
		South	4	Off-effort
	Stenella spp.	North	12	On-effort
	Unidentified small dolphins	South	40	On-effort

Twenty-six groups of delphinids were recorded, of which 13 were on-effort (Table 7). A total of 559 individuals were sighted, including *Stenella* dolphins, common bottlenose dolphins, Risso's dolphins, short-finned pilot whales, and unidentified small dolphins, which could have been *Stenella* spp., rough-toothed dolphins, and/or common bottlenose dolphins. There were no sightings on-effort in the northern stratum during August 2016. Short-finned pilot whales and Risso's dolphins were also observed only during the summer surveys (August 2015 and 2016), *Stenella* dolphins in the winter surveys, and common bottlenose dolphins in all surveys. Common bottlenose dolphins and *Stenella* dolphins were sighted in both strata, whereas short-finned pilot whales and Risso's dolphins were observed exclusively in the southern stratum (Table 7; Fig. 29).

Table 8. Summary statistics of the parameters' posterior distributions for animal density estimates. *SD* = Standard deviation, $n_{eff\,\%}$ = percentage of effective iterations respect to the total retained.

				Quantiles			
Parameter	**Prior distribution**	**Mean**	***SD***	**2.5%**	**50%**	**97.5%**	$n_{eff\,\%}$
Mean group size, $\tilde{S}$	*U*(1,4)	13.85	3.83	7.50	13.50	22.43	100
Alpha coefficients of the effective strip half-width							
α_0	*U*(-5,1)	-0.50	0.10	-0.70	-0.50	-0.30	100
α_1	*U*(-1,0.5)	-0.48	0.10	-0.70	-0.50	-0.30	85
α_2	*U*(0,1)	0.01	0.00	0.01	0.01	0.01	85

All MCMC chains for the posterior distributions of the estimated parameters converged ($\hat{R}$ = 1). The posterior mean of the group size (*n* = 26) was 13.85 animals (95 %-CI: 7.49 – 22.43) (Table 8). Perpendicular distance was measured in eight of the 13 on-effort sightings, thus to estimate the detection function, these along with 88 sightings borrowed from surveys in the Pacific Ocean were used (see Methods). As expected, the effective strip half-width was strongly influenced negatively by the Beaufort sea state (α_1 consistently negative) and positively by the group size (α_2 consistently positive) (Table 8). The effective strip half-width ranged from 0.1 to 2 km, but most were between 0.3 and 0.7 km. These distances are from the left-truncation point, at which *g*(0) was 0.68 (95%-CI: 0.44 – 0.87). (Fig. 30).

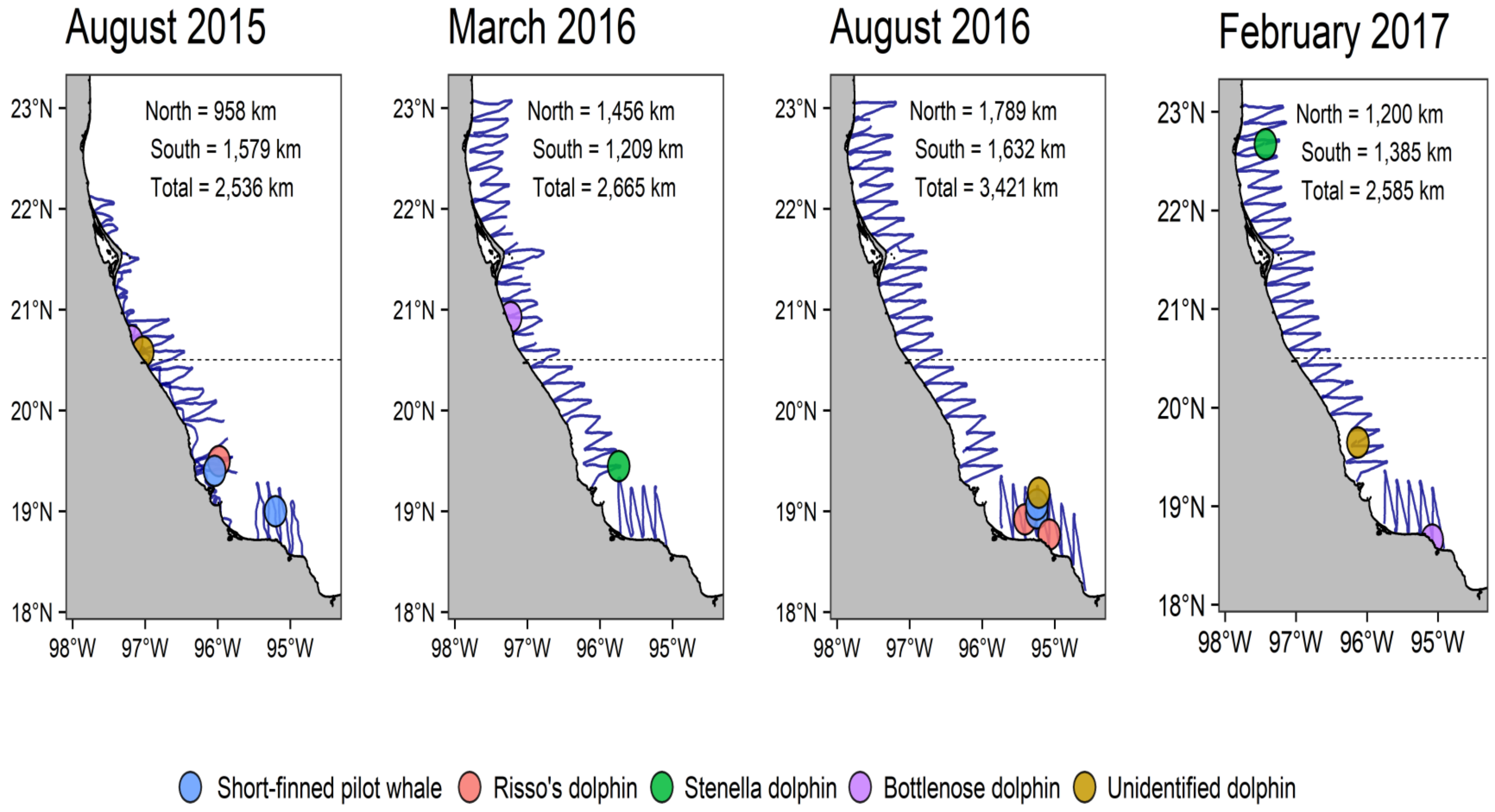

Figure 29. Effort summary for each survey (blue lines) and on-effort sightings (colored dots) in the southwestern Gulf of Mexico, 2015–2017. The dashed line represents the limit between the northern and southern strata.

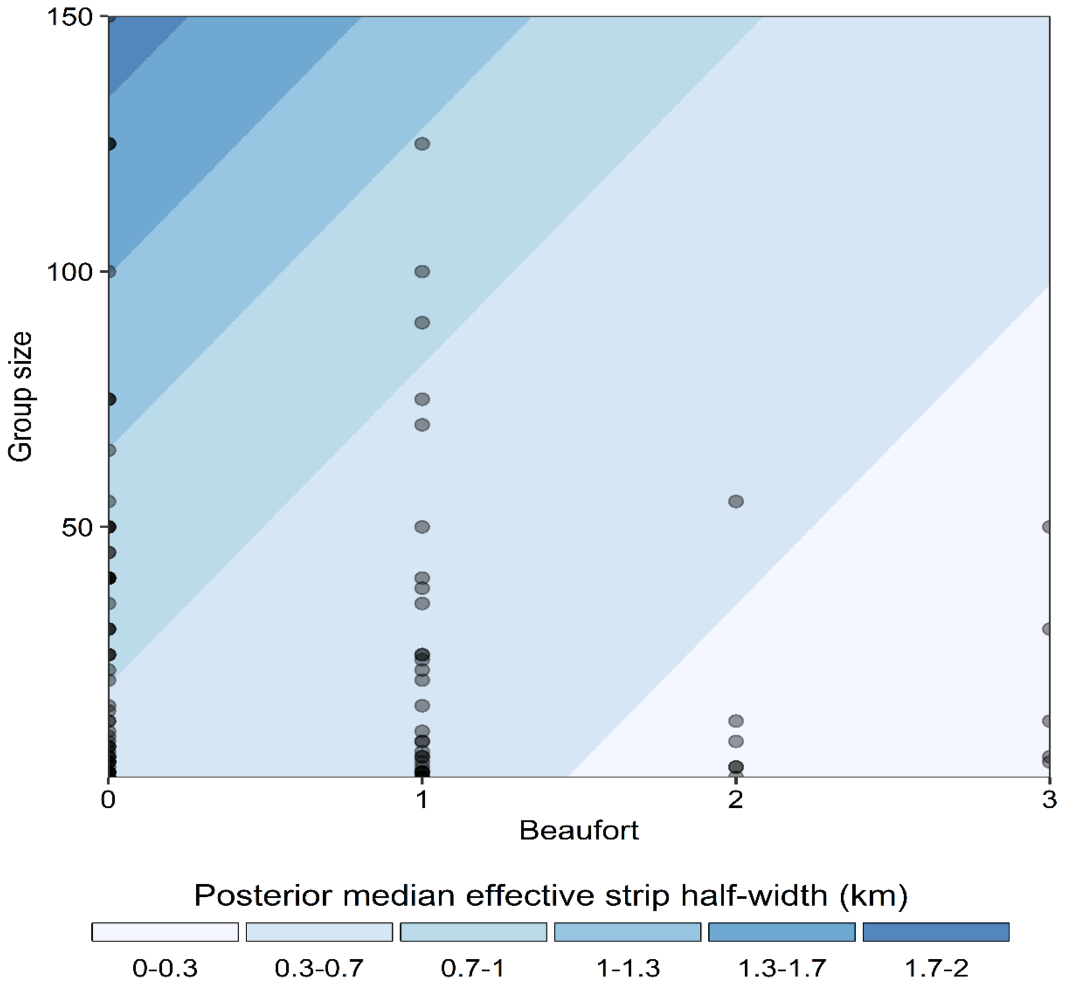

Figure 30. Posterior median of the effective strip half-width in kilometers (color scale), predicted from the co-variables Beaufort sea state and group size. Blacks dots represent the observations (n = 96).

The lowest abundance occurred in March 2016, with 475 individuals (95 %-CI: 242 – 839), whereas the highest was in August 2016, with 889 individuals (95 %-CI: 453 – 1,569) (Fig. 31). The number of animals was higher in the southern stratum than in the northern, with average abundances of 387 individuals (95 %-CI: 197 – 683) and 125 individuals (95%-CI: 77 – 268), respectively (Fig. 32). Global animal density was 1.91 individuals 100 km^{-2} (95 %-CI: 0.97 – 3.38), and the global abundance was 668 individuals (95 %-CI: 340 – 1,179) (Table 9).

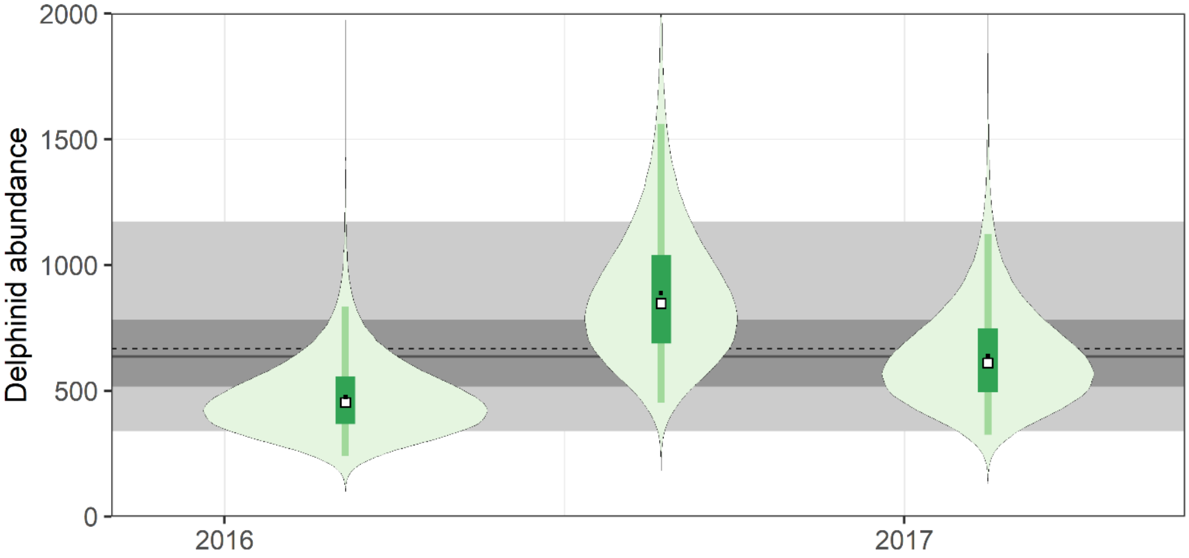

Figure 31. Posterior distributions of abundance estimates of delphinids per survey in the southwestern Gulf of Mexico (2015 – 2017). The horizontal dashed and solid lines are the mean and the median global abundance, respectively. The dark and light gray areas are the 50%- and the 95%-credible intervals, respectively. The solid and hollow squares are the means and the medians, respectively. The dark and light green error bars represent the 50%- and the 95%-credible intervals, respectively.

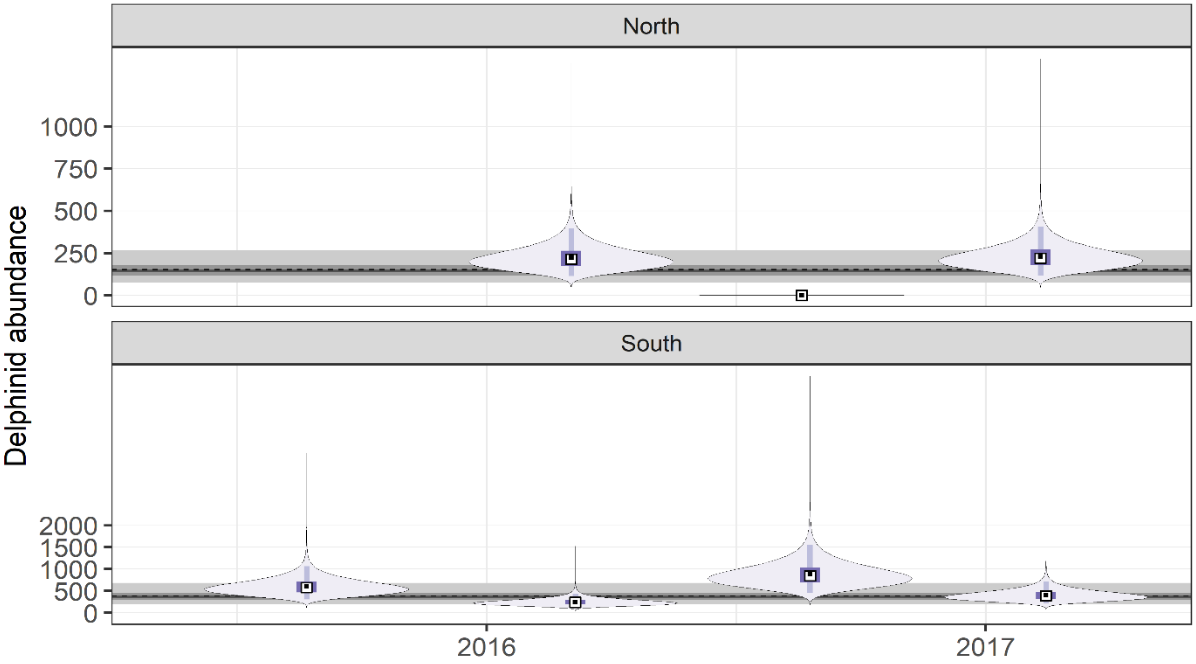

Figure 32. Posterior distributions of the abundance estimates of delphinids per strata in the southwestern Gulf of Mexico (2015 – 2017). The horizontal dashed and solid lines are the means and the medians of the mean strata's abundances, respectively. The dark and light gray areas are the 50%- and the 95%-credible intervals, respectively. The solid and hollow squares are the means and the medians, respectively. The dark and light purple error bars represent the 50%- and the 95%-credible intervals, respectively.

