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Short Note

Habitat Characterization of Bottlenose Dolphins (*Tursiops truncatus*) Along the Coast of Yucatan, Mexico

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Bottlenose dolphins (*Tursiops truncatus*) are the best known cetaceans in the world (Jefferson et al., 2015). They are distributed in tropical and temperate regions, both in coastal and oceanic habitats, mainly close to shore (Wells & Scott, 2009; Jefferson et al., 2015). In the Gulf of Mexico, it is the most widespread and common species of marine mammal (Harwood, 2010). This species is of great ecological importance since it is a top predator occupying one of the highest trophic links of the marine food web, influencing the community structure and responding to changes in the environment; thus, their study would elucidate the conservation status of the ecosystem (Schmidly & Würsig, 2009; Díaz-Gamboa et al., 2018).

There are very few studies regarding bottlenose dolphin habitat in the Gulf of Mexico. These have been carried out in the northern Gulf of Mexico (Davis et al., 1998; Miller, 2003) and in the Mexican states of Veracruz (Vázquez-Castán et al., 2007) and Campeche (Delgado-Estrella, 1997); however, in Yucatan, these type of studies of marine mammals are lacking. Although studies on bottlenose dolphin habitat have been conducted in different parts of the world, it cannot be assumed that these results will be similar in Yucatan since distribution and environmental factors are important habitat characteristics that depend on the area (Bräger et al., 2003). The aim of this study was to characterize and further contribute to our understanding of the habitats used by bottlenose dolphins along the Yucatan coast.

Bottlenose dolphin sightings were carried out through direct search and systematic observation using the line-transect sampling method (Navarro & Díaz-Gamboa, 2015) between July and August 2014, with zig-zag tracks utilized to maximize observations on longitudinal gradients (Chávez-Andrade, 2006; Figure 1a). Due to the extension of the continental shelf, surveys were made from the coastline to 10 m depth aboard a 150-hp outboard motor boat, starting at 0700 h when weather conditions (less than Beaufort scale 3) allowed. The average speed was 10 kts, which made it possible to sight dolphins as they came up to breathe and to avoid counting the same animals twice.

Two main observers with 7 × 50 binoculars equipped with compass and reticle were placed at the bow, each observer covering 90° to the right or to the left as needed, and a third observer, responsible for data collection, was placed in the center (Díaz-Gamboa et al., 2018). The observer positions were rotated every 30 min to minimize bias due to fatigue.

Each sighting was recorded on a cruise sheet and immediately thereafter on a sighting sheet, and its position was determined with a GPS. The time and initial position of the sighting, locality, number of all sightings per day, species, number of individuals (group size), and behavior were recorded. Oceanographic variables, including temperature, dissolved oxygen, salinity, and pH at the surface, were measured *in situ* using a multiparametric probe. The depth was obtained from a depth gauge. Chlorophyll *a* data were obtained from cumulative values of 3 days through 1,000 × 1,000 m resolution satellite images from AQUA/MODIS from the National Oceanic and Atmospheric Administration (NOAA) (2014). Tidal height was obtained through a tide chart, and the distance to the coast was estimated using the *Google Earth* program.

To characterize the habitats of bottlenose dolphins in Yucatan, oceanographic variables most related to the group size of bottlenose dolphins were determined. Each position where dolphins were recorded was considered as an independent and discrete sampling unit. Depending on the geographical location of the sightings, the study area was divided into two main zones: (1) the Western coast in the inner Gulf of Mexico and (2) the Eastern coast closer to the Caribbean Sea (Figure 1b). A principal component analysis (PCA) was performed to find

