Habitat suitability of cetaceans in the Gulf of Mexico using an ecological niche modeling approach

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Background. The Gulf of Mexico (GOM) is a semi-enclosed sea where the waters of the United States, Mexico and Cuba converge. Al least 21 species of cetaceans inhabit it. The only mysticete (baleen whale) is found in the northeast (U.S. waters). The distribution of the 20 species of odontocetes (toothed cetaceans) is well understood in U.S. waters, but practically unknown in Mexican and Cuban waters. In this study we used sighting data from several odontocete species to construct habitat suitability maps in order to identify geographical regions suitable for high diversity throughout the GOM. **Methods.** Historical datasets of georeferenced sightings from across the GOM were used to implement the maximum entropy algorithm (MaxEnt) to model the habitat suitability of each species. Five environmental predictors were used, selected for their influence over the occurrence of cetaceans: two oceanographic predictors (sea surface temperature and chlorophyll-*a* concentration), and three bathymetric predictors (depth, slope, and distance to 200-m isobath). A spatial approach based on the habitat suitability maps was used to identify the suitable regions. **Results.** Only 12 species were modeled, which were the ones with the minimum sample size required. The models performed well, showing good discriminatory power and slight overfitting. Overall, depth, minimum sea surface temperature, and bottom slope were the most contributing predictor in the models. 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 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.

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Abstract

Background. The Gulf of Mexico (GOM) is a semi-enclosed sea where the waters of the United States, Mexico and Cuba converge. Al least 21 species of cetaceans inhabit it. The only mysticete (baleen whale) is found in the northeast (U.S. waters). The distribution of the 20 species of odontocetes (toothed cetaceans) is well understood in U.S. waters, but practically unknown in Mexican and Cuban waters. In this study we used sighting data from several odontocete species to construct habitat suitability maps in order to identify geographical regions suitable for high diversity throughout the GOM.

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38 **Conclusions.** We were able to detect four geographic regions in the GOM where a high diversity

39 of odontocetes is expected, all located on the continental slope. Although the methodology to

40 identify them (spatial overlap) is a very conservative approach, it is useful for conservation and

41 management purposes. The paucity of data did not allow all species to be modeled, which

42 highlights the importance of establishing transboundary monitoring programs.

43

44 **Keywords:** Odontocetes, species distribution, MaxEnt, segregated distribution.

45

46 **Introduction**

47 Understanding species' geographic distribution patterns and related environmental factors is a

48 central topic of population ecology (Guisan & Zimmermann, 2000). Environmental factors

49 include both abiotic conditions that influence the physiological response (e.g., temperature)

50 determined in turn by the species' adaptive responses and the interspecific interactions (e.g., prey

51 availability) (Soberón & Peterson, 2005; Peterson et al., 2011). Cetaceans are a group of fully

52 aquatic mammals whose anatomical, morphological and physiological adaptations have allowed

53 them to colonize a wide variety of aquatic habitats (Katona & Whitehead, 1988). Nevertheless,

54 their distribution is usually explained in terms of the abundance of prey, primarily controlled by

55 dynamic oceanographic conditions (e.g., sea surface temperature and mesoscale processes), as

56 well as by physiographic features (e.g., bottoms depth and slope) (Kenney et al., 1997; Forcada,

57 2018).

58   The Gulf of Mexico (GOM) is a semi-enclosed sea connected to the Atlantic Ocean and

59 Caribbean Sea. It has a 1.6 million km² surface and includes the Exclusive Economic Zones

60 (EEZ) of Mexico (which represent ~55% of the total surface of the GOM), the United States

61   (~40%), and Cuba (~5%) (De Lanza Espino & Gómez-Rojas, 2004). There are at least 21 species

62   of cetaceans that inhabit the GOM, including one mysticete, the Bryde's whale (*Balaenoptera*

63   *edeni*), which is distributed exclusively in the northeastern GOM (Soldevilla et al., 2017), and

64   20 odontocetes (Würsig, 2017).

65   The distribution of cetaceans in the northern GOM (i.e., the U.S. EEZ) has been extensively

66   studied. Based on sighting records, Maze-Foley & Mullin (2006) divided the cetaceans into two

67   communities: (1) the continental shelf community, which includes the bottlenose dolphin

68   (*Tursiops truncatus*), the Atlantic spotted dolphin (*Stenella frontalis*), and the Bryde's whale, and

69   (2) the continental slope community, which comprises the remaining species, although the

70   rough-toothed dolphin (*Steno bredanensis*) can be found in both. More recently, Roberts et al.

71   (2016) used density surface models to describe the spatial distribution of cetaceans in the

72   northern GOM. Overall, their results are consistent with those of Maze-Foley & Mullin (2006),

73   although they highlight the importance of the continental slope and submarine canyons, such as

74   the Mississippi Canyon, as areas of high density of cetaceans. In contrast, the distribution of

75   cetaceans in the southern GOM (i.e., the EEZs of Mexico and Cuba) is poorly understood. In

76   fact, only one study has covered this region, but it was conducted by extrapolating data from the

77   northern GOM (Mannocci et al., 2017).

78   Besides the ecological relevance of the GOM, it is an important economic area where fishing,

79   tourism, and the hydrocarbon industry generate billions of dollars annually (Karnauskas et al.,

80   2013), and it is a key transportation region (Shepard et al., 2013). Given its economic

81   importance, the GOM ecosystem is under increasing anthropogenic pressure, threatening

82   cetacean populations (Roberts et al., 2016). To determine the extent and impact of these hazards

83   and to optimize threat mitigation and conservation measures, it is necessary to have accurate

84 predictions of their distribution on a broader scale; that is, at the ecosystem level. However, the

85 latter is complicated given the limited data on cetaceans in the southern GOM (Ramírez-León et

86 al., 2020), but one way to achieve this is to use ecological niche models (ENM).