Table 9. Animal density (individuals 100 km^{-2}) and abundance estimates of delphinids per survey and strata in the southwestern Gulf of Mexico. *SD* = Standard deviation, $n_{eff\,\%}$ = percentage of effective iterations respect to the total retained. No estimates were made for the northern stratum in August 2016 because there were no on-effort sightings.

	Animal density						**Abundance**					
			Quantiles						**Quantiles**			
	Mean	***SD***	**2.5%**	**50.0%**	**97.5%**	$n_{eff\,\%}$	**Mean**	**SD**	**2.5%**	**50.0%**	**97.5%**	$n_{eff\,\%}$
Global	1.91	0.62	0.97	1.82	3.38	100	668	216	340	637	1179	100
North	0.86	0.28	0.44	0.67	1.01	100	152	49	77	145	268	100
South	2.24	0.73	1.14	1.74	2.63	100	387	125	197	369	683	100
March 2016	1.36	0.44	0.69	1.30	2.40	100	475	154	242	453	839	100
North	1.27	0.41	0.65	1.21	2.25	100	225	73	114	214	397	100
South	1.45	0.47	0.74	1.38	2.56	100	250	81	127	239	442	100
August 2016	2.55	0.82	1.30	2.43	4.50	100	889	287	453	847	1569	100
North	-	-	-	-	-	-	-	-	-	-	-	-
South	5.15	1.67	2.62	4.91	9.10	100	889	287	453	847	1569	100
February 2017	1.83	0.59	0.93	1.75	3.23	100	639	206	326	398	743	100
North	1.31	0.42	0.67	1.24	2.31	100	231	75	118	220	407	100
South	2.37	0.77	1.21	2.26	4.18	100	408	132	208	389	721	100

4.5 Discussion

Delphinids abundance in the southwestern GOM was in the order of the hundreds animals, with a global density of 1.91 individuals 100 km^{-2}. Apparently, this abundance can vary spatially in the study area, which may be due to fact that the environments sampled are different between strata. In the northern stratum, most of the study area corresponds to the continental shelf, while the area surveyed in the southern stratum reach the continental shelf break and the slope waters. In the northern GOM, the continental slope region is characterized by high abundance of cetaceans (Mullin & Fulling, 2004; Roberts et al., 2016). On the other hand, abundance between years was similar between surveys, although it was not possible to analyze temporal trends, since the data come from three surveys only.

The global animal density estimate of 1.91 individuals 100 km^{-2} (95 %-CI: 0.97 – 3.38) was notably lower than that reported by Vázquez-Castán et al. (2009), 61 individuals 100 km^{-2} (95% confidence interval: 18 – 214) based on a single shipboard survey. This discrepancy could be explained by their small number of perpendicular distances to fit a detection function (only six sightings), leading to considerable overestimation if most of the groups were detected close to the transect line (i.e., underestimation of the effective strip half-width). On the other hand, the density estimation was also lower than the 19.8 individuals 100 km^{-2}, (95% confidence interval: 14.99 – 26.12) reported in the northern GOM at the same family level based on eight aerial surveys (Hansen et al., 1996).

The differences in the density estimates between the north and southwestern GOM may be due to different reasons. First, the difference in the study area's size, the search effort in this study only covered a portion of the southwestern GOM of 34,908 km^2 and most of these area correspond to the continental shelf, compared to 85,815 km^2 covered in the northern GOM, mainly in the upper slope waters (Hansen et al., 1996), where others studies reported high densities of cetaceans (Roberts et al., 2016). Secondly, even though sightings were pooled with other from borrowed sightings to fit a plausible detection function, density estimates in the southwestern GOM are based on 13 sightings only; hence the results may be negatively biased. Finally, or simply because the delphinids are in fact less abundant in the southwestern GOM.

Aerial surveys are commonly exposed to conditions that can affect animals' detection, leading to biased estimates (Marsh & Sinclair, 1989). It is possible that some individuals have not been detected (i.e., perception bias) due to inadequate weather conditions for aerial surveys (e.g., clouds, rain, and swell)

(Marsh & Sinclair, 1989; Barlow, 2015). Even when these conditions were actively avoided, this problem was common during the winter's surveys, mainly in the north stratum. Moreover, group sizes affect the detection probability, and therefore the estimate (Barlow et al., 2001). In this study, mean group sizes were small to moderate, thus it is possible that some groups were missed (i.e., perception bias). Also, cetaceans have a diving behavior, and it is possible that some animals were lost for being submerged (i.e., availability bias) when the aircraft flew across the transect-lines (Barlow et al., 1988; Marsh & Sinclair, 1989).

Despite the low number of sightings in this study, a plausible estimated was achieved with the available data. The latter was possible due to the strategy of pooling our distance data with those of other ongoing studies under a Bayesian framework, that otherwise (i.e., frequentist methods) would not have been possible, given the large number of sightings required to fit a robust detection function (Burnham et al., 1980; Buckland et al., 2001). Nevertheless, pooling distance data from the Pacific Ocean was not enough to fit each species' detection function in this study because not all were well represented. Therefore, estimates had to be limited at the family level. Although pooling the sightings of several species is a practical solution when there are not enough observations (e.g., Wade & Gerrodette, 1992; Forney et al., 1995), it has some disadvantages, since the differences between species affecting their perception are ignored, such as in their typical surface display, body size and color, grouping patterns, and that these may not follow the same abundance trend (Jewell et al., 2012). For example, it is easier to detect species with an active surface behavior like *Stenella* dolphins than those less active such as pilot whales.

The four species observed in this study represent 19% of those inhabiting the GOM (Maze-Foley & Mullin, 2006; Würsing, 2017). Although this diversity could seem relatively low, it was expected because most of our study area corresponds to continental shelf waters (≤ 200 m depth), and in the Gulf, only three species regularly occur in this type of habitat: the common bottlenose dolphin, the Atlantic spotted a dolphin, and the rough-toothed dolphin (Fulling et al., 2003). The remaining 16 species of odontocetes distribute mainly on the continental slope and pelagic waters (between 200 and 2500-m depth) (Jefferson & Schiro, 1997; Baumgartner et al., 2001; Davis et al., 2002).

In general, distribution patterns of delphinids in the southwestern GOM were similar to those reported for the GOM (Jefferson & Schiro, 1997; Davis et al., 2002; Chapter 3). Common bottlenose dolphins were observed in shallow waters close to shore, which is their preferred habitat in the region year-round (Martínez-Serrano et al., 2011). Although dolphins of the genus *Stenella* could not be identified at the species level, they likely were Atlantic spotted dolphins, dominant of the study area (Ortega-Ortiz, 2002;

Chapter 3). This species is usually found on the continental shelf, but it can approach the coast temporarily in the northern GOM (Perrin, 2002; Waring et al., 2016). During this study, *Stenella* dolphins were recorded only during the winter surveys, which agrees with their seasonal pattern (Waring et al., 2016). However, since unidentified small dolphins were recorded in all surveys, which could be *Stenella* dolphins and common bottlenose dolphins, and/or rough-toothed dolphins, it cannot assure that this seasonality actually occurs. Risso's dolphins and short-finned pilot whales were observed only in the southern stratum, which agrees to their preferred habitat, which is dominated mainly by deep waters, although they can be found on the continental slope and, occasionally, on the continental shelf (Baumgartner, 1997; Davis et al., 2002; Maze-Foley & Mullin, 2006). There is no information about these two species' movement patterns in the GOM (Wells et al., 2009, 2013), although it has been proposed that the Risso's dolphin could perform longitudinal seasonal movements (Mullin & Hoggard, 2000).

4.6 Summary

- The results suggest that the abundance of delphinids in the study area is of the order of hundreds of animals.

- The highest number of animals were estimate for August 2016 (889 individuals), while the lowest was for March 2016 (475 individuals).

- The results suggest that the species composition could vary seasonally since the short-finned pilot whales and Risso's dolphins were observed only during the summer surveys, *Stenella* dolphins in the winter surveys, and common bottlenose dolphins in all surveys.

Chapter 5. General discussion and conclusions

This thesis aims to establish a baseline on the distribution and abundance of the cetaceans that inhabit the GOM, with particular emphasis in the Mexican EEZ, based on three specific objectives: (1) to determine the state of knowledge on cetaceans in Mexican waters of the GOM (Chapter 2), (2) to analyze the habitat suitability of commonly sighted species and identify suitable regions capable of supporting high cetacean diversity at the ecosystem level (i.e., the entire GOM) (Chapter 3), and considering that the delphinids are an abundant group in the GOM, it was included (3) to estimate the abundance of this family in the southwestern GOM (Chapter 4). Overall, the objectives established were achieved, therefore the results found in this study can serve as baseline for future studies.

According to the analysis of the state of knowledge on cetaceans of the GOM, a substantial delay of ~40 years in cetacean research in the GOM compared to the U.S. and Mexico's Pacific region was found. Fourteen species of cetaceans were recorded, of the 21 that are distributed in the GOM. Nevertheless, a spatial bias exists within the records: most sightings are restricted to the waters of the continental shelf, and few of them were located in deep waters (i.e., beyond the upper continental slope). Moreover, the number of species increases to 17 taking into account the stranding records. Therefore, it is expected that the diversity of cetaceans for both the north and the south of the GOM will be similar. On the other hand, the study of cetaceans in Mexican waters started formally in the 1980s, with the common bottlenose dolphin being the most studied species since then, while the information of the remaining species was scarce, leaving large gaps in knowledge. The principal breach identified in Mexican cetacean research was that there is no information on the basic ecology (i.e., distribution and abundance) of most cetacean species, except for the common bottlenose dolphin.

Based on the results of the analysis of the state of knowledge, it was determined that odontocetes are the most common cetaceans found in the GOM. This study provided a baseline on the expected distribution pattern for this group from the information on presence-only records and by using MaxEnt models with five environmental predictors. This approximation allowed to model these species' habitat suitability in the entire GOM, including the Mexican and Cuban waters, where the available information is minimal. Nevertheless, only 12 were modeled of the 20 species present in the GOM, due to the paucity of data. Furthermore, it is important to emphasize that the resulting maps are integrated images that do not show seasonal or inter-annual variations, and neither represent the probability of a species' presence or its abundance.

Overall, two bathymetric predictors (bottom's slope and depth) and the minimum-SST broadly define high-suitability areas for cetaceans. For 10 of 12 species, these areas were located in the GOM's continental slope, where several oceanographic and biological processes occur, that makes these areas essential for them (Fig. 33). Four geographic regions were identified, where a high diversity of odontocetes is expected. These regions are the Mississippi Canyon, the west Florida, and the Louisiana-Texas slopes, in the northern GOM, and the Tamaulipas-Veracruz and the Rio Grande slopes in the central-west. However, these regions could increase if all the species of cetaceans in the GOM are considered, since the habitat suitability for all species was not modeled.

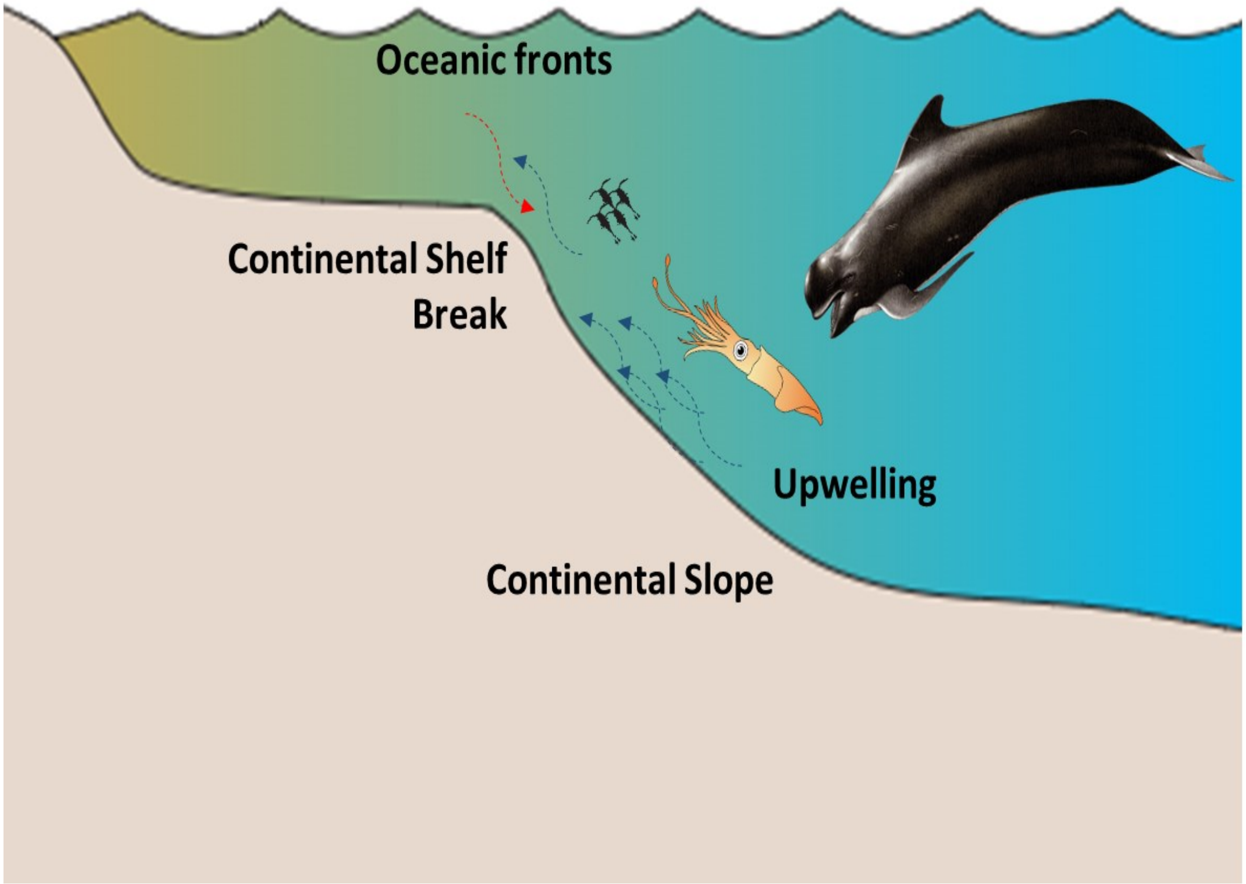

Figure 33. The conceptual model shows the continental shelf-break ecosystem as an important area for distributing cetaceans in the Gulf of Mexico. Modified image of Integration and Application Network, University of Maryland Center for Environmental Science (ian.umces.edu/imagelibrary/).

