

Sentinels of the Sea:
Marine Mammal Behavioral Responses to Environmental Change

by

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ABSTRACT

This research investigates how two potential sentinel species (the Galápagos Sea Lion (*Zalophus wollebaeki*) and the Guiana Dolphin (*Sotalia guianensis*)) respond to environmental factors, at both the large-scale and fine-scale levels. Sentinel species, defined as organisms able to respond to ecosystem variability and/or change in a timely and measurable way to nowcast or forecast otherwise unobserved environmental changes, can help mitigate or even avoid changes deleterious to both wildlife and human communities. Using two long-term datasets and a suite of respective social metrics and environmental factors, I analyzed potential external influences on these two species' behavioral ecology. My overall findings suggest that apex marine mammals respond differently to their surroundings at large-scale vs. fine-scale, and highlight the importance of including a range of environmental factors that include anthropogenic effects. Galápagos Sea Lions specifically respond to thermoregulation-linked factors, such as substrate temperature, and anthropogenic factors such as human presence and activity type. Guiana Dolphin social metrics are significantly related with traits linked to environmental water quality, water transparency. I expand on the sentinel implications of these results and introduce sample methodology and results for sentinel species based on the Guiana Dolphin case study.

DEDICATION

I dedicate this work wholeheartedly and with all my love to the Abalo, Lawson-Hellu, Iroko, Doumon and Jouret families.

ACKNOWLEDGMENTS

Thank you to my committee for their support, input and feedback. My deepest thanks to all who participated and contributed to data collection and field work. A big thanks all those who facilitated fieldwork and logistics. I'm grateful for the presence of various mentors that continue to guide me and who have helped bring this project to fruit. Lastly, my deep gratitude goes to my family for their presence and support throughout all this process.

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CHAPTER 1

GALÁPAGOS SEA LION CONSERVATION: HABITAT PREFERENCES AT DIFFERENT SCALES

Introduction

Worldwide, coastal zones face degradation due to impacts from human presence, including the increased frequency and intensity of harmful algal blooms, overfishing, loss of critical habitats, and the spread of persistent chemical pollutants (Aguirre and Tabor 2004, Tabor and Aguirre 2004). Within this context, the conservation of ecologically important apex predators such as large marine mammals is an increasingly high priority task (Hazen et al. 2019). To effectively conserve critical marine species through efficient conservation plans, stakeholders require knowledge of the mechanistic links and relationships between apex marine mammals and environmental factors (Simeone 2018). These broader ecological links can serve to advance the conservation of the species themselves. However, the necessary data or analyses necessary to establish these ecological links are often missing. This study aims to fill this gap by focusing on terrestrial habitat use patterns across spatio-temporal scales by a marine mammal apex predator, the Galápagos Sea Lion (*Zalophus wollebaeki*).

The behavioral ecology of marine mammals is an important consideration for effective conservation plans, as these organisms often display differential habitat type use between and among population segments (i.e. resident populations of one species in different geographical areas). By prioritizing certain environmental factors and habitat

types in a conservation plan, we may in turn support the population segments (i.e. females and young) critical to the reproduction and long-term survival of the overall population. Specifically, as organisms with dual-habitat (land and water) requirements, pinnipeds (i.e. sea lion and seal species) change their habitat use based on factors such as aquatic food availability and foraging area, terrestrial resting area, and proximity to certain sex and age classes. In addition, tropical pinnipeds need to stay close to the water for thermoregulation to maintain their body temperature within a certain critical range; this leads to a linear spread of colonies along the coast. Once on land, Sea Lions are no longer affected by marine or terrestrial predator threats; instead, thermoregulation and social hierarchy determine terrestrial behavior (Wolf et al. 2005, Wolf et al. 2007a, Wolf and Trillmich 2007, 2008). For such highly mobile animals with potential for long-distance dispersal, staying in a specific locale or shoreline home-range reflects a “choice” rather than a restriction due to limited dispersal abilities and demonstrates a response to limited suitable breeding habitats close to rich feeding grounds (Wolf and Trillmich 2007).