87   ENM are statistical tools that define the distribution of suitable habitats of a species based on

88 its ecological requirements (Peterson et al., 2011). The rationale is that the records, which are

89 discontinuous in nature, are related to environmental and/or spatial characteristics

90 (environmental predictors) to predict the suitable areas of the species in unsampled locations;

91 therefore, the maps produced are spatially continuous, showing the regions where greater

92 aggregation is expected (Franklin, 2010). Thus, areas of high habitat suitability are defined as

93 those sites were ideal (or favorable) conditions exist for a species' long-term subsistence

94 (Peterson & Soberón, 2012).

95   Our objective was to estimate the habitat suitability of the odontocetes of the GOM to

96 identify those geographical regions that could support a high diversity of these cetaceans. The

97 analysis included historical datasets of georeferenced sightings (presence-only data) recorded in

98 both the south and north of the GOM. We used the maximum entropy (MaxEnt) modeling

99 approach (Phillips, Anderson & Schapire, 2006), and five environmental predictors were selected

100 based on their documented importance in determining the occurrence of cetaceans, either directly

101 or indirectly: sea surface temperature, chlorophyll-a concentration, bottom depth and slope, and

102 distance to the 200-m isobath (e.g., Praca et al., 2009; Fernandez et al., 2018; Pace et al., 2018).

103

104 **Materials and Methods**

105 *Study and modeling area*

106 The modeling area was not restricted to the GOM, due to the high movement capacity of

107 cetaceans, and because there are no physicals barriers in the marine environment for them. The

108 area was extended to include the warm-temperate and tropical oceanic provinces of the

109 northwest Atlantic Ocean (Fig. 1a; Spalding et al., 2007).

110   The physiography of the GOM is complex and consists of 13 physiographic sub-provinces

111 (Fig 1b). The continental shelf (≤ 200 m deep) can be very narrow, as the Tamaulipas-Veracruz

112 shelf, or extensive, like the Yucatan and Florida shelves. The continental slope extends from the

113 200 m continental shelf break to 2,800 m depth, and there are vast canyons, such as the

114 Mississippi Canyon. The oceanic zone extends beyond the slope up to the abyssal plain, where

115 depths > 3,500 m are reached (Bouma & Roberts, 1990; Monreal-Gómez, Salas-de León &

116 Velasco-Méndoza, 2004). The GOM oceanic waters have oligotrophic conditions that contrast

117 with the eutrophic coastal regions, which receive a high nutrient input by river discharges,

118 mainly in the northern GOM (Biggs, 1992; Lohrenz et al., 1999; Muller-Karger et al., 2015).

119

120 *Presence-only data*

121 Historical georeferenced sightings (presence-only data) of odontocetes were compiled. We

122 discarded the Blainville's beaked whale (*Mesoplodon densirostris*), Gervais's beaked whale (*M.*

123 *europaeus*), killer whale (*Orcinus orca*), and Fraser's dolphin (*Lagenodelphis hosei*) from our

124 study because sightings of these species are infrequent (Würsig, 2017). The presence-only data

125 of the remaining 16 species (Table 1; Supplemental Data S1) were collected from the literature

126 (e.g., peer-reviewed articles, thesis, and technical reports), and digital databases of the Sistema

127 Nacional de Información Sobre la Biodiversidad (SNIB; http://www.snib.mx/; CONABIO, 2016)

128 and Ocean Biogeographic Information System Spatial Ecological Analysis of Megavertebrate

129 Populations (OBIS-SEAMAP; http://seamap.env.duke.edu/; Halpin et al., 2006). To reduce the

130 sampling bias (the north of the GOM is oversampled relative to the south) and the spatial

131 autocorrelation that negatively affects model performance (Boria et al., 2014; Varela et al.,

132 2014), we filtered our databases (one per species) using the spThin package (Aiello-Lammens et

133 al., 2015) in R software (R Core Team, 2019). The *thin* function uses a random approach to

134 return a dataset with the maximum number of records for a given distance restriction, which in

135 this study it was defined by the average daily displacement of each species (Table 1;

136 Supplemental Information S2).

137

138 *Environmental predictors*

139 Five environmental predictors were selected based on previous knowledge about the

140 environmental factors that influence the cetaceans' occurrence (e.g., Praca et al., 2009; Fernandez

141 et al., 2018; Pace et al., 2018). The selected predictors included both oceanographic and

142 bathymetric variables. Used oceanographic predictors were the sea surface temperature (SST,

143 °C) and chlorophyll-*a* concentration (Chl-*a*, mg/m^3), included in three metrics: mean, minimum,

144 and maximum. Data of both variables were downloaded from the Ocean Color portal

145 (https://oceancolor.gsfc.nasa.gov/; NASA, 2018) of the MODIS-Aqua sensor for the period July

146 2002 –December 2018. The data are at an L3 processing level with a spatial resolution of 0.041°

147 (~4 km). Weekly values (8-d composite) were downloaded and averaged across the 16 years

148 with available data. Bathymetric predictors were depth (*D*, m), bottom slope (*S*, degrees), and

149 distance to the 200-m isobath (D_{200}, m). The first was acquired from the General Bathymetric

150 Chart of the Ocean (GEBCO; https://www.gebco.net/; IOC & IHO, 2018) with a spatial

151 resolution of 0.008° (~1 km); the other two were calculated from the depth using the raster

152   package (Hijmans et al., 2013) in R software. These bathymetric predictors were re-projected at

153   a spatial resolution of 0.041°.

154   The co-linearity among environmental predictors was evaluated using the Pearson correlation

155   coefficient (ρ) (Dormann et al., 2012; Cruz-Cárdenas et al., 2014). If $\rho \geq 0.70$ (Dormann et al.,

156   2013), a principal component analysis was performed (Supplemental Information S3) to

157   determine which of the correlated predictors should be discarded.