Likewise, given the scarce information on the abundance of cetaceans in the southwestern GOM, this study provided a baseline for the delphinids abundance, which was in the order of hundreds of animals. These results suggested that abundance could vary spatially with higher numbers of animals in continental shelf break environments, which coincide with the high habitat suitability values found in these environments. Besides, there were differences in the abundance and species composition between surveys. Although, more animals were estimated during the summer surveys (August), temporal trends were not analyzed due to the lack of data (only two years of surveys). Moreover, the distribution pattern of delphinids in the southwestern GOM was similar to that reported for the northern GOM, and those reported previously in the same region, and resembled by the prediction of the habitat suitability models.

This study expanded the knowledge about cetaceans in the GOM's Mexican waters and the results are deemed largely useful for ecological studies, as well as management and conservation planning. However, it is necessary to keep working and economically invest in the Mexican research capability to increase the amount, range, scope and quality of the information about cetaceans. Thus it will be likely to obtained abundance estimates for each species that distribute in southwestern GOM, which will serve as complement to the estimates made in the northern GOM, and therefore have a population analysis at the ecosystem level. Moreover, it will be possible to detect seasonal changes in both abundance and distribution, which were not accomplished in this thesis. To this end, it is essential to establish large-scale and long-term transboundary research and monitoring program for cetaceans that include aerial and ship surveys and other alternative methods, such as acoustic monitoring, biopsy sampling, and telemetry. This will allow it to evaluate potential impacts of human activities on cetacean populations of the GOM.

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Appendix 1

Table 10. Database of historical records of cetacean sightings in Mexican waters of the Gulf of Mexico. Records for common bottlenose dolphins are not included.

Specie	Longitude	Latitude	Year	Group size	Source	Reference
Balaenoptera physalus	-92.48	21.50	1997	1	Thesis	Ortega-Ortiz (2002)
Megaptera novaeangliae	-96.05	20.87	1995	1	Abstract	Ortega-Ortiz et al. (1998)
Physeter macrocephalus	-94.05	22.19	1952	1	Thesis	Lowery (1974) cited by Ortega-Ortiz (2002)
Physeter macrocephalus	-96.65	23.20	1980	3	Scientific paper	Collum & Fritts (1985)
Physeter macrocephalus	-96.72	23.13	1980	4	Scientific paper	Collum & Fritts (1985)
Physeter macrocephalus	-93.98	20.97	1983	3	Technical report	Urbán & Aguayo (1983)
Physeter macrocephalus	-93.18	20.95	1983	1	Technical report	Urbán & Aguayo (1983)
Physeter macrocephalus	-94.07	21.02	1991	3	Scientific paper	Jefferson & Lynn (1994)
Physeter macrocephalus	-96.57	22.58	1991	3	Scientific paper	Jefferson & Lynn (1994)
Physeter macrocephalus	-96.58	22.78	1991	3	Scientific paper	Jefferson & Lynn (1994)
Physeter macrocephalus	-96.60	23.02	1991	2	Scientific paper	Jefferson & Lynn (1994)
Physeter macrocephalus	-96.80	22.68	1995	1	Abstract	Ortega-Ortiz et al. (1998)
Physeter macrocephalus	-94.53	19.78	1995	1	Abstract	Ortega-Ortiz et al. (1998)
Physeter macrocephalus	-94.27	19.43	1995	1	Abstract	Ortega-Ortiz et al. (1998)
Physeter macrocephalus	-94.60	19.03	1995	1	Abstract	Ortega-Ortiz et al. (1998)
Physeter macrocephalus	-96.73	21.32	1995	2	Abstract	Ortega-Ortiz et al. (1998)
Physeter macrocephalus	-95.70	19.82	1995	3	Abstract	Ortega-Ortiz et al. (1998)
Physeter macrocephalus	-95.88	19.67	1995	3	Abstract	Ortega-Ortiz et al. (1998)
Physeter macrocephalus	-94.85	19.23	1995	2	Abstract	Ortega-Ortiz et al. (1998)
Physeter macrocephalus	-95.57	19.80	1995	3	Abstract	Ortega-Ortiz et al. (1998)
Physeter macrocephalus	-96.37	20.43	1995	3	Abstract	Ortega-Ortiz et al. (1998)
Physeter macrocephalus	-96.35	20.43	1995	1	Abstract	Ortega-Ortiz et al. (1998)
Physeter macrocephalus	-96.87	21.97	1995	2	Abstract	Ortega-Ortiz et al. (1998)
Physeter macrocephalus	-91.53	21.05	1995	5	Abstract	Ortega-Ortiz et al. (1998)
Physeter macrocephalus	-96.13	21.60	1995	1	Abstract	Ortega-Ortiz et al. (1998)
Physeter macrocephalus	-93.99	20.50	1997	2	Thesis	Ortega-Ortiz (2002)
Physeter macrocephalus	-94.65	19.30	1998	1	Thesis	Ortega-Ortiz (2002)
Physeter macrocephalus	-93.71	21.15	1998	1	Thesis	Ortega-Ortiz (2002)
Physeter macrocephalus	NA	NA	NA	NA	Abstract	Antochiw-Alonzo & Manzano-Kantún (2004)
Physeter macrocephalus	-95.82	19.54	2015	3		CIGoM (2018)

Specie	Longitude	Latitude	Year	Group size	Source	Reference
Kogia sima	NA	NA	NA	NA	Abstract	Antochiw-Alonzo & Manzano-Kantún (2004)
Orcinus orca	-92.17	20	1978	10	Scientific paper	O'Sullivan & Mullin (1997)
Orcinus orca	-94.12	19	1995	6	Abstract	Ortega-Ortiz et al. (1998)
Pseudorca crassidens	-87.23	21.75	1986	3	Technical report	Zacarías et al. (1987)
Pseudorca crassidens	-91.05	19.40	1987	4	Abstract	Fuentes-Allen & Aguayo-Lobo (1992)
Pseudorca crassidens	-94.18	20.55	1995	4	Abstract	Ortega-Ortiz et al. (1998)
Pseudorca crassidens	-95.33	20.58	1995	NA	Abstract	Ortega-Ortiz et al. (1998)
Pseudorca crassidens	-95.55	20.95	2008	50	Scientific paper	Vázquez-Castán et al. (2009)
Feresa attenuata	-90.02	21.17	2013	13	Scientific paper	Díaz-Gamboa (2015)
Globicephala macrorhynchus	-94.17	19.08	1954	30	Scientific paper	Caldwell (1955)
Globicephala macrorhynchus	-94.48	18.54	1970	1	Thesis	Lowery (1974) cited by Ortega-Ortiz (2002)
Globicephala macrorhynchus	-95.50	20.98	1984	7	Technical report	López-Sánchez et al. (1984)
Globicephala macrorhynchus	-93.73	19.60	1984	10	Technical report	Padilla et al. (1985)
Globicephala macrorhynchus	-96.70	20.88	1984	6	Technical report	Padilla et al. (1985)
Globicephala macrorhynchus	-95.23	19.03	1984	16	Technical report	Sánchez et al. (1985)
Globicephala macrorhynchus	-90.02	23.40	1987	15	Abstract	Fuentes-Allen & Aguayo-Lobo (1992)
Globicephala macrorhynchus	-96.48	22.13	1991	25	Scientific paper	Jefferson & Lynn (1994)
Globicephala macrorhynchus	-95.05	18.90	1995	3	Abstract	Ortega-Ortiz et al. (1998)
Globicephala macrorhynchus	-95.28	18.98	1995	20	Abstract	Ortega-Ortiz et al. (1998)
Globicephala macrorhynchus	-89.52	23.65	1995	10	Abstract	Ortega-Ortiz et al. (1998)
Globicephala macrorhynchus	-93.85	18.95	1995	20	Abstract	Ortega-Ortiz et al. (1998)
Globicephala macrorhynchus	-96.12	20.57	1995	15	Abstract	Ortega-Ortiz et al. (1998)
Globicephala macrorhynchus	-94.02	19.05	1995	2	Abstract	Ortega-Ortiz et al. (1998)
Globicephala macrorhynchus	-94.33	19.90	1995	20	Abstract	Ortega-Ortiz et al. (1998)
Globicephala macrorhynchus	-95.25	18.95	1995	5	Abstract	Ortega-Ortiz et al. (1998)
Globicephala macrorhynchus	-92.43	19.80	1995	2	Abstract	Ortega-Ortiz et al. (1998)
Globicephala macrorhynchus	-94.83	18.67	1995	6	Abstract	Ortega-Ortiz et al. (1998)
Globicephala macrorhynchus	-94.95	18.90	1995	5	Abstract	Ortega-Ortiz et al. (1998)
Globicephala macrorhynchus	-96.67	21.08	1995	6	Abstract	Ortega-Ortiz et al. (1998)
Globicephala macrorhynchus	-94.62	18.85	1995	4	Abstract	Ortega-Ortiz et al. (1998)
Globicephala macrorhynchus	-94.63	18.87	1995	8	Abstract	Ortega-Ortiz et al. (1998)
Globicephala macrorhynchus	-96.03	20.08	1995	3	Abstract	Ortega-Ortiz et al. (1998)
Globicephala macrorhynchus	-92.68	21.72	1995	2	Abstract	Ortega-Ortiz et al. (1998)
Globicephala macrorhynchus	-95.85	20.42	1995	1	Abstract	Ortega-Ortiz et al. (1998)

Specie	**Longitude**	**Latitude**	**Year**	**Group size**	**Source**	**Reference**
Globicephala macrorhynchus	-95.32	19.12	1995	NA	Abstract	Ortega-Ortiz et al. (1998)
Globicephala macrorhynchus	-94.18	20.55	1995	NA	Abstract	Ortega-Ortiz et al. (1998)
Globicephala macrorhynchus	-95.08	19.07	1995	10	Abstract	Ortega-Ortiz et al. (1998)
Globicephala macrorhynchus	-92.52	19.80	1995	30	Abstract	Ortega-Ortiz et al. (1998)
Globicephala macrorhynchus	-95.27	20.63	1995	30	Abstract	Ortega-Ortiz et al. (1998)
Globicephala macrorhynchus	-90.40	20.85	1995	4	Abstract	Ortega-Ortiz et al. (1998)
Globicephala macrorhynchus	NA	NA	NA	NA	Abstract	Patiño-Valencia et al. (2000)
Globicephala macrorhynchus	NA	NA	NA	NA	Abstract	Patiño-Valencia et al. (2000)
Globicephala macrorhynchus	NA	NA	NA	NA	Abstract	Patiño-Valencia et al. (2000)
Globicephala macrorhynchus	NA	NA	NA	NA	Abstract	Patiño-Valencia et al. (2000)
Globicephala macrorhynchus	NA	NA	NA	NA	Abstract	Patiño-Valencia et al. (2000)
Globicephala macrorhynchus	NA	NA	NA	NA	Abstract	Patiño-Valencia et al. (2000)
Globicephala macrorhynchus	NA	NA	NA	NA	Abstract	Patiño-Valencia et al. (2000)
Globicephala macrorhynchus	NA	NA	NA	NA	Abstract	Patiño-Valencia et al. (2000)
Globicephala macrorhynchus	NA	NA	NA	NA	Abstract	Patiño-Valencia et al. (2000)
Globicephala macrorhynchus	NA	NA	NA	NA	Abstract	Patiño-Valencia et al. (2000)
Globicephala macrorhynchus	-94.50	18.78	1998	18	Thesis	Ortega-Ortiz (2002)
Globicephala macrorhynchus	-93.64	21.15	1998	14	Thesis	Ortega-Ortiz (2002)
Globicephala macrorhynchus	-94.45	21.12	1998	2	Thesis	Ortega-Ortiz (2002)
Globicephala macrorhynchus	-95.69	19.76	2006	NA	Scientific paper	Galindo et al. (2009)
Globicephala macrorhynchus	-96.05	19.40	2015	9		CIGoM (2018)
Globicephala macrorhynchus	-95.20	19.00	2015	24		CIGoM (2018)
Globicephala macrorhynchus	-95.25	18.98	2016	7		CIGoM (2018)
Globicephala macrorhynchus	-95.25	19.07	2016	1		CIGoM (2018)
Globicephala macrorhynchus			2018	50		CIGoM (2018)
Steno bredanensis	-92.72	21.05	1983	4	Technical report	Urbán & Aguayo (1983)
Steno bredanensis	-95.02	20.52	1987	7	Abstract	Fuentes-Allen & Aguayo-Lobo (1992)
Steno bredanensis	-93.18	18.45	1992	20	Thesis	Delgado-Estrella (1994)
Steno bredanensis	-93.07	18.44	1992	65	Thesis	Delgado-Estrella (1994)
Steno bredanensis	-93.16	18.46	1992	25	Thesis	Delgado-Estrella (1994)
Steno bredanensis	-96.03	23.78	1992	NA	Thesis	Jefferson (1995)
Steno bredanensis	-92.92	18.48	1993	35	Thesis	López-Hernández (1997)
Steno bredanensis	-92.92	21.18	1995	30	Abstract	Ortega-Ortiz et al. (1998)
Steno bredanensis	-92.55	21.23	1995	30	Abstract	Ortega-Ortiz et al. (1998)

Specie	Longitude	Latitude	Year	Group size	Source	Reference
Steno bredanensis	-95.68	19.02	1995	3	Abstract	Ortega-Ortiz et al. (1998)
Steno bredanensis	-97.17	20.97	1995	22	Abstract	Ortega-Ortiz et al. (1998)
Steno bredanensis	-91.59	22.00	1997	27	Thesis	Ortega-Ortiz (2002)
Steno bredanensis	-95.54	19.43	1998	9	Thesis	Ortega-Ortiz (2002)
Steno bredanensis	-93.07	18.42	1999	60	Thesis	Delgado-Estrella (2002)
Steno bredanensis	-93.22	18.42	1999	20	Thesis	Delgado-Estrella (2002)
Steno bredanensis	-93.37	18.42	1999	10	Thesis	Delgado-Estrella (2002)
Steno bredanensis	NA	NA	NA	NA	Abstract	Antochiw-Alonzo & Manzano-Kantún (2004)
Steno bredanensis	NA	NA	NA	NA	Abstract	Antochiw-Alonzo & Manzano-Kantún (2004)
Steno bredanensis	NA	NA	NA	NA	Scientific paper	Galindo et al. (2009)
Steno bredanensis	-94.85	19.10	2008	15	Scientific paper	Vázquez-Castán et al. (2009)
Steno bredanensis	NA	NA	NA	NA	Abstract	Sauz-Sánchez & Díaz Gamboa (2016)
Steno bredanensis	NA	NA	NA	NA	Abstract	Sauz-Sánchez & Díaz Gamboa (2016)
Steno bredanensis	NA	NA	NA	NA	Abstract	Sauz-Sánchez & Díaz Gamboa (2016)
Steno bredanensis	NA	NA	NA	NA	Abstract	Sauz-Sánchez & Díaz Gamboa (2016)
Steno bredanensis	NA	NA	NA	NA	Abstract	Sauz-Sánchez & Díaz Gamboa (2016)
Steno bredanensis	NA	NA	NA	NA	Abstract	Sauz-Sánchez & Díaz Gamboa (2016)
Steno bredanensis	NA	NA	NA	NA	Abstract	Sauz-Sánchez & Díaz Gamboa (2016)
Steno bredanensis	NA	NA	NA	NA	Abstract	Sauz-Sánchez & Díaz Gamboa (2016)
Steno bredanensis	NA	NA	NA	NA	Abstract	Sauz-Sánchez & Díaz Gamboa (2016)
Steno bredanensis	NA	NA	NA	NA	Abstract	Sauz-Sánchez & Díaz Gamboa (2016)
Steno bredanensis	NA	NA	NA	NA	Abstract	Sauz-Sánchez & Díaz Gamboa (2016)
Steno bredanensis	NA	NA	NA	NA	Abstract	Sauz-Sánchez & Díaz Gamboa (2016)
Steno bredanensis	NA	NA	NA	NA	Abstract	Sauz-Sánchez & Díaz Gamboa (2016)
Steno bredanensis	NA	NA	NA	NA	Abstract	Sauz-Sánchez & Díaz Gamboa (2016)
Steno bredanensis	NA	NA	NA	NA	Abstract	Sauz-Sánchez & Díaz Gamboa (2016)
Steno bredanensis	NA	NA	NA	NA	Abstract	Sauz-Sánchez & Díaz Gamboa (2016)
Steno bredanensis	NA	NA	NA	NA	Abstract	Sauz-Sánchez & Díaz Gamboa (2016)
Steno bredanensis	NA	NA	2018	NA		CIGoM (2018)
Steno bredanensis	NA	NA	2018	NA		CIGoM (2018)
Grampus griseus	-95.98	19.50	2015	40		CIGoM (2018)
Grampus griseus	-95.41	18.92	2016	4		CIGoM (2018)
Grampus griseus	-95.08	18.77	2016	3		CIGoM (2018)
Lagenodelphis hosei	-96.15	25.23	1992	NA	Scientific paper	Leatherwood et al. (1993)