Habitat choice is important for *Z. wolfebaeki*, where male attendance or the proximity to females and time spent around females have been shown as significantly linked to male reproductive success (Porschmann *et al.*, 2010). As the sex/age population segment with the most social fluidity (Abalo, 2011a), females have a 60% chance of participating in a group in physical contact with other individuals. However, due to an extended maternal care period of up to 3 years, very often these groups consist of a

mother with her young. Further, the species has been known to form “nursery groups,” in which one or two females guard an assemblage of young pups or juveniles while the mothers forage. Because females show site fidelity to an extent, and continue to associate with genetically related individuals, the potential advantages of ensuring gene transmission of relatives are clearly present (Wolf et al. 2007a, Wolf and Trillmich 2007, 2008). Female-young dyads, which are the central units of harems and territories of Galápagos Sea Lions, often make up nursery groups and night resting groups.

The social benefits of group membership may mitigate thermoregulation costs due to increased contact or being in close proximity to other individuals (Porschmann et al. 2010). However, it is suggested that critical thresholds of group size and composition are important to balance the benefits of group formation with the costs, such as increased intraspecific and intrasexual competition for group membership and prime micro-habitat choice. Group size thresholds play a role in reaching “a critical mass” for specific categories of groups and for encouraging other individuals to leave or join groups (Azevedo et al. 2005, Kunc and Wolf 2008, Trillmich and Wolf 2008, Wolf and Trillmich 2008, Acevedo-Gutiérrez 2009, Porschmann et al. 2010, Cantor et al. 2012a, Cantor et al. 2012b, Bisi et al. 2013, Cunha et al. 2014, de Andrade et al. 2015).

Several environmental factors have been shown to affect sea lions’ choice of terrestrial habitat. Substrate type, substrate color, and beach Tidal Variability may influence group formation, individual placement and prioritized use of shore spaces (Wolf et al. 2005, Wolf et al. 2007b, Wolf and Trillmich 2008). Thermoregulation and

costs of locomotion appear to be major determinants of terrestrial habitat use; animals were found to prefer simple flat surfaces near the sea with shade and tide pools present (Wolf et al. 2005). Habitat use differed by sex, with males more abundant in suboptimal inland habitats. In addition, females with newborns showed different habitat use from those with older offspring or no offspring. Wolf et al. (2005) characterize the sex differences “as by-products of social processes, primarily intrasexual competition and female avoidance of male harassment, linked to the polygynous mating system.” This suggests that habitat segregation is not intentional but rather stems from polygyny; however, given the “lek-like” nature of males and the solid social hierarchy present in *Z. wollebaeki*, it can also be hypothesized that habitat selection and specific individual placement on a fine-scale is directly related to social-hierarchy based competition for optimal resting places, depending on various factors such as the time of the day, tide level, insolation, water and air temperature, neighboring individuals, and group compositions (Wolf et al. 2005). These social effects are likely to be persistent, because dominance hierarchies in pinniped species such as *Z. wollebaeki* are maintained throughout the year (Wolf et al. 2005).

Currently, 90% of the Galápagos Sea Lion population resides on the central and southern islands (Floreana, Santa Cruz, San Cristóbal, Isabela, Santiago, Española, Mosquera, Santa Fé, and Fernandina), which are nine out of 125 islands and islets in the Galápagos archipelago (Schramm et al. 2009). Four of these nine islands (Floreana, Santa Cruz, San Cristóbal, and Isabela) are the only islands with permitted and ongoing human

presence in the Galápagos, prompting an interest in investigating human presence as a potential factor in *Z. wollebaeki* behavioral ecology. Including human presence in behavioral ecology is especially important for long term conservation planning for this species, due its current IUCN endangered status and close co-habitation with human populations (Villegas-Amtmann and Costa 2010, Trillmich et al. 2016). However, previous research on Galápagos Sea Lion terrestrial behavioral ecology has been mostly conducted on islands devoid of human presence, such as Caamaño Islet (Wolf et al. 2005, Wolf et al. 2007a, Wolf et al. 2007b, Wolf and Trillmich 2007, Trillmich and Wolf 2008, Wolf et al. 2008, Wolf and Trillmich 2008). These past studies showed sea lion behavioral ecology variable by temporal, spatial and social scales, prompting the need for further study at fine-scale vs. large-scale to investigate underlying dynamics (Trillmich and Wolf 2008, Wolf and Trillmich 2008). Therefore, this study explores whether there is differential habitat use by different sex/age and social categories in a population of Galápagos Sea Lions at different scales on San Cristóbal island (an island with a recent history of increasing human population). In doing so, this study directly addresses a gap in knowledge of sea lion behavioral patterns, by establishing a baseline of group behavioral patterns, through analyses of finer-scale, behavioral observations over a two-year period at four human-occupied beach sites in the Galápagos. I hypothesize that there are select environmental factors associated with specific Galápagos Sea Lion sex and age classes. Increasing urbanization and climate change impacts further emphasize the

urgency of effective conservation action for the *Z. wollebaeki*, which must take into account its behavioral ecology.