158

159   *Habitat suitability modeling*

160   We used the MaxEnt algorithm (Phillips, Anderson & Schapire, 2006) to predict the habitat

161   suitability of odontocetes in the GOM. MaxEnt assumes that the species are distributed

162   uniformly (i.e., the maximum entropy distribution) on the modeling area, and the environmental

163   values constrain this distribution at the presence of records locations (Phillips, Anderson &

164   Schapire, 2006; Phillips et al., 2017). The habitat suitability modeling for each species was

165   conducted using the ENMeval package (Muscarella et al., 2014, 2016) in R. We built models

166   with a random sample of 10,000 background points (i.e., points not registered as occurrence

167   records in the modeling area that are contrasted with the occurrence positions) and select the

168   *Linear*, *Quadratic,* and *Hinge* features of the MaxEnt algorithm. The cross-validation of the

169   models was done using the block method that splits the presence data into four bins, three as

170   training data and one as test data, based on the latitude and longitude lines that divided the

171   occurrence localities (Muscarella et al., 2014).

172   The performance of each model was evaluated using the area under the receiver-operator

173   curve (AUC), which measures the discriminatory ability of each model, and the omission rate

174   (OR), which indicates the proportion of test localities that fall into cells not predicted as suitable

175   (Philips, Anderson & Schapire, 2006). An AUC of 1 indicates perfect discrimination between

176   sites where the species is present or absent, and an AUC < 0.5 indicates that the model

177   performance is less than a random assumption (Elith et al., 2006). We used the 10-percentile

178   training omission rate (OR_{10}) because it is less sensitive to the outlier presence locations

179   (Radosavljevic & Anderson, 2014). Omission rates greater than the expected value of 0.1 (or

180   10%) suggest model overfitting (Peterson et al., 2011; Radosavljevic & Anderson, 2014).

181   Finally, we used the contribution percentages returned by each MaxEnt model to evaluate the

182   contribution of each environmental predictor (Phillips, Anderson & Schapire, 2006).

183   We selected the logistic output and obtained the habitat suitability for each 0.041° x 0.041°

184   cell of the modeling area, which was expressed in an interval between 0 (unsuitable conditions)

185   and 1 (highly suitable conditions). In this study, high suitability areas were defined as those sites

186   (cells) with suitability values ≥ 0.6 (Kaschner et al., 2011). A spatial approach based on the

187   habitat suitability maps was used to identify suitable regions for cetaceans; that is, regions

188   capable of supporting a high diversity of cetaceans (i.e., suitable regions) were defined as regions

189   where the high suitability areas of at least seven species overlap.

190

191   **Results**

192   Habitat suitability was modeled for only twelve species (Table 1), which were those that after

193   filtering had the minimum sample required (≥ 30 presence records; Wisz et al., 2008). The

194   pygmy sperm whale (*Kogia breviceps*), pygmy killer whale (*Feresa attenuata*), false killer whale

195   (*Pseudorca crassidens*), and melon-head whale (*Peponocephala electra*) were excluded due to

196   small sample size (Table 1).

197   The models showed a good degree of discriminatory ability based on the AUC scores, which

198   ranged from 0.74 (the pantropical spotted dolphin, *Stenella attenuata*, model) to 0.91 (the

199   bottlenose dolphin model) (Table 2). On the other hand, the OR_{10} value was close to the expected

200   value in some models, such as the rough-toothed dolphin, but in others it was higher, as in the

201   spinner dolphin (*Stenella longirostris*) model (Table 2), suggesting some degree of overfitting.

202   The environmental predictors used in each model differ (Table 2; Supplemental Information

203   S4). The bottlenose dolphin models had the fewest predictors, while the Risso's dolphin

204   (*Grampus griseus*), Atlantic spotted dolphin, pantropical spotted dolphin and spinner dolphin

205   models had the most. Slope was included in 11 models, while both depth and minimum-SST in

206   10 (Table 2). However, in terms of contribution, depth was the most important environmental

207   predictor, with a contribution of > 25% in seven models, followed by the minimum-SST, which

208   had an important contribution in five models.

209   High suitability areas for 10 species were located on the continental slope (Figs. 2-4). The

210   pantropical spotted dolphin seems to be the species with the widest distribution, potentially

211   occupying the entire continental slope. High suitability areas for the sperm whale (*Physeter*

212   *macrocephalus*), short-finned pilot whale (*Globicephala macrorhynchus*), and spinner dolphin

213   were found on the inner continental slope, while for the rough-toothed dolphin they were located

214   both on the outer continental shelf and on the slope. Dwarf sperm whale (*Kogia sima*), Risso's

215   dolphin, and Cuvier's beaked whale (*Ziphius cavirostris*) models show almost continuous high

216   suitability along the northern continental slope, from Florida to Louisiana-Texas, even extending

217   to the Rio Grande and Tamaulipas-Veracruz slopes. High suitability areas for the Clymene

218   dolphin (*Stenella clymene*) were found on the northern slope, with small patches on the

219   Tamaulipas-Veracruz slope. Striped dolphin (*Stenella coeruleoalba*) model identified as high

220   suitability areas some patches on the Tamaulipas-Veracruz slope and on the bay of Campeche.

221   The Atlantic spotted dolphin model indicates that high suitability areas are located from the

222   continental shelf to the inner slope of the entire GOM, whereas the model of the bottlenose

223   dolphin points to the continental shelf, from Florida to the Tamaulipas-Veracruz.