Specie	**Longitude**	**Latitude**	**Year**	**Group size**	**Source**	**Reference**
Stenella attenuata	-91.08	21.73	1954	3	Scientific paper	Caldwell (1955)
Stenella attenuata	-90.98	21.65	1954	2	Scientific paper	Caldwell (1955)
Stenella attenuata	-91.55	21.12	1954	1	Scientific paper	Caldwell (1955)
Stenella attenuata	-93.50	18.72	1954	3	Scientific paper	Caldwell (1955)
Stenella attenuata	-92.57	19.80	1983	60	Technical report	Salinas-Zacarías et al. (1984)
Stenella attenuata	-90.75	21.28	1983	2	Technical report	Salinas-Zacarías et al. (1984)
Stenella attenuata	-87.52	22.27	1985	1	Abstract	Fuentes-Allen & Aguayo-Lobo (1992)
Stenella attenuata	-87.95	23.62	1985	6	Abstract	Fuentes-Allen & Aguayo-Lobo (1992)
Stenella attenuata	-87.62	22.20	1985	3	Abstract	Fuentes-Allen & Aguayo-Lobo (1992)
Stenella attenuata	-89.17	22.17	1986	6	Abstract	Fuentes-Allen & Aguayo-Lobo (1992)
Stenella attenuata	-89.15	22.07	1986	5	Abstract	Fuentes-Allen & Aguayo-Lobo (1992)
Stenella attenuata	-89.22	22.07	1986	8	Abstract	Fuentes-Allen & Aguayo-Lobo (1992)
Stenella attenuata	-89.18	22.10	1986	7	Abstract	Fuentes-Allen & Aguayo-Lobo (1992)
Stenella attenuata	-87.82	22.27	1986	4	Abstract	Fuentes-Allen & Aguayo-Lobo (1992)
Stenella attenuata	-86.73	21.92	1986	15	Abstract	Fuentes-Allen & Aguayo-Lobo (1992)
Stenella attenuata	-87.68	21.75	1986	5	Technical report	Zacarías et al. (1987)
Stenella attenuata	-87.33	22.08	1988	4	Abstract	Fuentes-Allen & Aguayo-Lobo (1992)
Stenella attenuata	-87.28	22.02	1988	2	Abstract	Fuentes-Allen & Aguayo-Lobo (1992)
Stenella attenuata	-91.85	19.92	1988	20	Abstract	Fuentes-Allen & Aguayo-Lobo (1992)
Stenella attenuata	-96.57	22.68	1991	60	Scientific paper	Jefferson & Lynn (1994)
Stenella attenuata	-92.08	22.05	1995	30	Abstract	Ortega-Ortiz et al. (1998)
Stenella attenuata	-91.68	21.85	1995	4	Abstract	Ortega-Ortiz et al. (1998)
Stenella attenuata	-92.10	21.05	1995	20	Abstract	Ortega-Ortiz et al. (1998)
Stenella attenuata	-89.20	24.00	1995	50	Abstract	Ortega-Ortiz et al. (1998)
Stenella attenuata	-92.22	20.87	1995	1	Abstract	Ortega-Ortiz et al. (1998)
Stenella attenuata	-91.38	21.05	1995	6	Abstract	Ortega-Ortiz et al. (1998)
Stenella attenuata	-93.37	21.27	1995	5	Abstract	Ortega-Ortiz et al. (1998)
Stenella attenuata	-94.38	21.63	1995	40	Abstract	Ortega-Ortiz et al. (1998)
Stenella attenuata	-95.88	19.55	1995	30	Abstract	Ortega-Ortiz et al. (1998)
Stenella attenuata	-92.12	20.27	1995	2	Abstract	Ortega-Ortiz et al. (1998)
Stenella attenuata	-89.65	23.50	1995	10	Abstract	Ortega-Ortiz et al. (1998)
Stenella attenuata	-89.88	23.30	1995	30	Abstract	Ortega-Ortiz et al. (1998)
Stenella attenuata	-91.72	21.87	1995	6	Abstract	Ortega-Ortiz et al. (1998)
Stenella attenuata	-92.05	22.03	1995	8	Abstract	Ortega-Ortiz et al. (1998)

Specie	**Longitude**	**Latitude**	**Year**	**Group size**	**Source**	**Reference**
Stenella attenuata	-96.30	19.93	1995	5	Abstract	Ortega-Ortiz et al. (1998)
Stenella attenuata	-93.85	18.95	1995	10	Abstract	Ortega-Ortiz et al. (1998)
Stenella attenuata	-93.05	19.42	1995	10	Abstract	Ortega-Ortiz et al. (1998)
Stenella attenuata	-96.75	21.37	1995	50	Abstract	Ortega-Ortiz et al. (1998)
Stenella attenuata	-97.05	21.50	1995	15	Abstract	Ortega-Ortiz et al. (1998)
Stenella attenuata	-97.10	20.77	1995	5	Abstract	Ortega-Ortiz et al. (1998)
Stenella attenuata	-95.45	18.95	1995	15	Abstract	Ortega-Ortiz et al. (1998)
Stenella attenuata	-96.45	20.13	1995	10	Abstract	Ortega-Ortiz et al. (1998)
Stenella attenuata	-96.75	20.60	1995	5	Abstract	Ortega-Ortiz et al. (1998)
Stenella attenuata	-92.40	20.85	1995	8	Abstract	Ortega-Ortiz et al. (1998)
Stenella attenuata	-95.73	20.12	1995	6	Abstract	Ortega-Ortiz et al. (1998)
Stenella attenuata	-96.70	20.65	1995	7	Abstract	Ortega-Ortiz et al. (1998)
Stenella attenuata	-95.85	20.45	1995	12	Abstract	Ortega-Ortiz et al. (1998)
Stenella attenuata	-96.13	20.58	1995	140	Abstract	Ortega-Ortiz et al. (1998)
Stenella attenuata	-96.42	21.32	1995	6	Abstract	Ortega-Ortiz et al. (1998)
Stenella attenuata	-95.37	19.33	1995	20	Abstract	Ortega-Ortiz et al. (1998)
Stenella attenuata	-92.02	21.40	1995	6	Abstract	Ortega-Ortiz et al. (1998)
Stenella attenuata	-96.38	20.52	1995	30	Abstract	Ortega-Ortiz et al. (1998)
Stenella attenuata	-95.82	19.88	1995	50	Abstract	Ortega-Ortiz et al. (1998)
Stenella attenuata	-94.33	18.62	1995	8	Abstract	Ortega-Ortiz et al. (1998)
Stenella attenuata	-93.07	19.57	1995	4	Abstract	Ortega-Ortiz et al. (1998)
Stenella attenuata	-92.13	20.25	1995	15	Abstract	Ortega-Ortiz et al. (1998)
Stenella attenuata	-95.80	21.13	1995	33	Abstract	Ortega-Ortiz et al. (1998)
Stenella attenuata	-92.05	20.17	1995	2	Abstract	Ortega-Ortiz et al. (1998)
Stenella attenuata	-97.50	23.42	1995	15	Abstract	Ortega-Ortiz et al. (1998)
Stenella attenuata	-92.43	20.87	1995	3	Abstract	Ortega-Ortiz et al. (1998)
Stenella attenuata	-94.57	21.00	1995	50	Abstract	Ortega-Ortiz et al. (1998)
Stenella attenuata	-90.20	23.73	1995	3	Abstract	Ortega-Ortiz et al. (1998)
Stenella attenuata	-97.27	24.00	1995	18	Abstract	Ortega-Ortiz et al. (1998)
Stenella attenuata	-90.12	22.32	1995	2	Abstract	Ortega-Ortiz et al. (1998)
Stenella attenuata	-90.03	22.38	1995	12	Abstract	Ortega-Ortiz et al. (1998)
Stenella attenuata	-92.35	21.42	1995	2	Abstract	Ortega-Ortiz et al. (1998)
Stenella attenuata	-91.99	22.00	1997	2	Thesis	Ortega-Ortiz (2002)
Stenella attenuata	-94.65	18.91	1998	22	Thesis	Ortega-Ortiz (2002)

Specie	Longitude	Latitude	Year	Group size	Source	Reference
Stenella attenuata	-94.46	18.75	1998	5	Thesis	Ortega-Ortiz (2002)
Stenella attenuata	NA	NA	NA	NA	Abstract	Holst et al. (2006)
Stenella attenuata	NA	NA	NA	NA	Abstract	Antochiw-Alonzo & Manzano-Kantún (2004)
Stenella attenuata	NA	NA	NA	NA	Abstract	Antochiw-Alonzo & Manzano-Kantún (2004)
Stenella attenuata	-96.88	22.75	2005	NA	Scientific paper	Galindo et al. (2009)
Stenella clymene	-95.30	22.75	2008	30	Scientific paper	Vázquez-Castán et al. (2009)
Stenella longirostris	-92.18	21.13	1983	5	Technical report	Urbán & Aguayo (1983)
Stenella longirostris	-89.75	21.38	1983	20	Technical report	Urbán & Aguayo (1983)
Stenella longirostris	-91.42	22.12	1983	5	Technical report	Urbán & Aguayo (1983)
Stenella longirostris	NA	NA	1983	3	Technical report	Salinas-Zacarías et al. (1984)
Stenella longirostris	-94.54	18.74	1984	3	Technical report	Padilla et al. (1985)
Stenella longirostris	NA	NA	NA	NA	Abstract	Antochiw-Alonzo & Manzano-Kantún (2004)
Stenella longirostris	NA	NA	NA	NA	Abstract	Antochiw-Alonzo & Manzano-Kantún (2004)
Stenella longirostris	NA	NA	NA	NA	Abstract	Antochiw-Alonzo & Manzano-Kantún (2004)
Stenella longirostris	-87.15	21.40	2005	2	Scientific paper	Galindo et al. (2009)
Stenella frontalis	-97.58	23.17	1979	NA	Thesis	Bergey (1979) cited by Ortega-Ortiz (2002)
Stenella frontalis	-97.37	23.45	1979	NA	Thesis	Bergey (1979) cited by Ortega-Ortiz (2002)
Stenella frontalis	-97.38	24.80	1979	NA	Thesis	Bergey (1979) cited by Ortega-Ortiz (2002)
Stenella frontalis	-87.20	23.28	1979	NA	Thesis	Rademacher (1991)
Stenella frontalis	-91.53	22.28	1983	40	Technical report	Urbán & Aguayo (1983)
Stenella frontalis	-91.77	22.10	1983	3	Technical report	Urbán & Aguayo (1983)
Stenella frontalis	-92.32	20.97	1983	12	Technical report	Urbán & Aguayo (1983)
Stenella frontalis	-92.45	21.08	1983	14	Technical report	Urbán & Aguayo (1983)
Stenella frontalis	-92.18	20.93	1983	10	Technical report	Urbán & Aguayo (1983)
Stenella frontalis	-92.28	21.05	1983	4	Technical report	Urbán & Aguayo (1983)
Stenella frontalis	-91.93	21.18	1983	6	Technical report	Urbán & Aguayo (1983)
Stenella frontalis	-91.80	21.22	1983	4	Technical report	Urbán & Aguayo (1983)
Stenella frontalis	-91.68	21.27	1983	9	Technical report	Urbán & Aguayo (1983)
Stenella frontalis	-91.30	21.05	1983	6	Technical report	Urbán & Aguayo (1983)
Stenella frontalis	-90.48	22.35	1983	30	Technical report	Urbán & Aguayo (1983)
Stenella frontalis	-86.75	22.33	1983	7	Technical report	Urbán & Aguayo (1983)
Stenella frontalis	-88.38	23.27	1983	20	Technical report	Urbán & Aguayo (1983)
Stenella frontalis	-88.38	23.73	1983	15	Technical report	Urbán & Aguayo (1983)
Stenella frontalis	-89.68	22.23	1983	30	Technical report	Urbán & Aguayo (1983)