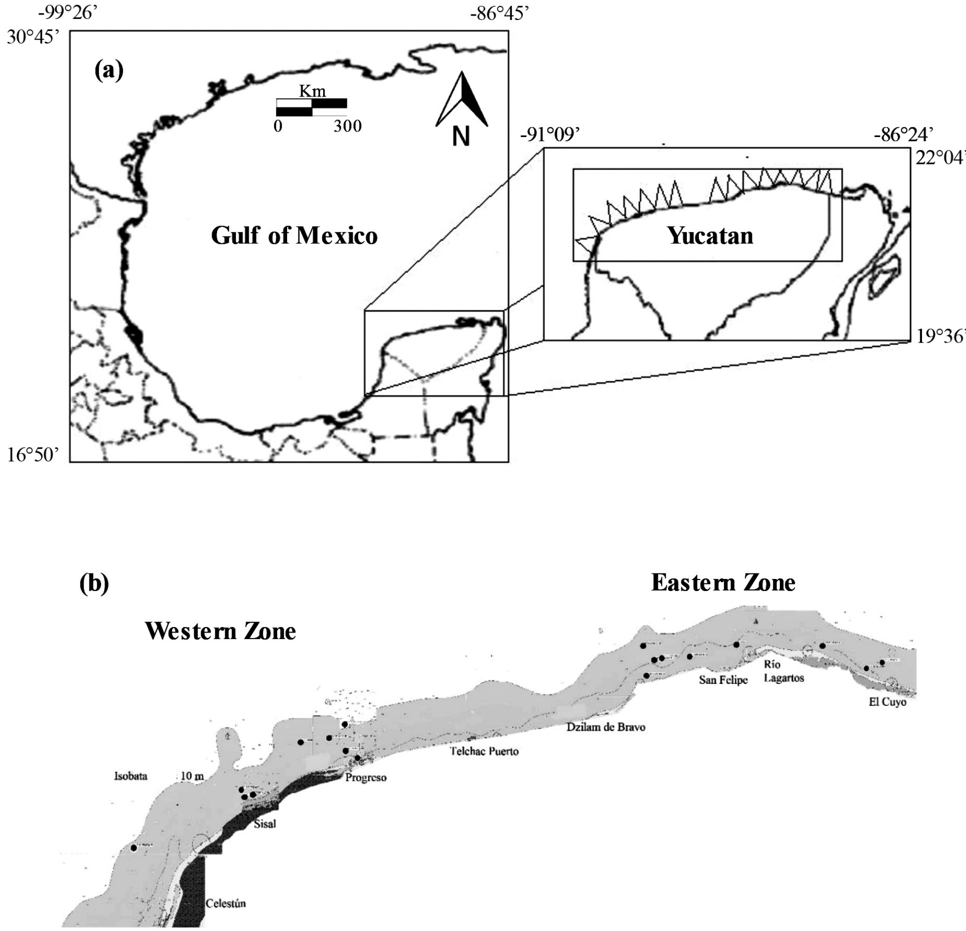

Figure 1. Line transects in the coast of Yucatan, Mexico, in the Gulf of Mexico (a), and bottlenose dolphin sightings (black dots) in two zones of the coast of Yucatan (b).

similarities between zones to recognize the variables with the greatest influence on those sites. The variables used in this analysis were temperature, depth, salinity, dissolved oxygen, pH, tidal height, distance to shore, and chlorophyll *a*. The program *Past*, Version 2.10, was utilized.

The normality of the data was tested, and a one-way analysis of variance was performed to determine significant differences between the Eastern and Western Zones using the same variables described before, followed by an unequal N Tukey HSD *post-hoc* multiple comparison test to find differences among them using *Statistica*, Version 7, software.

To find the importance of oceanographic variables in relation to the group size of bottlenose dolphins, generalized linear models were built using the negative binomial model. The best models were compared, and those built with group size of bottlenose dolphins without oceanographic variables were contrasted with those built with oceanographic variables. Oceanographic variables that were important in the analysis of major components (i.e., depth, temperature, tidal height, salinity, distance to the shore, and chlorophyll *a*) and the group size of bottlenose dolphins were used, assuming a 0.05 significance level. The 'BiodiversityR' package for program *R* was used for this analysis.

Eighteen sightings were recorded during 10 surveys and through 921 km of effort in the summer of 2014 (Figure 1b). Each zone represented 50% of sightings (i.e., 9 sightings on each zone), with 111 bottlenose dolphins observed in total. Smaller groups (~4 individuals) were detected in the Eastern Zone compared to the slightly larger groups in the Western Zone (~8 individuals). The sightings were located in depths between 3.7 to 10.7 m and at 0.9 to 23.2 km distance from the shore.