224   The main region of high diversity of odontocetes was located between the Mississippi Canyon

225   and the Louisiana-Texas slope (Fig. 5). Other suitable regions were identified on the west Florida

226   slope and on the western continental slope, between the Rio Grande and Tamaulipas-Veracruz

227   slopes

228

229   **Discussion**

230   ENM are powerful tools for generating spatially explicit maps of species' habitat suitability. We

231   used the MaxEnt approach to model the habitat suitability of the GOM odontocetes, using data

232   from both the north and south, and managed to identify regions where high diversity can be

233   expected. We decided to use this approach because it allows the development of reliable models

234   of the potential distribution based on presence-only data, although it is important to emphasize

235   that these models do not represent the probability of the presence of a species. However, due to

236   the paucity of data, we were able to model only 12 of the 20 species present in the GOM.

237   Furthermore, because we use historical sighting records, the resulting maps are integrated images

238   that show no temporal variations, and no biotic interaction were considered. Biotic interactions

239   might improve habitat suitability models, however, require abundance demographic data at

240   population over time (Anderson, 2017).

241   All models had a good discrimination power, with AUC values > 0.70, indicating that the

242   results are reliable, and can be used in planning management and conservation measures (Elith et

243   al., 2006; Raes & Aguirre-Gutiérrez, 2018). On the other hand, the OR_{10} values were higher than

244   the expected value; however, they are within the range reported in other studies (e.g., Kramer-

245   Schadt et al., 2013; Arthur, Morrison & Morey, 2019). High OR_{10} values suggest overfitting,

246   which could be due to sampling bias and/or noise in the presence data (Anderson & Gonzalez,

247   2011; Merow et al., 2014). In our study area, the south of the GOM is under-sampled compared

248   to the north. We attempted to reduce this bias using the spatial filtering to minimize the omission

249   error, but it may not have been completely successful, especially in the case of the spinner

250   dolphin model.

251   Among the used environmental predictors, depth was the most important, followed by

252   minimum SST and bottom slope. These results are not surprising since it is well known that

253   these variables influence the occurrence of cetaceans directly; for example, some species display

254   relatively persistent bathymetric associations (Yen, Sydeman & Hyrenbach, 2004; Harvey et al.,

255   2017), but mainly indirectly by playing a determining role in the availability, distribution, and

256   abundance of their prey (Davis et al., 2002; MacLeod, 2009; Forcada, 2018). In fact, previous

257   studies have shown that the distribution of several species of cetaceans of the GOM is strongly

258   related to depth (e.g., Baumgartner, 1997; Davis et al., 1998; Baumgartner et al., 2001).

259   Our results are consistent with the segregated distribution of cetaceans proposed by Maze-

260   Foley & Mullin (2006) for the northern GOM. The two dolphin species of the shelf community,

261   the Atlantic spotted dolphins and the bottlenose dolphins, use different habitats. High suitability

262   areas of the Atlantic spotted dolphins were located on the outer continental shelf and the inner

263   slope, while the bottlenose dolphin has coastal habitats, occupying shallower waters; actually, it

264   is the only species that inhabits lagoons, estuaries, and bays (e.g., Mullin et al., 1990; Griffin &

265   Griffin, 2003; Martínez-Serrano et al., 2011). The continental slope community is composed of

266   the remaining species (Maze-Foley & Mullin, 2006; present study), although densities of these

267   can vary seasonally, at least in the northern GOM (Roberts et al., 2016; Mannocci et al., 2017).

268   The aggregation of multiple species reveals important biological regions capable of supporting a

269   high cetacean diversity (Harvey et al., 2017). Ten of the 12 species modeled showed habitat

270   suitability areas along the continental slope, consistent with the relatively high diversity of

271   cetaceans observed on the northern GOM continental slope (Davis et al., 2002; Maze-Foley &

272   Mullin, 2006; Roberts et al., 2016). The exploitation of different types of habitat and prey allows

273   this co-existence (Bearzi, 2005; Schick et al., 2011). The continental slope of the GOM covers a

274   large area and presents underwater canyons (Bouma & Roberts, 1990), where the main prey

275   (e.g., cephalopods) of the deep-diving species can accumulate (Biggs, Leben & Ortega-Ortiz,

276   2000; O'Hern & Biggs, 2009; Moors-Murphy, 2014). On the other hand, the species that

277   primarily feed on epipelagic prey preferentially use the upper layers of the water column, where

278   mesoscale structures occur (Davis et al., 1998, 2002).

279   We identify four suitable regions. The most notable was located in the north, encompassing

280   the Mississippi Canyon and the Louisiana-Texas slopes, consistent with that previously reported

281   for the north of the GOM (e.g., Mullin & Fulling, 2006; Roberts et al., 2016). The other regions

282   were located on the west Florida slope (east-northeast of the GOM), the Rio Grande slope (west-

283   northwestern of the GOM), and the Tamaulipas-Veracruz slope (west-southwestern of the

284   GOM). All these regions are characterized by their high primary productivity. In the north,

285   productivity is directly influenced by the input of nutrients from the Mississippi and Atchafalaya

286   rivers (Lohrenz et al., 1999), while in the west by the Grande and Pánuco rivers (Salmerón-

287   García et al., 2011). The plumes of nutrient-rich waters are transported through the continental

288   shelf (Del Castillo et al., 2001; Morey et al., 2003; Zavala-Hidalgo, Morey & O'Brien, 2003),

289   reaching the slope by the interactions of anticyclonic-cyclonic eddies (Toner, 2003; Martínez-

290   López & Zavala-Hidalgo, 2009). However, the largest region suitable for cetaceans was located

291   in the north for two possible reasons. First, the large nutrient input from the Mississippi River

292   into the shelf ecosystem favors huge phytoplankton blooms on spatial scales of tens to hundreds

293   of kilometers (Lohrenz et al., 1997). Second, the continental slope in this region is extremely

294   wide, which could favor the convergence of a greater number of cetacean species.