Specie	**Longitude**	**Latitude**	**Year**	**Group size**	**Source**	**Reference**
Stenella frontalis	-89.85	22.45	1983	3	Technical report	Salinas-Zacarías et al. (1984)
Stenella frontalis	-90.52	21.53	1983	3	Technical report	Salinas-Zacarías et al. (1984)
Stenella frontalis	-91.28	21.08	1983	1	Technical report	Salinas-Zacarías et al. (1984)
Stenella frontalis	-91.45	21.37	1983	5	Technical report	Salinas-Zacarías et al. (1984)
Stenella frontalis	-90.73	21.48	1983	2	Technical report	Salinas-Zacarías et al. (1984)
Stenella frontalis	-94.53	18.40	1984	5	Technical report	Padilla et al. (1985)
Stenella frontalis	-93.68	18.47	1984	2	Technical report	Padilla et al. (1985)
Stenella frontalis	-96.90	20.98	1984	15	Technical report	Padilla et al. (1985)
Stenella frontalis	-94.67	18.70	1984	10	Technical report	Sánchez et al. (1985)
Stenella frontalis	-94.75	18.73	1984	20	Technical report	Sánchez et al. (1985)
Stenella frontalis	-93.88	18.65	1984	6	Technical report	Sánchez et al. (1985)
Stenella frontalis	-93.82	18.68	1984	10	Technical report	Sánchez et al. (1985)
Stenella frontalis	-93.82	18.53	1984	2	Technical report	Sánchez et al. (1985)
Stenella frontalis	-93.17	18.62	1984	2	Technical report	Sánchez et al. (1985)
Stenella frontalis	-92.83	18.78	1984	3	Technical report	Sánchez et al. (1985)
Stenella frontalis	-92.82	18.58	1984	2	Technical report	Sánchez et al. (1985)
Stenella frontalis	-92.72	18.67	1984	1	Technical report	Sánchez et al. (1985)
Stenella frontalis	-92.72	18.67	1984	10	Technical report	Sánchez et al. (1985)
Stenella frontalis	-92.67	18.68	1984	8	Technical report	Sánchez et al. (1985)
Stenella frontalis	-87.43	21.88	1986	2	Abstract	Fuentes-Allen & Aguayo-Lobo (1992)
Stenella frontalis	-88.00	22.13	1985	30	Abstract	Fuentes-Allen & Aguayo-Lobo (1992)
Stenella frontalis	-91.25	20.18	1985	15	Abstract	Fuentes-Allen & Aguayo-Lobo (1992)
Stenella frontalis	-91.38	20.12	1985	3	Abstract	Fuentes-Allen & Aguayo-Lobo (1992)
Stenella frontalis	-91.15	20.52	1985	3	Abstract	Fuentes-Allen & Aguayo-Lobo (1992)
Stenella frontalis	-91.83	20.75	1985	2	Abstract	Fuentes-Allen & Aguayo-Lobo (1992)
Stenella frontalis	-89.17	21.90	1985	2	Abstract	Fuentes-Allen & Aguayo-Lobo (1992)
Stenella frontalis	-89.17	22.07	1985	4	Abstract	Fuentes-Allen & Aguayo-Lobo (1992)
Stenella frontalis	-89.17	22.38	1985	10	Abstract	Fuentes-Allen & Aguayo-Lobo (1992)
Stenella frontalis	-87.83	22.17	1985	12	Abstract	Fuentes-Allen & Aguayo-Lobo (1992)
Stenella frontalis	-87.20	23.45	1985	20	Abstract	Fuentes-Allen & Aguayo-Lobo (1992)
Stenella frontalis	-88.00	23.78	1985	6	Abstract	Fuentes-Allen & Aguayo-Lobo (1992)
Stenella frontalis	-87.95	23.60	1985	12	Abstract	Fuentes-Allen & Aguayo-Lobo (1992)
Stenella frontalis	-95.63	18.92	1986	4	Abstract	Fuentes-Allen & Aguayo-Lobo (1986)
Stenella frontalis	-97.28	20.88	1986	6	Technical report	Zacarías et al. (1987)

Specie	**Longitude**	**Latitude**	**Year**	**Group size**	**Source**	**Reference**
Stenella frontalis	-96.88	21.00	1986	2	Technical report	Zacarías et al. (1987)
Stenella frontalis	-91.78	21.00	1986	2	Technical report	Zacarías et al. (1987)
Stenella frontalis	-91.78	21.00	1986	10	Technical report	Zacarías et al. (1987)
Stenella frontalis	-91.95	21.03	1986	2	Technical report	Zacarías et al. (1987)
Stenella frontalis	-92.03	21.05	1986	6	Technical report	Zacarías et al. (1987)
Stenella frontalis	-92.18	21.07	1986	1	Technical report	Zacarías et al. (1987)
Stenella frontalis	-92.23	21.08	1986	6	Technical report	Zacarías et al. (1987)
Stenella frontalis	-91.22	21.48	1987	4	Abstract	Fuentes-Allen & Aguayo-Lobo (1992)
Stenella frontalis	-91.02	21.88	1987	2	Abstract	Fuentes-Allen & Aguayo-Lobo (1992)
Stenella frontalis	-87.83	23.13	1987	11	Abstract	Fuentes-Allen & Aguayo-Lobo (1992)
Stenella frontalis	-86.80	21.90	1987	7	Abstract	Fuentes-Allen & Aguayo-Lobo (1992)
Stenella frontalis	-87.67	21.95	1987	6	Abstract	Fuentes-Allen & Aguayo-Lobo (1992)
Stenella frontalis	-88.08	23.43	1988	12	Abstract	Fuentes-Allen & Aguayo-Lobo (1992)
Stenella frontalis	-87.90	23.17	1988	4	Abstract	Fuentes-Allen & Aguayo-Lobo (1992)
Stenella frontalis	-87.90	23.07	1988	13	Abstract	Fuentes-Allen & Aguayo-Lobo (1992)
Stenella frontalis	-87.90	23.02	1988	12	Abstract	Fuentes-Allen & Aguayo-Lobo (1992)
Stenella frontalis	-87.62	21.85	1988	22	Abstract	Fuentes-Allen & Aguayo-Lobo (1992)
Stenella frontalis	-91.50	20.25	1989	NA	Scientific paper	Delgado-Estrella (1997)
Stenella frontalis	-91.92	20.50	1989	NA	Scientific paper	Delgado-Estrella (1997)
Stenella frontalis	-91.74	19.23	1989	NA	Scientific paper	Delgado-Estrella (1997)
Stenella frontalis	-91.74	20.30	1989	NA	Scientific paper	Delgado-Estrella (1997)
Stenella frontalis	-91.89	20.54	1989	NA	Scientific paper	Delgado-Estrella (1997)
Stenella frontalis	-91.67	19.18	1989	NA	Scientific paper	Delgado-Estrella (1997)
Stenella frontalis	-91.39	20.07	1989	NA	Scientific paper	Delgado-Estrella (1997)
Stenella frontalis	-91.57	19.82	1989	NA	Scientific paper	Delgado-Estrella (1997)
Stenella frontalis	-91.76	20.24	1989	NA	Scientific paper	Delgado-Estrella (1997)
Stenella frontalis	-91.87	20.45	1989	NA	Scientific paper	Delgado-Estrella (1997)
Stenella frontalis	-91.93	20.54	1989	NA	Scientific paper	Delgado-Estrella (1997)
Stenella frontalis	-91.89	19.24	1989	NA	Scientific paper	Delgado-Estrella (1997)
Stenella frontalis	-91.46	19.56	1989	NA	Scientific paper	Delgado-Estrella (1997)
Stenella frontalis	-91.46	20.31	1989	NA	Scientific paper	Delgado-Estrella (1997)
Stenella frontalis	-91.46	20.36	1989	NA	Scientific paper	Delgado-Estrella (1997)
Stenella frontalis	-91.64	19.90	1989	NA	Scientific paper	Delgado-Estrella (1997)
Stenella frontalis	-91.80	19.24	1989	NA	Scientific paper	Delgado-Estrella (1997)

Specie	Longitude	Latitude	Year	Group size	Source	Reference
Stenella frontalis	-91.80	19.20	1989	NA	Scientific paper	Delgado-Estrella (1997)
Stenella frontalis	-91.55	19.54	1989	NA	Scientific paper	Delgado-Estrella (1997)
Stenella frontalis	-91.91	20.49	1989	NA	Scientific paper	Delgado-Estrella (1997)
Stenella frontalis	-91.70	20.26	1989	NA	Scientific paper	Delgado-Estrella (1997)
Stenella frontalis	-91.53	19.90	1989	NA	Scientific paper	Delgado-Estrella (1997)
Stenella frontalis	-91.87	20.30	1989	NA	Scientific paper	Delgado-Estrella (1997)
Stenella frontalis	-91.83	20.49	1989	NA	Scientific paper	Delgado-Estrella (1997)
Stenella frontalis	-91.43	20.26	1989	NA	Scientific paper	Delgado-Estrella (1997)
Stenella frontalis	-91.59	19.59	1989	NA	Scientific paper	Delgado-Estrella (1997)
Stenella frontalis	-97.40	24.00	1990	NA	Thesis	Jefferson (1995)
Stenella frontalis	-96.22	19.78	1990	NA	Thesis	Jefferson (1995)
Stenella frontalis	-94.00	18.65	1990	NA	Thesis	Jefferson (1995)
Stenella frontalis	-94.07	18.67	1990	NA	Thesis	Jefferson (1995)
Stenella frontalis	-94.77	18.75	1990	NA	Thesis	Jefferson (1995)
Stenella frontalis	-93.00	19.00	1990	NA	Thesis	Jefferson (1995)
Stenella frontalis	-92.93	19.12	1990	NA	Thesis	Jefferson (1995)
Stenella frontalis	-92.00	20.60	1990	NA	Thesis	Jefferson (1995)
Stenella frontalis	-91.50	21.50	1990	NA	Thesis	Jefferson (1995)
Stenella frontalis	-90.50	21.95	1990	NA	Thesis	Jefferson (1995)
Stenella frontalis	-90.52	22.40	1990	NA	Thesis	Jefferson (1995)
Stenella frontalis	-90.02	22.62	1990	NA	Thesis	Jefferson (1995)
Stenella frontalis	-89.52	22.00	1990	NA	Thesis	Jefferson (1995)
Stenella frontalis	-87.15	22.17	1990	NA	Thesis	Jefferson (1995)
Stenella frontalis	-87.50	22.10	1990	NA	Thesis	Jefferson (1995)
Stenella frontalis	-96.05	19.20	1995	2	Abstract	Ortega-Ortiz et al. (1998)
Stenella frontalis	-92.15	21.58	1995	2	Abstract	Ortega-Ortiz et al. (1998)
Stenella frontalis	-89.82	22.37	1995	3	Abstract	Ortega-Ortiz et al. (1998)
Stenella frontalis	-88.22	24.12	1995	5	Abstract	Ortega-Ortiz et al. (1998)
Stenella frontalis	-88.27	24.15	1995	5	Abstract	Ortega-Ortiz et al. (1998)
Stenella frontalis	-87.42	25.08	1995	20	Abstract	Ortega-Ortiz et al. (1998)
Stenella frontalis	-92.42	20.85	1995	6	Abstract	Ortega-Ortiz et al. (1998)
Stenella frontalis	-92.16	22.00	1997	4	Thesis	Ortega-Ortiz (2002)
Stenella frontalis	-92.01	22.00	1997	22	Thesis	Ortega-Ortiz (2002)
Stenella frontalis	-91.61	22.00	1997	3	Thesis	Ortega-Ortiz (2002)

Specie	Longitude	Latitude	Year	Group size	Source	Reference
Stenella frontalis	-90.57	21.51	1997	3	Thesis	Ortega-Ortiz (2002)
Stenella frontalis	-92.09	21.50	1997	6	Thesis	Ortega-Ortiz (2002)
Stenella frontalis	-92.36	21.50	1997	11	Thesis	Ortega-Ortiz (2002)
Stenella frontalis	-91.63	21.06	1997	2	Thesis	Ortega-Ortiz (2002)
Stenella frontalis	-92.47	19.50	1997	22	Thesis	Ortega-Ortiz (2002)
Stenella frontalis	-92.57	19.50	1997	12	Thesis	Ortega-Ortiz (2002)
Stenella frontalis	-94.33	18.65	1998	76	Thesis	Ortega-Ortiz (2002)
Stenella frontalis	-93.75	18.81	1998	11	Thesis	Ortega-Ortiz (2002)
Stenella frontalis	-96.93	21.01	1999	17	Thesis	Ortega-Ortiz (2002)
Stenella frontalis	-93.33	18.42	1999	30	Thesis	Delgado-Estrella (2002)
Stenella frontalis	-90.36	21.01	1999	3	Thesis	Delgado-Estrella (2002)
Stenella frontalis	NA	NA	NA	NA	Abstract	Antochiw-Alonzo & Manzano-Kantún (2004)
Stenella frontalis	NA	NA	NA	NA	Abstract	Antochiw-Alonzo & Manzano-Kantún (2004)
Stenella frontalis	NA	NA	NA	NA	Abstract	Antochiw-Alonzo & Manzano-Kantún (2004)
Stenella frontalis	NA	NA	NA	NA	Abstract	Antochiw-Alonzo & Manzano-Kantún (2004)
Stenella frontalis	NA	NA	NA	NA	Abstract	Antochiw-Alonzo & Manzano-Kantún (2004)
Stenella frontalis	NA	NA	NA	NA	Abstract	Antochiw-Alonzo & Manzano-Kantún (2004)
Stenella frontalis	NA	NA	NA	NA	Abstract	Antochiw-Alonzo & Manzano-Kantún (2004)
Stenella frontalis	NA	NA	NA	NA	Abstract	Antochiw-Alonzo & Manzano-Kantún (2004)
Stenella frontalis	NA	NA	NA	NA	Abstract	Antochiw-Alonzo & Manzano-Kantún (2004)
Stenella frontalis	NA	NA	NA	NA	Abstract	Antochiw-Alonzo & Manzano-Kantún (2004)
Stenella frontalis	NA	NA	NA	NA	Abstract	Antochiw-Alonzo & Manzano-Kantún (2004)
Stenella frontalis	NA	NA	NA	NA	Abstract	Antochiw-Alonzo & Manzano-Kantún (2004)
Stenella frontalis	NA	NA	NA	NA	Abstract	Antochiw-Alonzo & Manzano-Kantún (2004)
Stenella frontalis	NA	NA	NA	NA	Abstract	Antochiw-Alonzo & Manzano-Kantún (2004)
Stenella frontalis	NA	NA	NA	NA	Abstract	Antochiw-Alonzo & Manzano-Kantún (2004)
Stenella frontalis	NA	NA	NA	NA	Abstract	Holst et al. (2006)
Stenella frontalis	NA	NA	NA	NA	Abstract	Holst et al. (2006)
Stenella frontalis	NA	NA	NA	NA	Abstract	Holst et al. (2006)
Stenella frontalis	NA	NA	NA	NA	Abstract	Holst et al. (2006)
Stenella frontalis	NA	NA	NA	NA	Abstract	Holst et al. (2006)
Stenella frontalis	NA	NA	NA	NA	Abstract	Holst et al. (2006)
Stenella frontalis	NA	NA	NA	NA	Abstract	Holst et al. (2006)
Stenella frontalis	-96.65	21.90	2008	14	Scientific paper	Vázquez-Castán et al. (2009)