The PCA results showed that two components were the most important, and both accounted for more than 63% of the total variance (Figure 2). Component 1 (42.25%) was related to depth, temperature, and distance from shore, while Component 2 (21.08%) was related to salinity, tidal height, and chlorophyll *a*. Depth was the variable most related to Component 1, while salinity was the variable most related to Component 2. Depth was positively related to distance to the shore and negatively to temperature and pH, while salinity was negatively related to tidal height and chlorophyll *a*.

Bottlenose dolphin distribution in the Eastern Zone was associated with higher temperature, higher pH values, and higher concentrations of chlorophyll *a*, as well as lower depth, tidal height, oxygen values, and shorter distance to the shore compared to the Western Zone. Analyzing variance determined that the two zones were significantly different from each other ($F_{(8, 9)} = 5.08$; $p = 0.012$), mainly due to three variables: (1) depth, (2) tidal height, and (3) pH. In the Western Zone, bottlenose dolphins were located in deeper areas with higher tides and lower pH compared to the Eastern Zone (Table 1).

The comparison of best negative binomial models was not significant ($p = 0.3541$)—that is, the first model (group size without oceanographic variables) was not better than the second model (group size with oceanographic variables); therefore, none of the oceanographic variables had more influence on the group size of bottlenose dolphins in Yucatan. However, the second model generated suggests a trend in the group size of bottlenose dolphins with depth ($p = 0.03$).

In general, cetacean habitats are very complex. They are three-dimensional environments determined by different factors (i.e., oceanographic variables), and these habitats are related to the distribution of each species (Forcada, 2009). Group size varies depending on the sighting zone (Grigg & Markowitz, 1997; Delgado-Estrella, 2015), with small groups frequently found in coastal waters (Morteo et al., 2004; Pérez-Cao et al., 2009; Díaz-Gamboa et al., 2018). In this study, average group size varied between the two zones, and most of the groups were small, which is common in shallow areas. The number of individuals in a group has been related to advantages in overcoming selective pressures, including, but not limited to, protection against harassment and predation, improving food acquisition, and energy efficiency (Shane et al., 1986).

The systems inhabited by bottlenose dolphins are dynamic and include the interaction of different factors. Some studies of habitat characterization of bottlenose dolphins report the importance of oceanographic variables in the presence of these animals such as temperature, salinity, depth, distance to the shore, tidal height, and chlorophyll *a* (Baumgartner

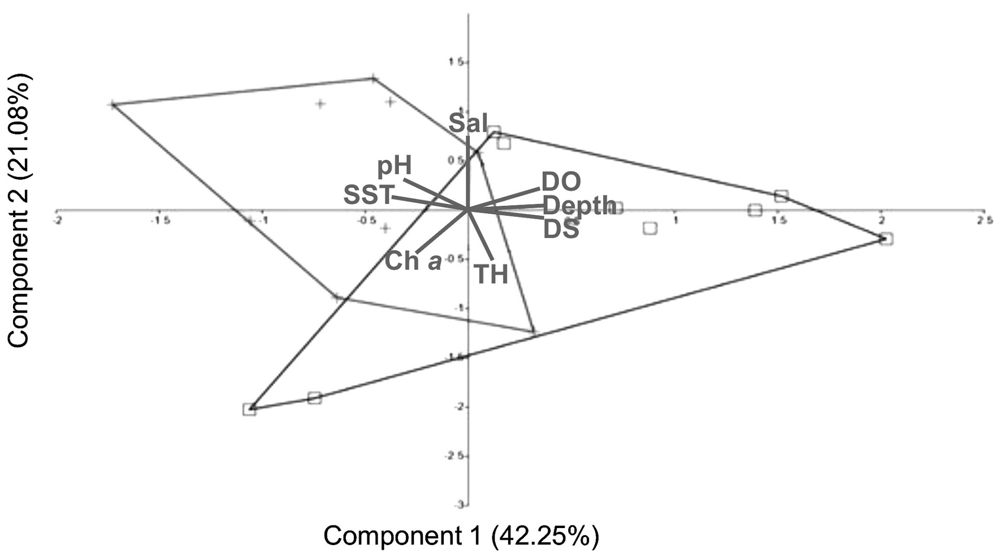

Figure 2. Principal component chart: squares = western zone and crosses = eastern zone; oceanographic variables: Sal = salinity, DO = dissolved oxygen, DS = distance to the shore, TH = tidal height, Ch *a* = chlorophyll *a*, and SST = sea surface temperature.