295

Conclusions

297   We identified areas of high suitability for 12 species of odontocetes in the GOM through the

298   implementation of an ENM. Unfortunately, the paucity of data did not allow modeling all the

299   species, which highlights the importance to establish transboundary research and monitoring

300   programs between the U.S., Cuba, and Mexico to improve knowledge on the cetaceans of the

301   GOM. Even so, we were able to detect four geographic regions where a high diversity of

302   odontocetes is expected, all located on the continental slope. These suitable regions were

303   identified using a spatial overlay, which although it is a very conservative approach (Harvey et

304   al., 2017), it can be useful to detect areas where to focus conservation efforts (Tolimieri et al.,

305   2015).

306

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315

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Georeferenced records for 16 odontocetes from the Gulf of Mexico

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

1   **Table 1.** Total number of georeferenced sightings of 16 odontocetes in the Gulf of Mexico, period of the presence data, filtering

2   distance (average daily displacement in km), and number of sightings used in modeling (sample size). Modeled species are marked

3   with *.

Scientific name	Common name	Period	Total sightings	Filtering distance	Used sightings (n)
*Physeter macrocephalus**	Sperm whale	1978 - 2017	810	90[1]	70
Kogia breviceps	Pygmy sperm whale	1992 - 2011	51	75[2]	17
*Kogia sima**	Dwarf sperm whale	1990 - 2011	319	75[2]	37
*Ziphius cavirostris**	Cuvier's beaked whale	1990 - 2017	88	25[3]	39
Feresa attenuata	Pygmy killer whale	1990 - 2008	24	70[4]	16
Peponocephala electra	Melon-headed whale	1992 - 2011	70	70[5]	25
Pseudorca crassidens	False killer whale	1986 - 2017	96	70[6]	25
*Globicephala macrorhynchus**	Short-finned pilot whale	1984 - 2017	200	80[7]	61
*Steno bredanensis**	Rough-toothed dolphin	1983 - 2017	90	90[8]	37
*Grampus griseus**	Risso's dolphin	1990 - 2017	330	80[9]	54
*Stenella frontalis**	Atlantic spotted dolphin	1979 - 2015	1,557	70[10]	128

5   **Table 1.** Continuation.

Scientific name	Common name	Period	Total sightings	Filtering distance	Used sightings (n)
Stenella attenuata*	Pantropical spotted dolphin	1983 - 2012	800	90[11]	93
Stenella coeruleoalba*	Striped dolphin	1992 - 2005	76	90[12]	35
Stenella longirostris*	Spinner dolphin	1983 - 2012	126	80[13]	41
Stenella clymene*	Clymene dolphin	1990 - 1998	108	70[12]	37
Tursiops truncatus*	Bottlenose dolphin	1971 - 2017	3,778	35[14]	305

6   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),

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8   (2018), [14]Irvine et al. (1981)

Statistics of each model and contribution percentages of each environmental predictor

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.

1 **Table 2.** Values of the area under the receiver operator curve (AUC) and of the 10-percentile training omission rate (OR_{10}), and

2 percent of contribution of the environmental predictors in each model. Environmental predictors: SST_m = mean sea surface

3 temperature, SST_{min} = minimum sea surface temperature, SST_{max} = maximum sea surface temperature, Chl-a_m = mean chlorophyll-*a*

4 concentration, Chl-a_{min} = minimum chlorophyll-*a* concentration, Chl-a_{max} = maximum chlorophyll-*a* concentration, *D* = depth, *S* =

5 slope, D_{200} = distance to the 200-m isobath.

Species	AUC	OR	SST_m	SST_{min}	SST_{max}	Chl-a_m	Chl-a_{min}	Chl-a_{max}	*D*	*S*	D_{200}
						Environmental predictors					
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

7 **Table 2.** Continuation

| Specie | AUC | OR | Environmental predictors | | | | | | | | |
			SST_m	SST_{min}	SST_{max}	Chl-a_m	Chl-a_{min}	Chl-a_{max}	D	S	D_{200}
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
Bottlenose dolphin	0.91	0.16		20.18	1.07	2.91			75.84		