Appendix 2

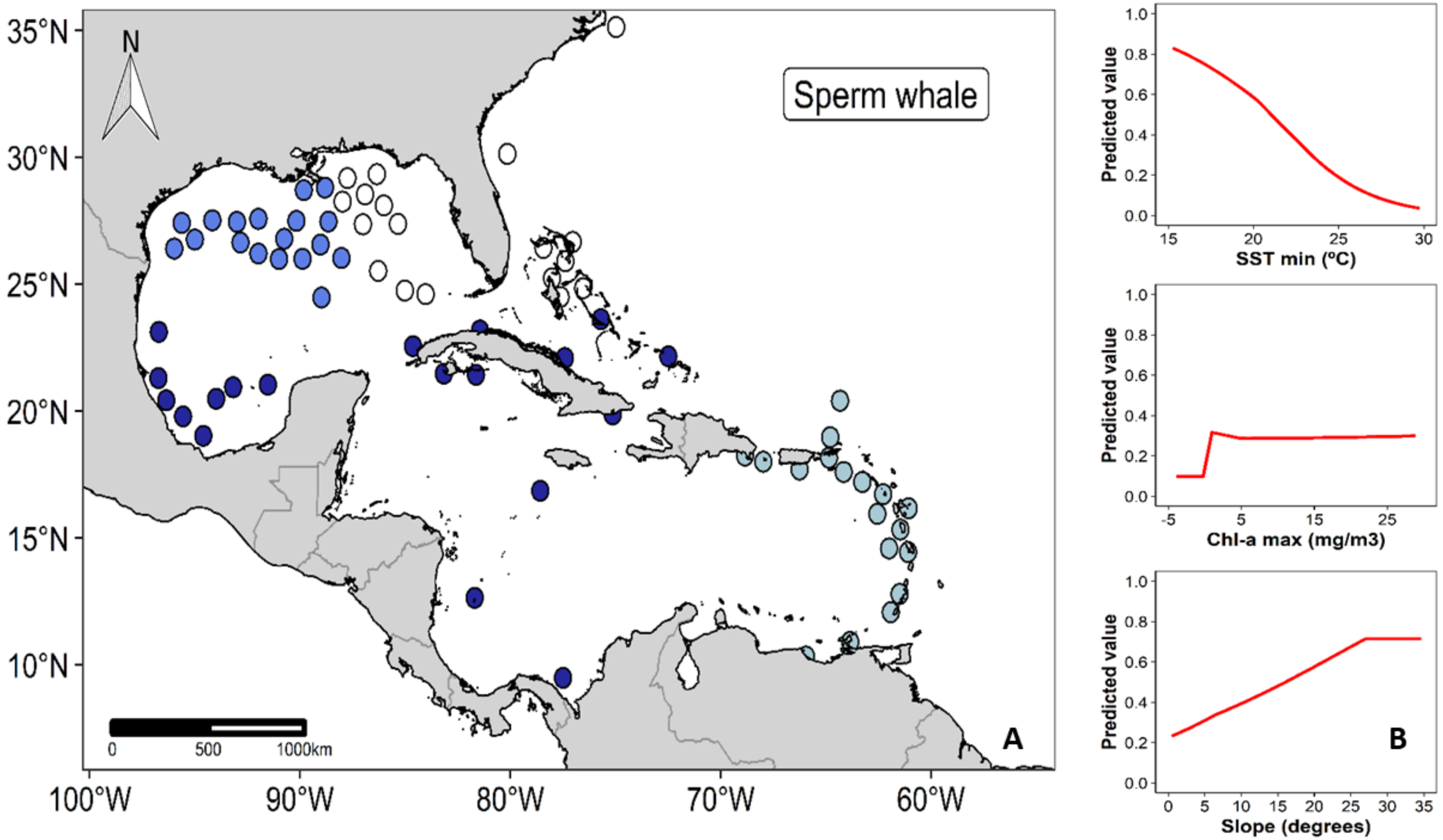

Figure 34. (A) Portioned records for evaluation and training the sperm whale model. (B) Response curves of the environmental predictors that contributed to the model.

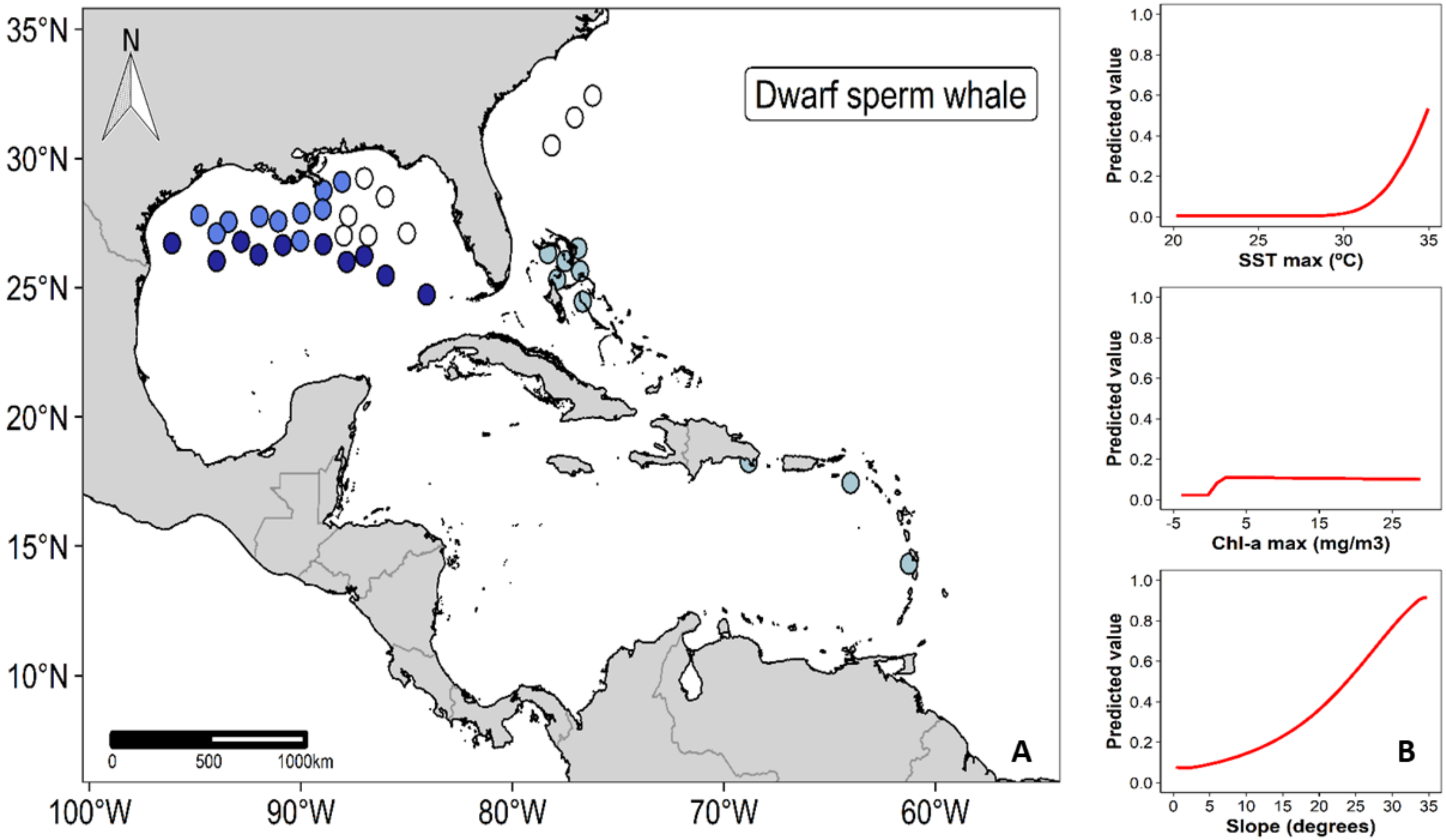

Figure 35. (A) Portioned records for evaluation and training the dwarf sperm whale model. (B) Response curves of the environmental predictors that contributed to the model.

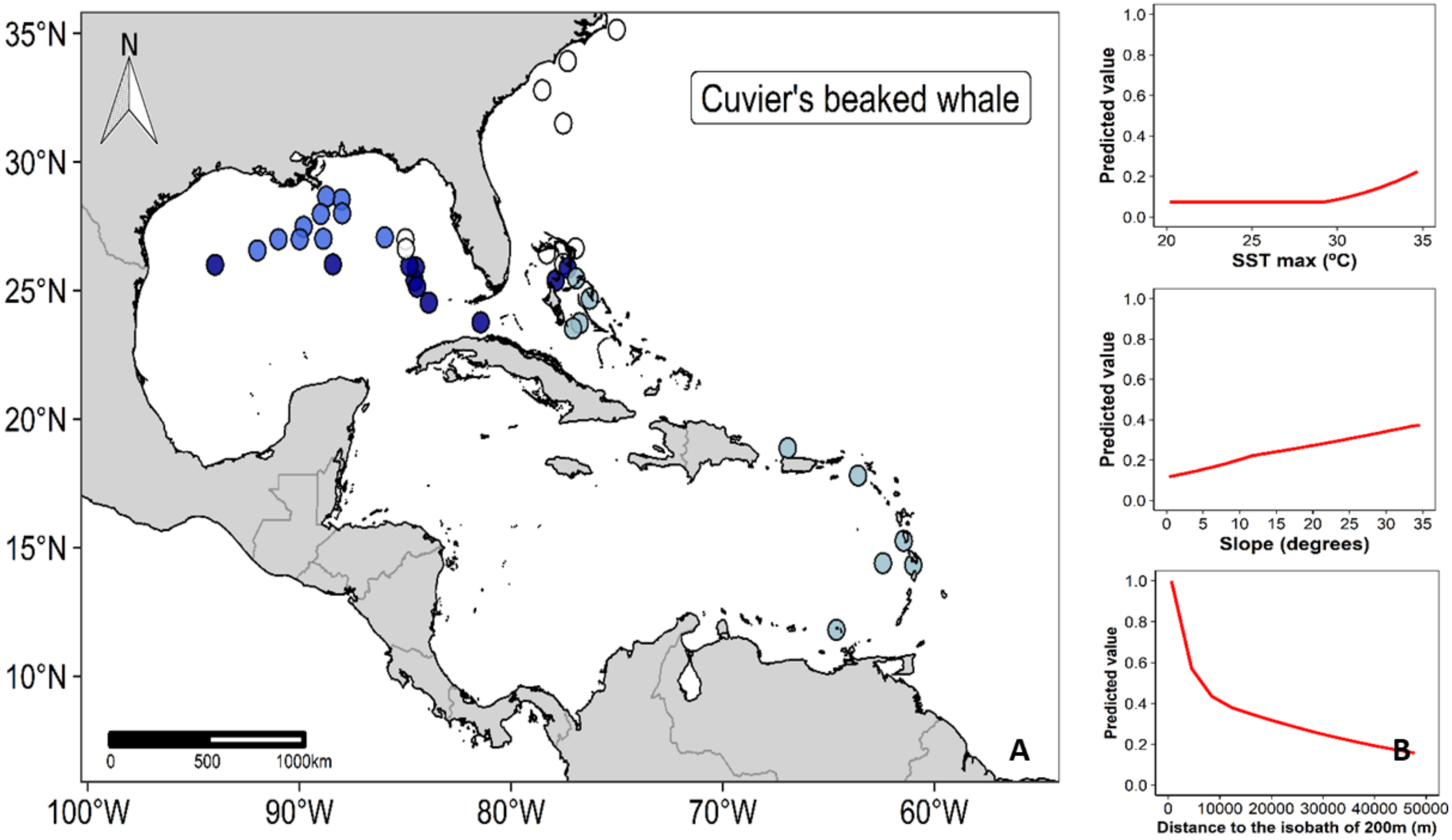

Figure 36. (A) Portioned records for evaluation and training the Cuvier's beaked whale model. (B) Response curves of the environmental predictors that contributed to the model.

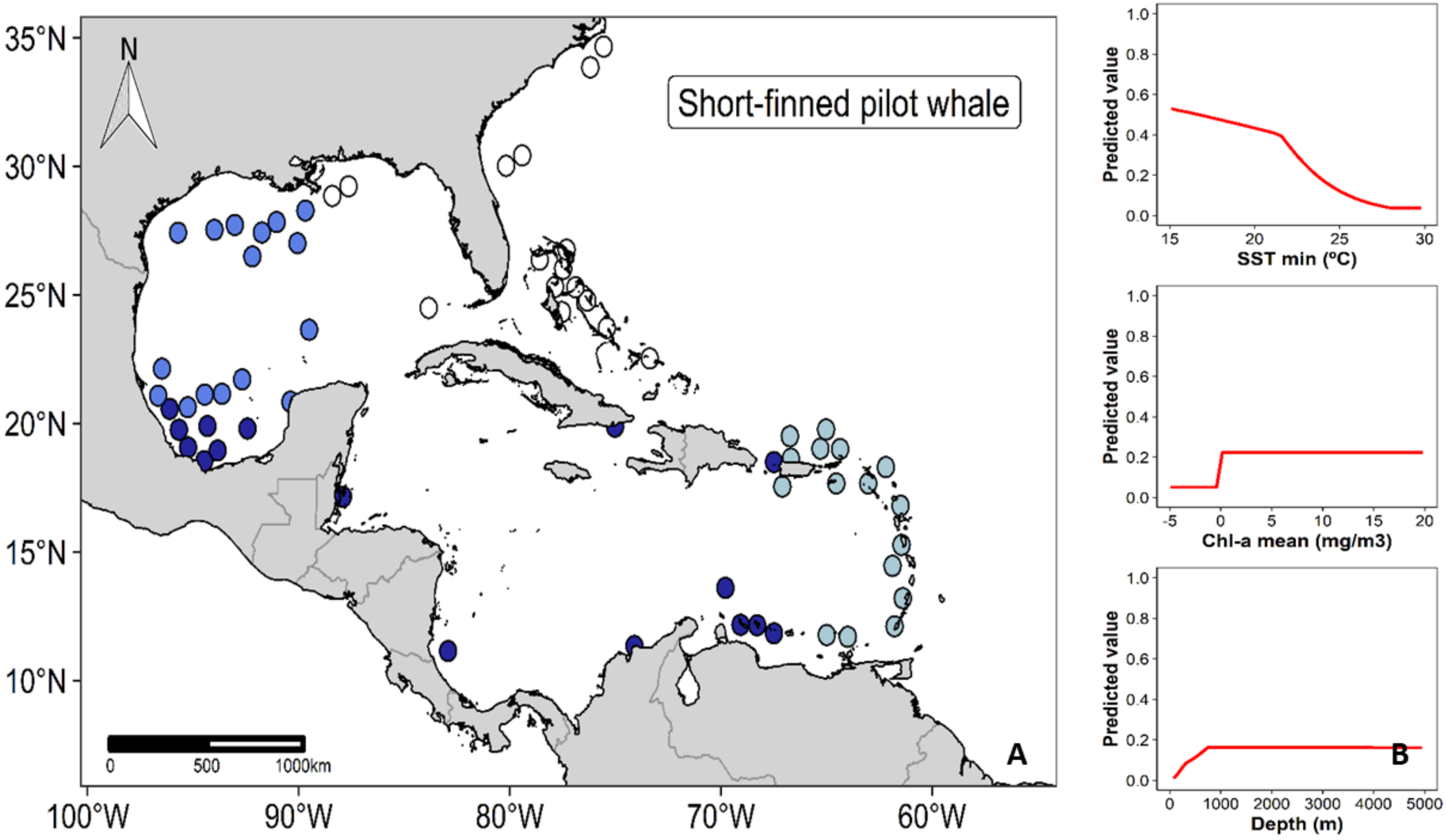

Figure 37. (A) Portioned records for evaluation and training the short-finned pilot model. (B) Response curves of the environmental predictors that contributed to the model.