Methods and Materials

Study Site

Officially Ecuadorian territory, the Galápagos islands are recognized as a province of Ecuador, among other designations such as UNESCO World Natural Heritage Site, National Park, a Marine Reserve, a Marine Protected Area, National Tourism Area and Special Development Emphasis Area. Within the Galápagos province, as one of the four main inhabited islands, San Cristóbal serves as the main capital of the Galápagos archipelago. The general total human population in the Galápagos numbers about 20,000 residents (Quiroga, 2009). Specifically, the bay port town of Puerto Baquerizo Moreno, located on the southwestern end of the island and home to about 5,600 inhabitants, is the seat of mayor offices (Figure 1, Malecón site).

Sea lion habitat use was observed at beaches on the Bahía de los Naufragios (Shipwreck Bay) on San Cristóbal (Quiroga 2009). The Shipwreck Bay of Puerto Baquerizo Moreno is a documented site for encountering and observing populations of *Z. wollebaeki* (Figure 1). Previous population censuses show a population of around 700 individuals in the bay, with 60% site fidelity among specific tagged sea lion individuals (Montero Serra 2012). The presence of both Galápagos sea lions and humans in fine-scale coexistence yields an ideal study site to investigate the anthropogenic impacts of development on sea lion behavioral ecology.

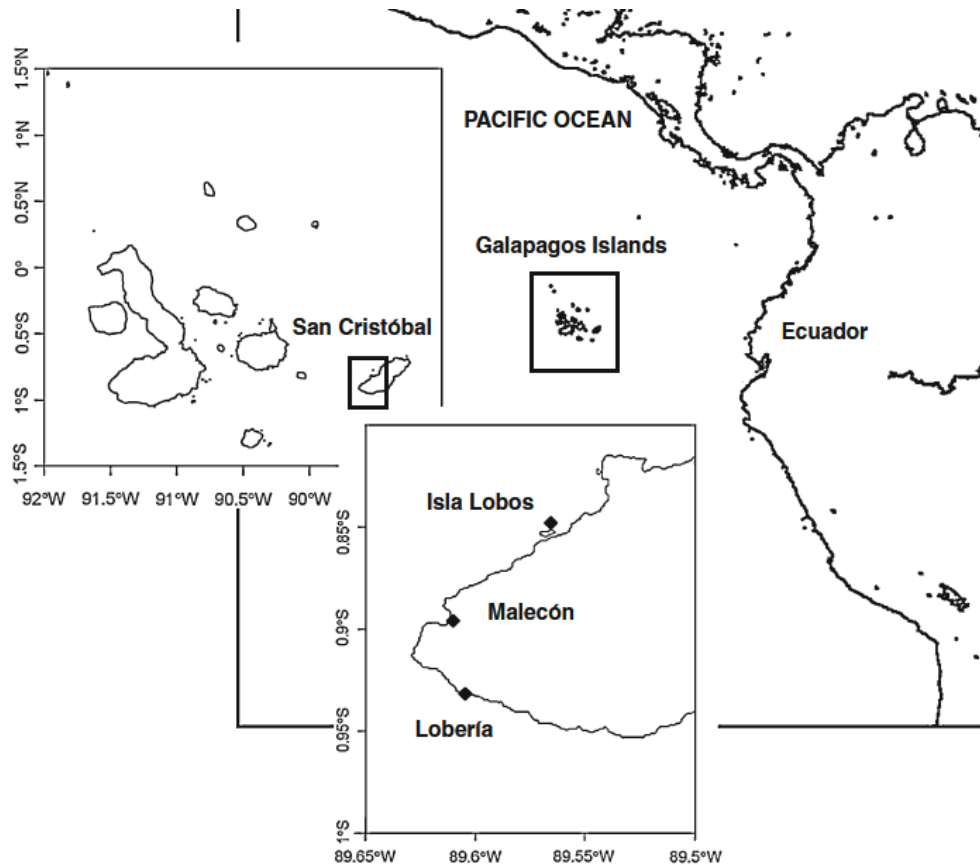


Figure 1. Research study site on San Cristóbal in the Galápagos Islands. Sea lions were observed at sites on Shipwreck Bay (marked Malecón on the map). The archipelago of volcanic islands is located about 1000 km west of the Ecuadorian coast (Paez-Rosas and Aurióles-Gamboá 2010). Figure modified from Paez-Rosas *et al.* (2010).

Data Collection

Data on sea lion habitat use and grouping formations were collected over two field seasons (2011 and 2013) during the non-reproductive period (May-July) (see Appendix). Methods for anthropogenic disturbance site, pinniped identification criteria,

and behavioral data collection were modified from previous studies (Wolf et al. 2005, Wolf et al. 2007a, Wolf and Trillmich 2007, 2008).