Figure 1

Study and modeling area

(A) Geographic extension of the modeling area in the northwestern Atlantic Ocean. (B) Gulf of Mexico and physiographic sub-provinces: 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. Bay of Campeche. 11. Bank of Campeche, 12. Yucatan shelf, 13. Campeche terrace, and 14. Sigsbee plain.
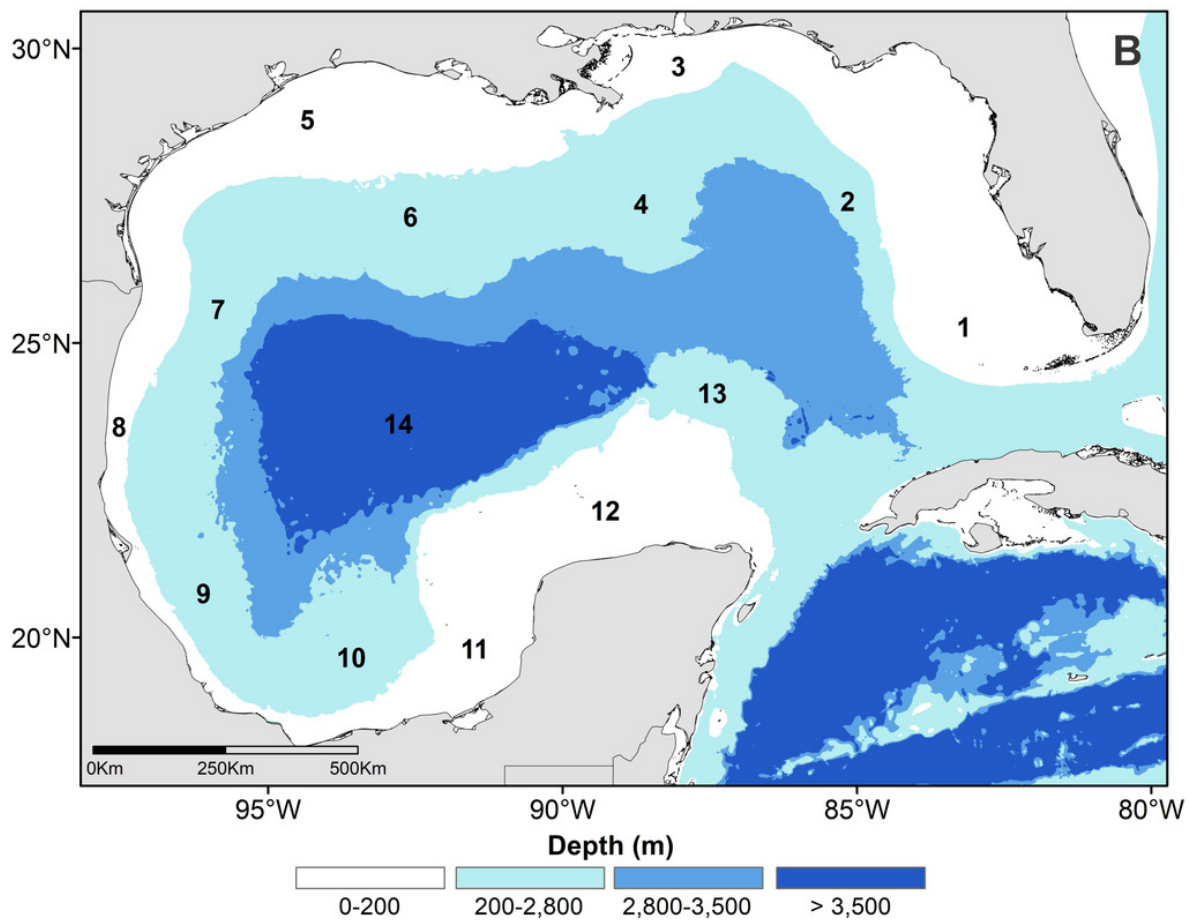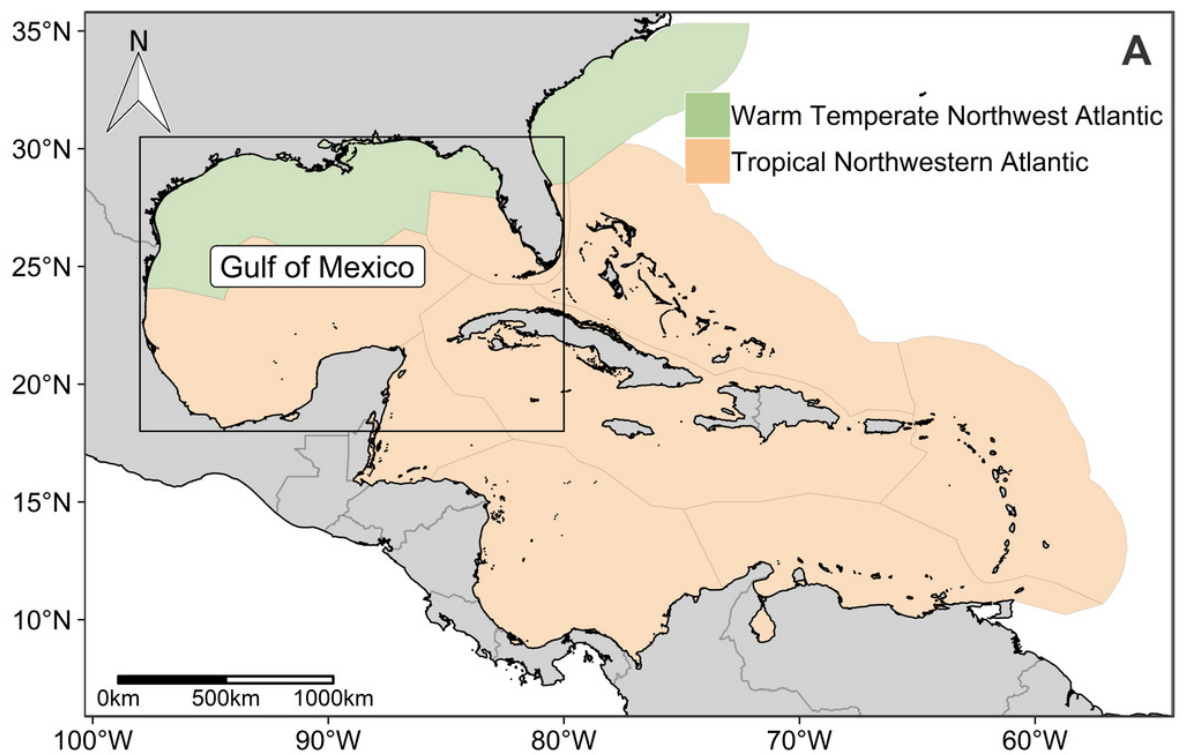
Figure 2