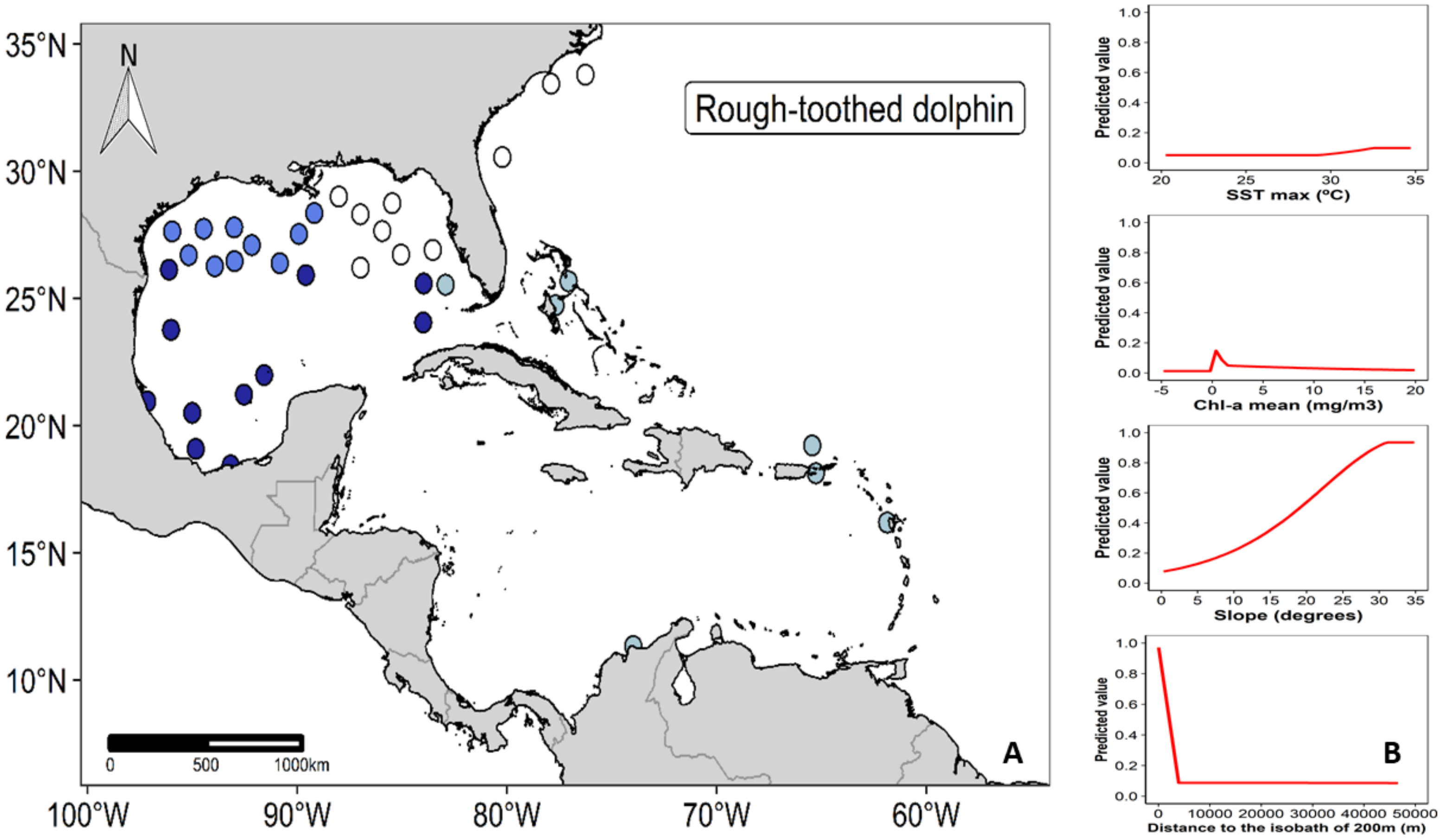

Figure 38. (A) Portioned records for evaluation and training the rough-toothed dolphin. (B) Response curves of the environmental predictors that contributed to the model.

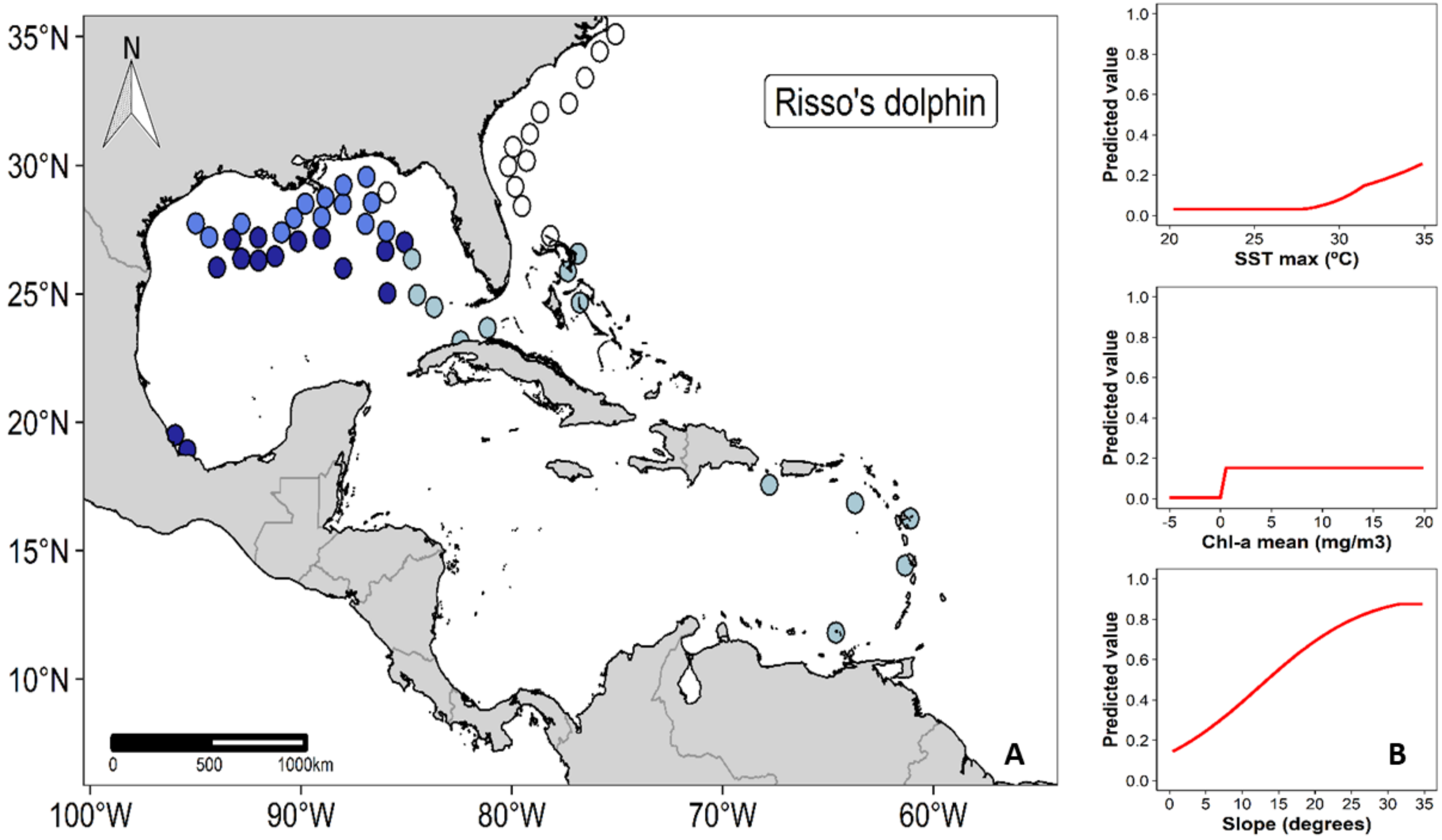

Figure 39. (A) Portioned records for evaluation and training the Risso's dolphin model. (B) Response curves of the environmental predictors that contributed to the model.

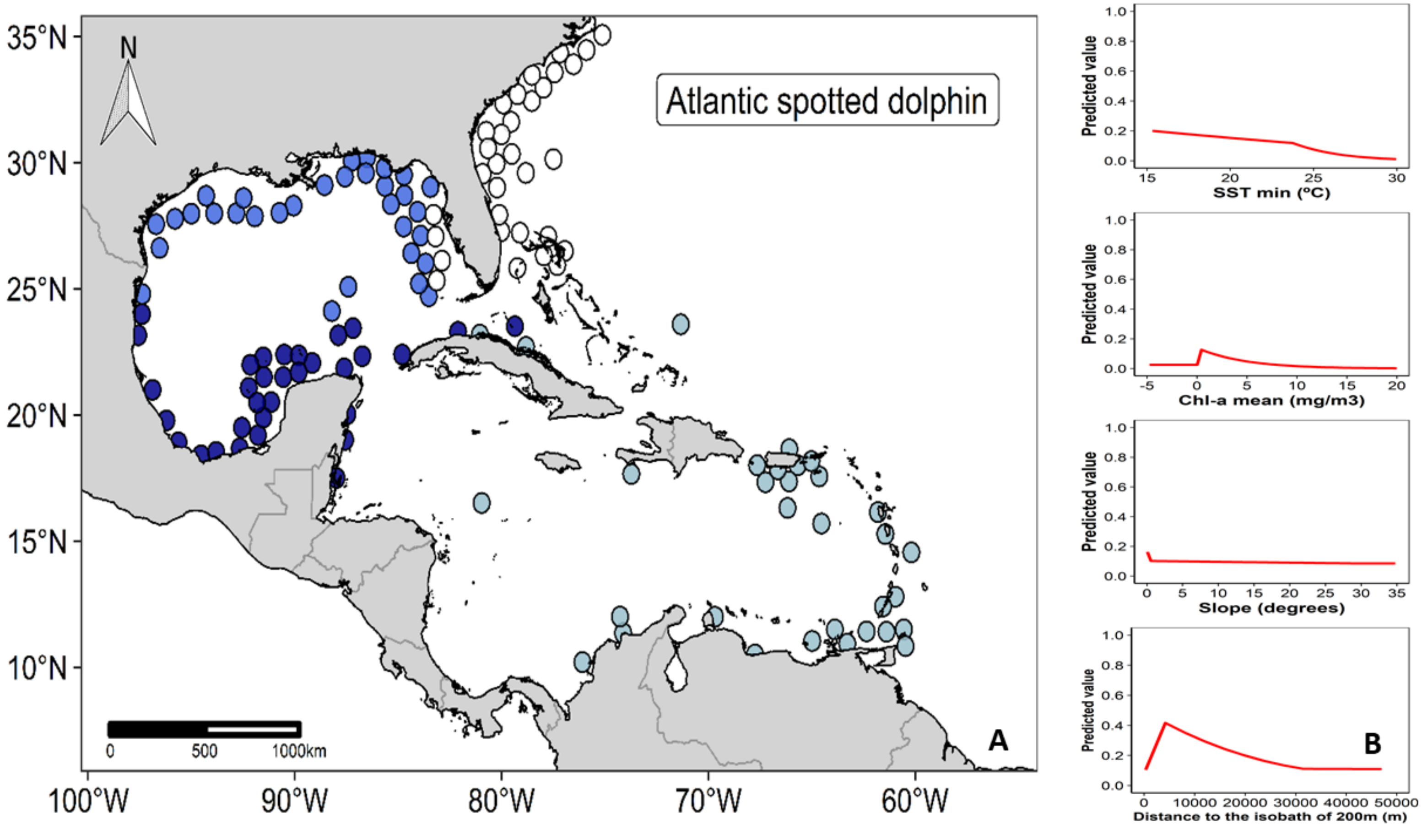

Figure 40. (A) Portioned records for evaluation and training the Atlantic spotted dolphin model. (B) Response curves of the environmental predictors that contributed to the model.

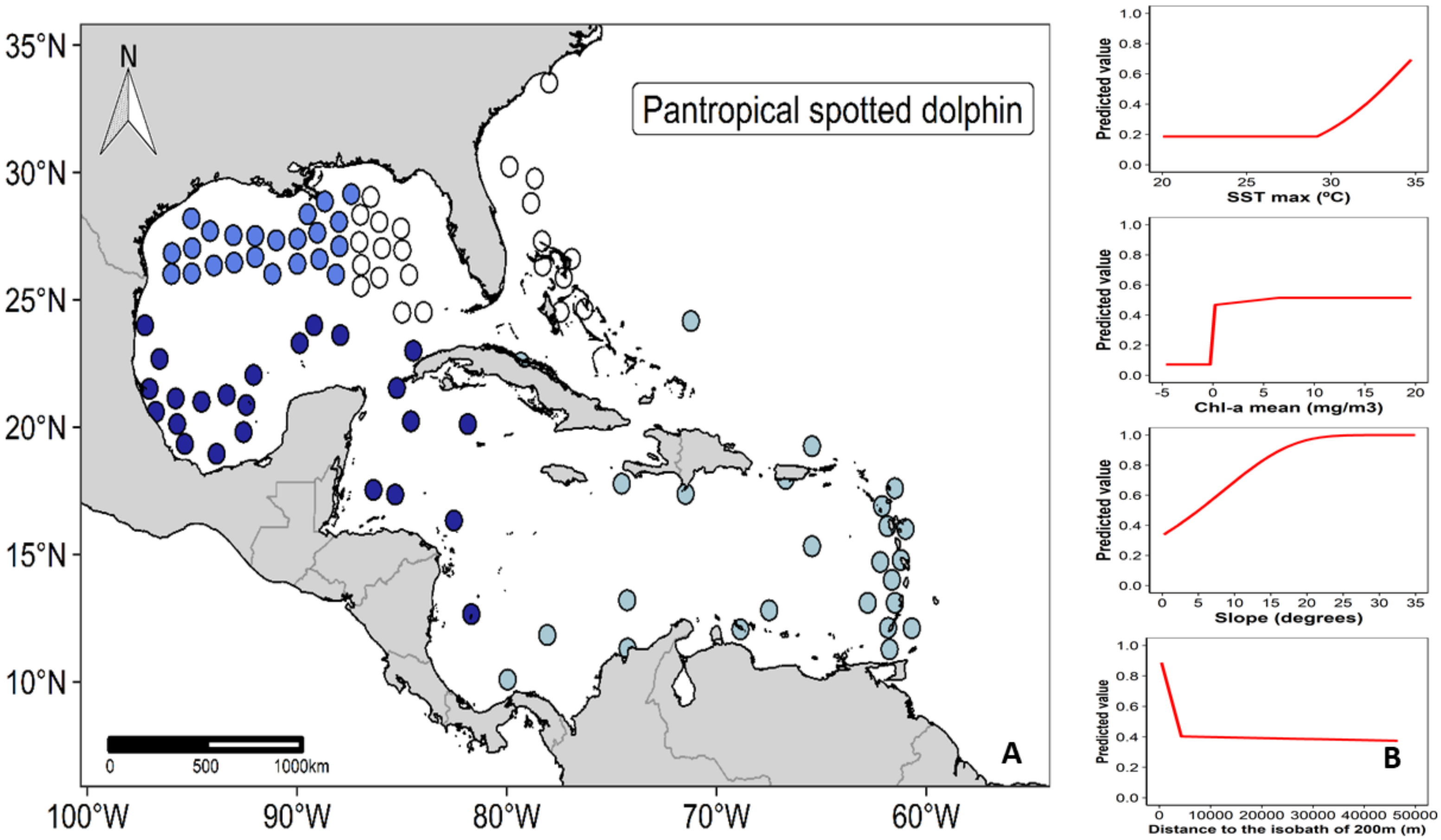

Figure 41. (A) Portioned records for evaluation and training the pantropical spotted dolphin model. (B) Response curves of the environmental predictors that contributed to the model.