Table 1. Data for oceanographic variables by zones, showing the mean values or concentrations (SD = standard deviation) in the studied regions, to characterize the habitat conditions of bottlenose dolphins (*Tursiops truncatus*) in Yucatan, Mexico

Variable	Eastern Zone (SD)	Western Zone (SD)	*p* value
Depth (m)	5.43 (1.078)	7.63 (1.977)	0.009*
Temperature (°C)	27.07 (1.709)	26.61 (1.648)	0.575
Salinity (ppm)	36.75 (0.053)	36.73 (0.056)	0.381
pH	7.07 (0.048)	6.85 (0.199)	0.005*
Dissolved oxygen (mg/L)	8.56 (0.434)	8.84 (0.368)	0.153
Tidal height (cm)	9.77 (7.980)	25.5 (12.22)	0.005*
Chlorophyll *a* (mg/m^3)	2.66 (1.414)	1.76 (1.401)	0.194
Distance to the shore (km)	5.09 (2.859)	8.19 (6.876)	0.228

*Statistically significant ($p < 0.05$)

et al., 2001; Natoli et al., 2005; Chávez-Andrade, 2006; Valdes-Arellanes et al., 2011). Of these variables, depth is mentioned most often in those studies (Davis et al., 1998; Baumgartner et al., 2001; Chávez-Andrade, 2006; Bearzi et al., 2008; Cañadas & Hammond, 2008), which is in agreement with our results showing that depth was the only variable that had a significant value in the negative binomial model and contributed significantly to differentiate the Eastern and Western Zones. Depth is a variable that influences the group size of bottlenose dolphins, including coastal and offshore ecotypes, at different intervals (Morteo et al., 2004) since group size decreases as depth also decreases (Würsig et al., 2000; Díaz-Gamboa et al., 2018). This may reflect a preference of this species to inhabit coastal systems, including in shallow waters such as the continental shelf of Yucatan, which would provide shelter and protection against predators.

Depth is also related to chlorophyll *a*, resulting in an increase in chlorophyll at lower depths, which is very important in the characterization of habitats of bottlenose dolphins (Baumgartner et al., 2001; Davis et al., 2001). Many records show that cetaceans are very frequent in areas of high productivity (Smith et al., 1986; Young & Phillips, 2002; Alava, 2009). This may be related to the presence of bottlenose dolphin prey since the continental shelf of Yucatan is very shallow, and the Yucatan current moves in parallel to the coastline, resulting in a productive marine zone and foraging area, increasing the availability of food throughout the year.

Distance to shore is related to the presence of bottlenose dolphins, especially in shallow waters (Valdes-Arellanes et al., 2011) since this variable has been shown to be a predictor of the presence of these cetaceans (Bearzi et al., 2008). Proximity to the coast could also be influenced by the high productivity that occurs in these areas, taking into account that the coast of Yucatan is defined by an extended continental shelf reaching up to 300 km from the coastline.

Depth, distance to shore, and tidal height have been related to the feeding activities of bottlenose dolphins, and all of these combined with upwellings present in the area promote conditions for high primary productivity, which benefits the abundance of prey available (Toledo Ocampo, 2005). The group size of bottlenose dolphins has shown a relationship with tidal height depending on the time of day. Group size also influences the direction in which these animals travel (Santos et al., 2010), as well as the display of some behaviors such as socialization, rest, and diving (Loizaga de Castro et al., 2013).

Some studies demonstrated that temperature is not an important variable linked to the group size of bottlenose dolphins (Pérez-Cao et al., 2009), which may be related to the high tolerance of these animals to different environmental factors (Meagher et al., 2008). In this study, the temperature in the two zones was similar without significant differences, determining a homogeneous warm water (~27°C); this coincided with the distribution of bottlenose dolphins throughout the study area.

In this study, we defined the habitat of bottlenose dolphins in Yucatan, Mexico's Eastern and Western Zones. The two zones were different with respect to the oceanographic variables measured without observing differences in the distribution of bottlenose dolphins between these areas. This may reflect the tolerance and ability of this species to adapt to different oceanographic conditions as long as the habitat provides a sufficient food source.

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