Habitat suitability map

Habitat suitability of (A) sperm whale, (B) dwarf sperm whale, (C) Cuvier's beaked whale, and (D) Short-finned pilot whale. In the scale bar, reds indicates high habitat suitability values (≥ 0.6) encompassed by the solid line, and light yellow indicates low habitat suitability values.
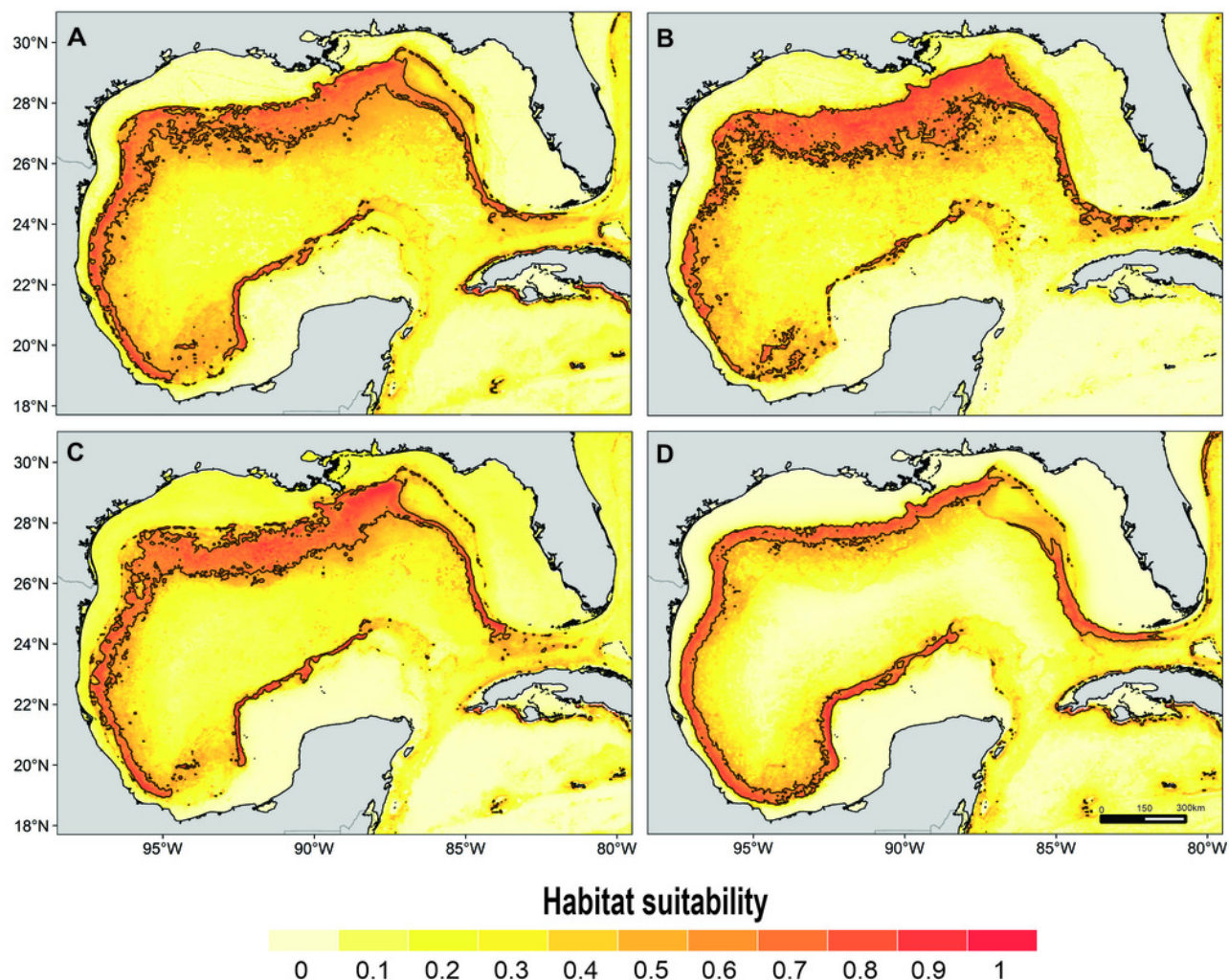
Figure 3

Habitat suitability map

Habitat suitability of (A) rough-toothed dolphin, (B) Risso's dolphin, (C) Atlantic spotted dolphin, and (D) pantropical spotted dolphin. In the scale bar, reds indicates high habitat suitability values ($\geq$ 0.6) encompassed by the solid line, and light yellow indicates low habitat suitability values.
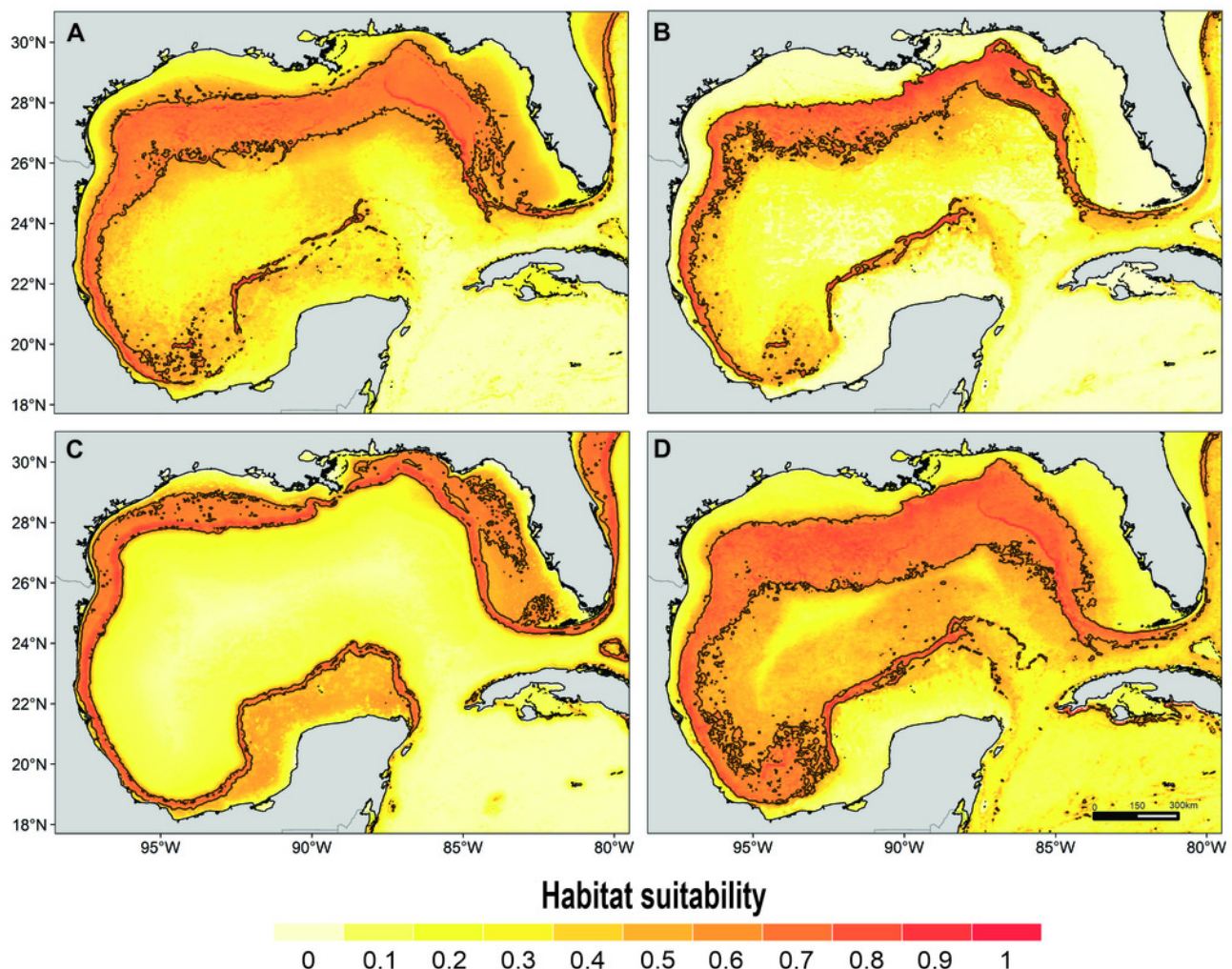
Figure 4