Data were collected at three daily intervals three times per week over the two-month field season for four beach localities selected *a priori* for their level of anthropogenic disturbance: Carola, Playa Mann, Oro (Malecón) and Los Marinos (Figure 2). In order to minimize error due to double-counting, beach walks were conducted along the same unidirectional transect from one side of the beach to the other. Further, as another precaution, Sea Lions observed to be emerging or recently emerging from the water were not counted. Only Sea Lions observed on a variety of sand and rock substrates on the beach were noted for data collection. The three daily collection time intervals (fine temporal scale) occurred in the morning (5:00-7:00 am), mid-day (11:30-1:00pm), and afternoon (5:00 pm-6:30 pm). Each census was conducted by 2-3 people. In order to reduce observer bias and promote observer precision and accuracy, the same six people, on a rotating schedule, collected data over the time period. In addition, all observers were consistently trained over a period of two weeks to identify and sex Sea Lions according to the same criteria.

The four beach sample sites range across a spectrum of anthropogenic disturbance and use, with Carola farthest from the highly populated areas of Puerto Baquerizo Moreno, Los Marinos closest, and Mann and Oro in between (Figure 2). Upon arrival at each study site, sand temperature, air temperature, weather conditions, tide level, wave height level, and the number of people present were documented, as well as the type of

human activity being conducted. The type of anthropogenic activity was then classified and ranked according to its level of intensity (0 = no activity, 1 = passive activity (i.e. sunbathing), 2 = active (i.e. construction work, use of machinery to repair boat, etc.). For each beach census, the following information was collected: total number of individuals present, sex and age categories of all present individuals, locations of each individual, as well as substrate type “choices.”

Z. wollebaeki individuals were identified as males, subadult males, females, juveniles, and pups. The different sex/age classes were identified and classified by physical and behavioral characteristics (Table 3). Clustering and grouping information such as group membership, group size and distance to nearest non-group neighbor were also collected. For each sea lion, variables such as shade presence and proximity, proximity to water were also documented. The two combined field seasons (2011 & 2013) yielded a sample size (N) of ~9000 observations. In this study, an “observation” was defined as a sighting of an individual or group of sea lions on a transect. See Appendix, Tables 1 and 2 for further details on data collection.