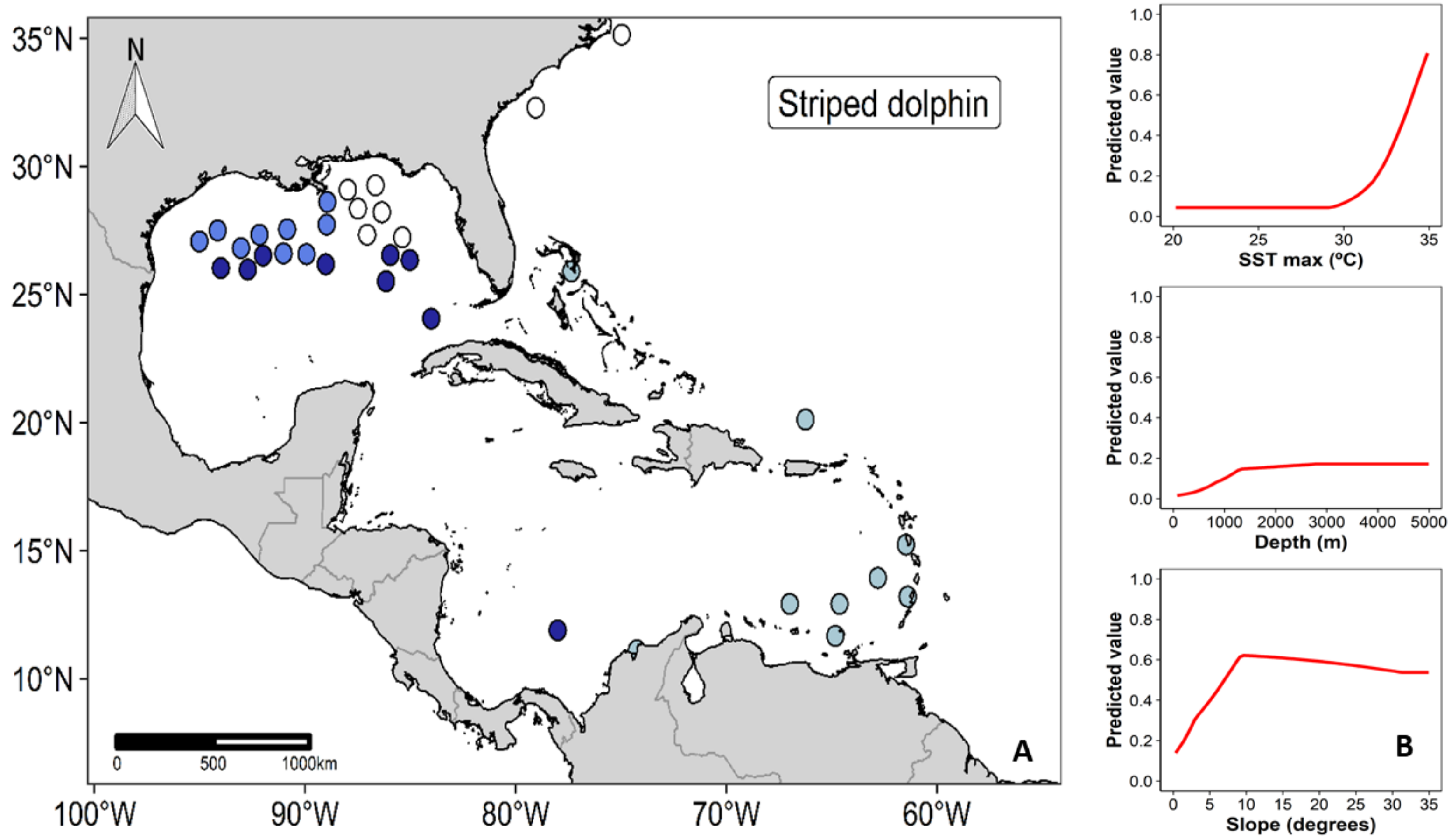

Figure 42. (A) Portioned records for evaluation and training the striped dolphin model. (B) Response curves of the environmental predictors that contributed to the model.

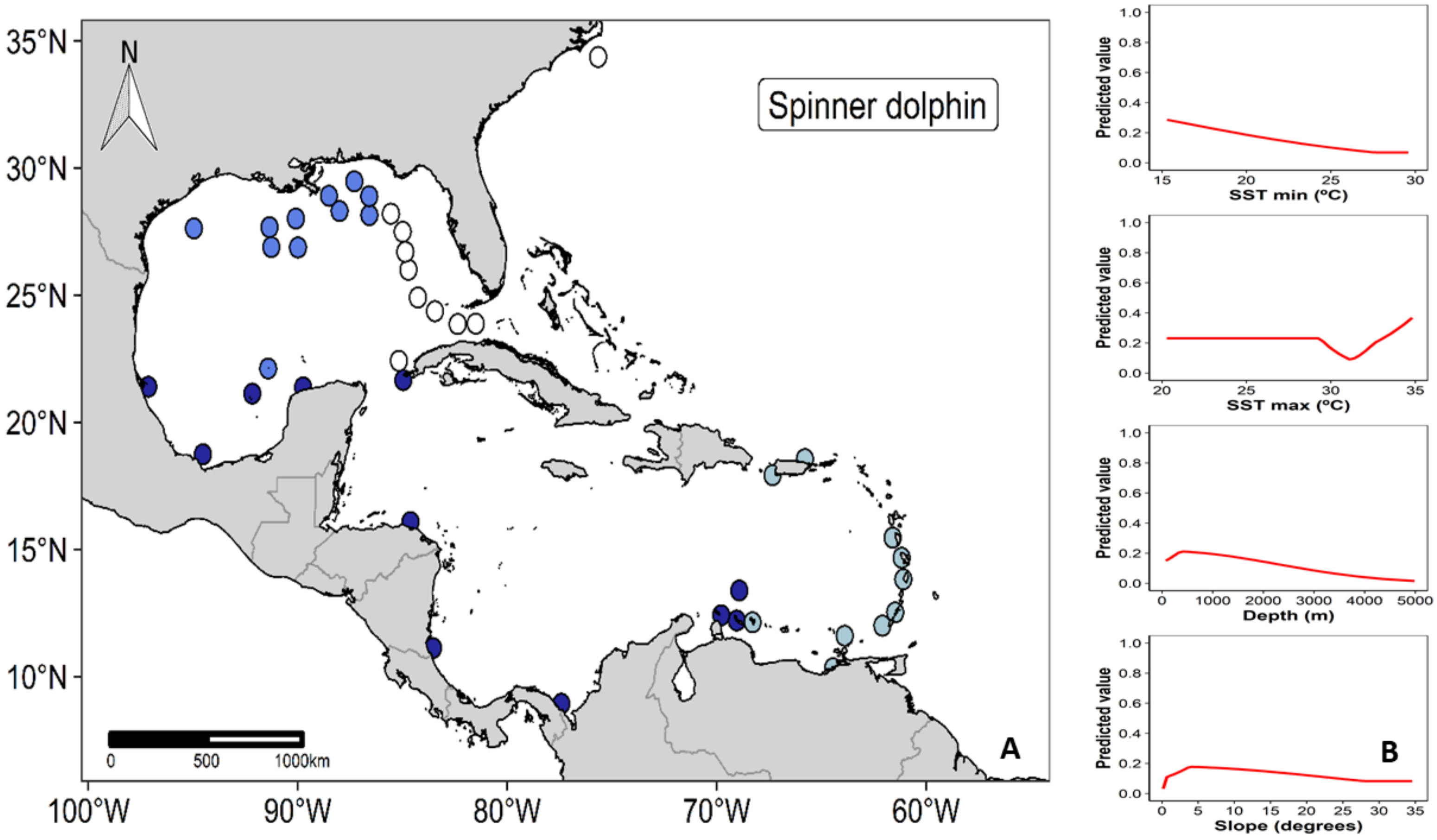

Figure 43. (A) Portioned records for evaluation and training the spinner dolphin model. (B) Response curves of the environmental predictors that contributed to the model.

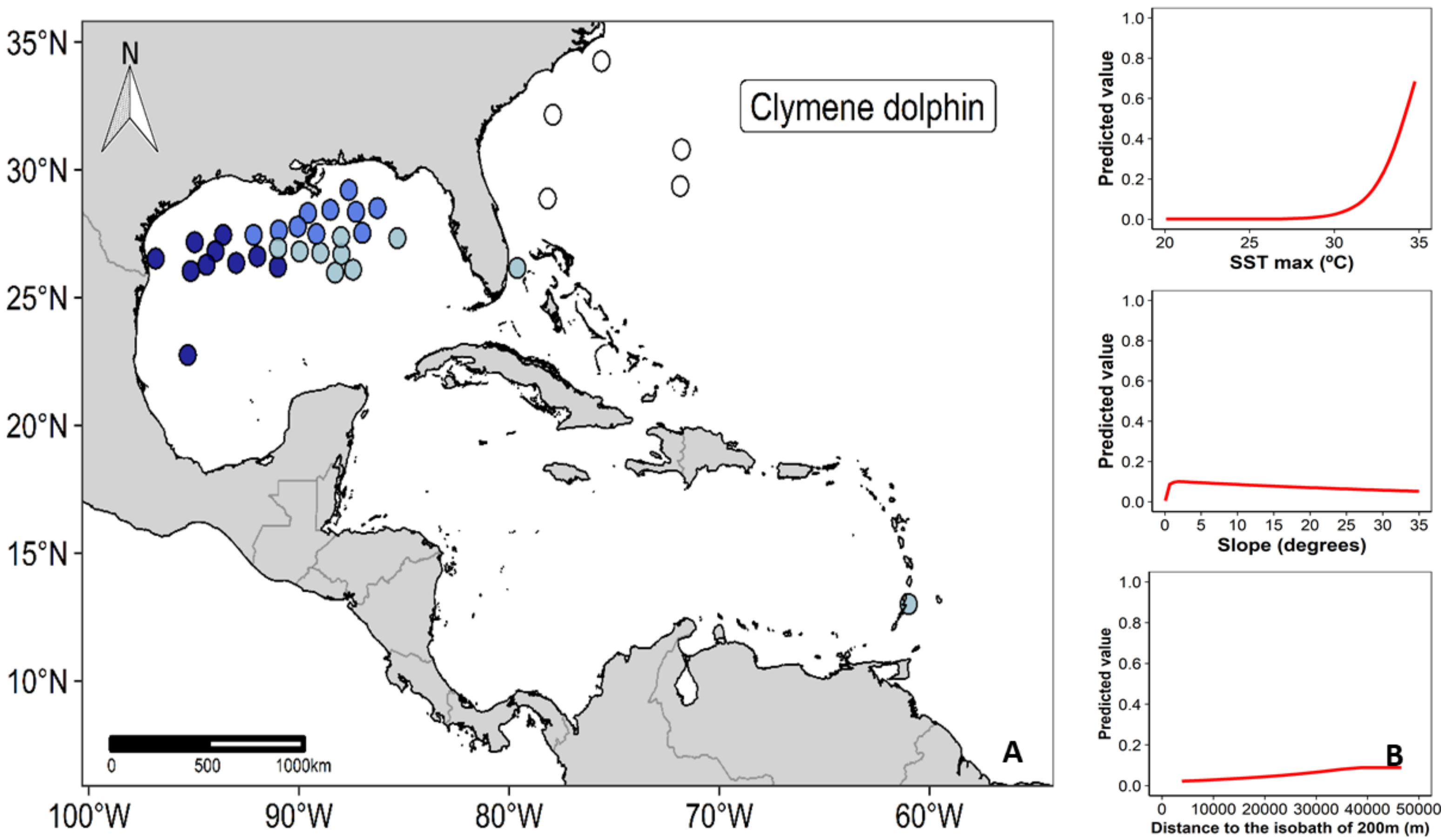

Figure 44. (A) Portioned records for evaluation and training the Clymene dolphin model. (B) Response curves of the environmental predictors that contributed to the model.

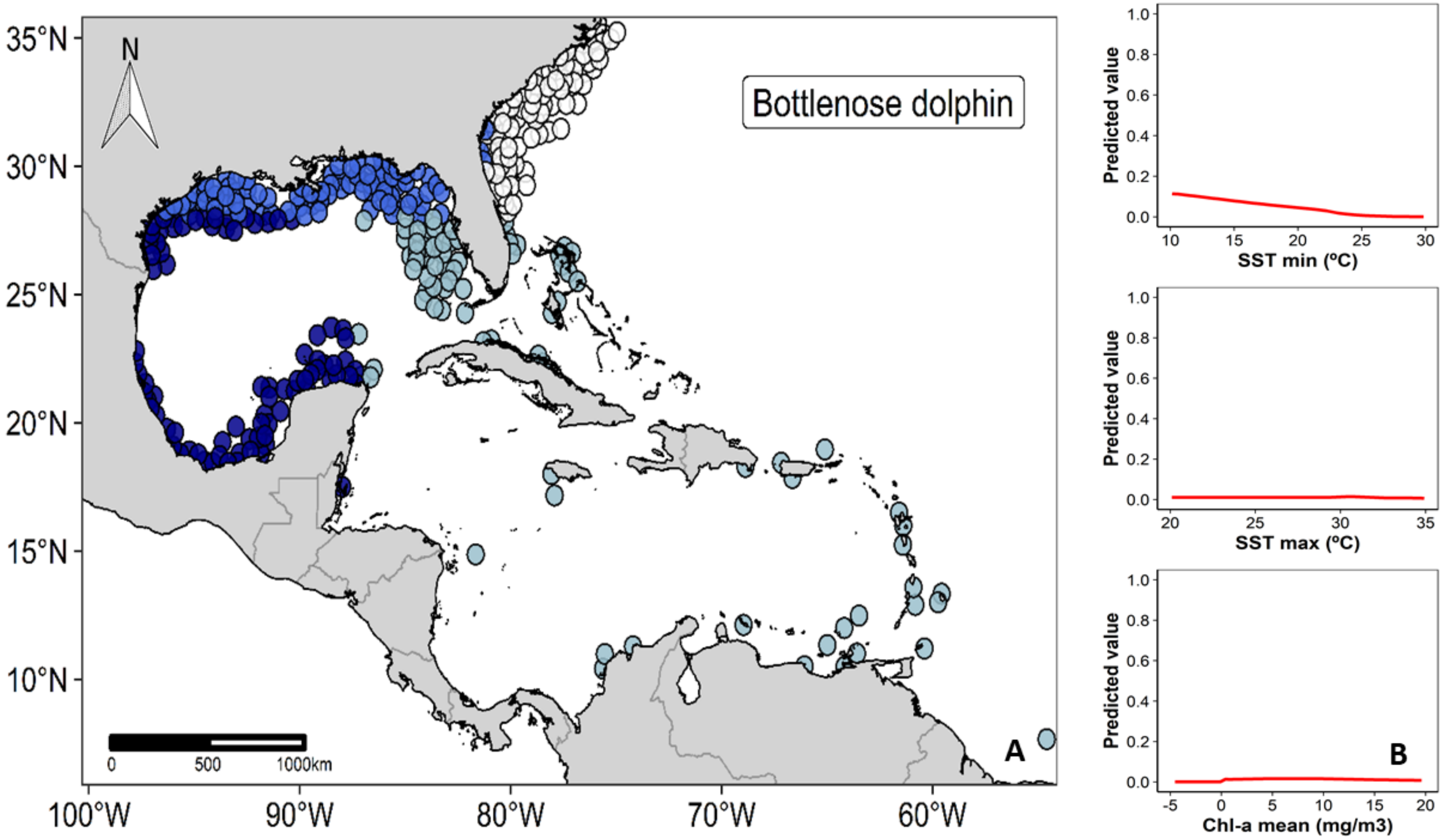

Figure 44. (A) Portioned records for evaluation and training the common bottlenose dolphin model. (B) Response curves of the environmental predictors that contributed to the model.