Habitat suitability map

Habitat suitability of (A) striped dolphin, (B) spinner dolphin, (C) clymene dolphin, and D) bottlenose dolphin. In the scale bar, reds indicates high habitat suitability values (≥ 0.6) encompassed by the solid line, and light yellow indicates low habitat suitability values.
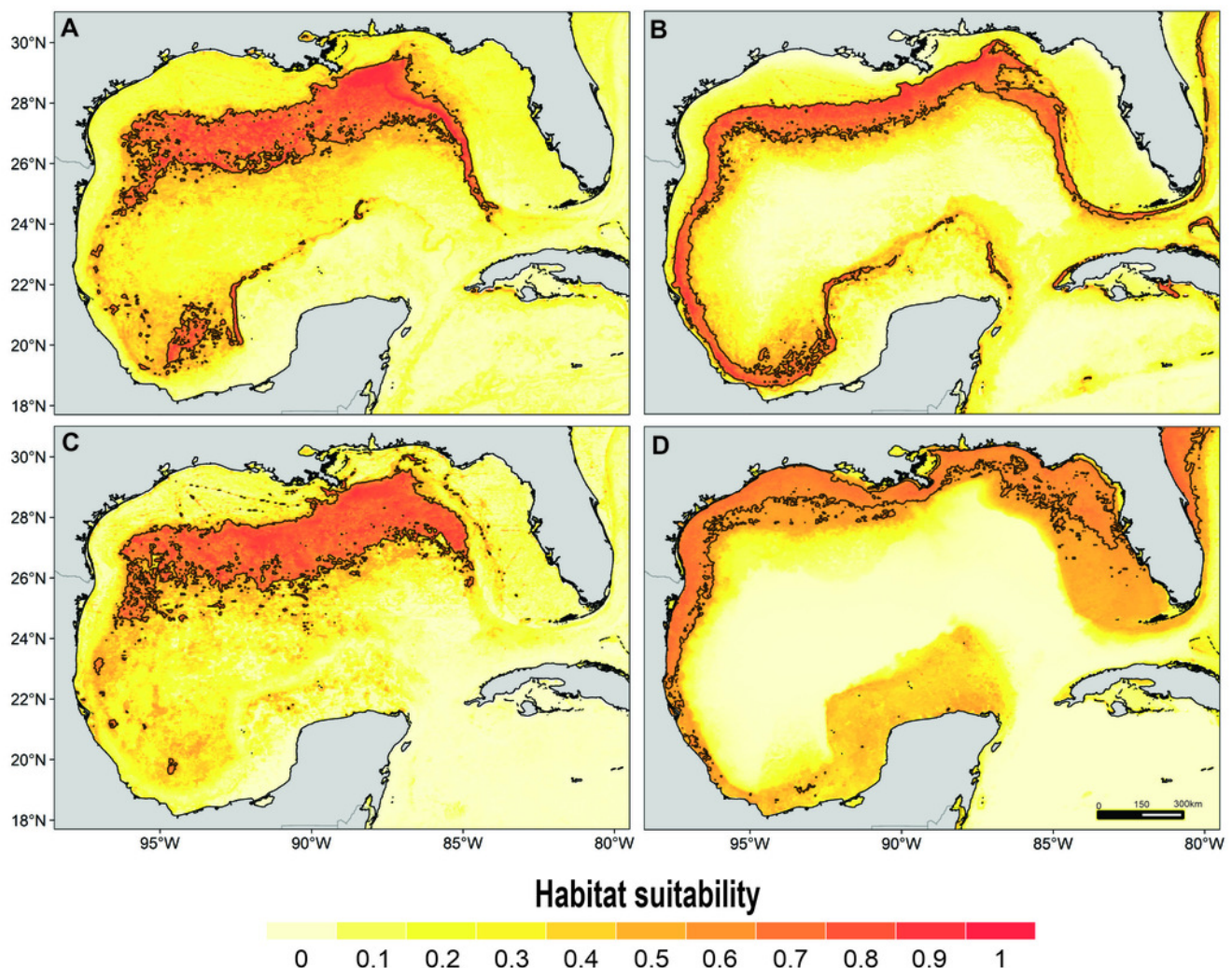
Figure 5

Suitable regions map

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.