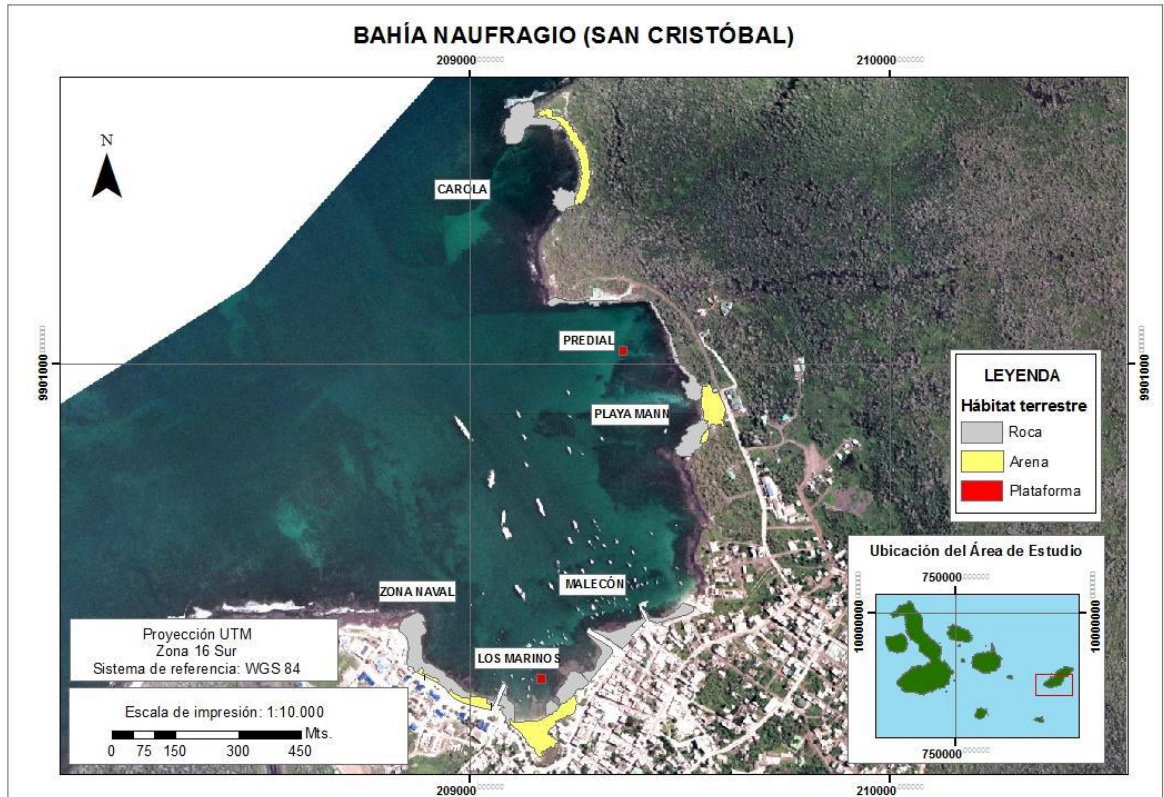


Figure 2. A fine-scale perspective depicting Shipwreck Bay of Puerto Barquerizo Moreno on the island San Cristóbal and its accompanying study sites (Montero Serra 2011). The yellow and grey zones indicate the beach study sites (along Shipwreck Bay) of Carola, Playa Mann, Oro (Malecón) and Los Marinos. Figure modified from Montero (2012).

Data Analysis

Data Spatial Referencing

To place sea lion behavioral data on spatial maps of the beach study sites, standard spatial analysis and data preparation was conducted using a suite of geospatial and statistical software, following reference studies (Wolf et al. 2005, Rossi-Santos et al.

2010). Each beach polygon (representing beach area at low tide) was converted into discrete 5m X 5m quadrants using the ArcGIS10.6.1 Extension Repeating Shapes Tool (Version 1.5.152) (Jenness 2012). Using the dataset of ~9000 observations, sea lion individuals and groups were assigned to these quadrants on each beach, to translate census position data into GPS locations. Microsoft Excel was used for data editing. Spatial analysis of feature and raster layers were conducted through ArcGIS 10.6.1 and ArcGIS Pro.

Large-scale Data Models

To determine the effects of large-scale (temporal-based) beach factors on Galápagos Sea Lions, environmental data were summarized by census (Table 1). We used beach area data to calculate derived and composite variables describing location-based environmental factors for each beach (e.g. Tidal Variability and beach Access Line). The variable beach Access Line was calculated using the Polygon to Centerline Tool for ArcGIS (Version 9_3_10_1) (Dilts 2015). The tool generated a line running laterally from end of the beach to the other, remaining parallel to the water line and equidistant from either edge of the polygon. Beach Tidal Variability was calculated using this formula:

$$\frac{\text{Beach area at low tide} - \text{Beach area at high tide}}{\text{Beach length}}$$

This metric also served as a proxy for beach slope.

We used Generalized Linear Mixed Model regressions (GLMM) to investigate the relationships between Galápagos Sea Lion social metrics (i.e., the numbers of groups

and individuals observed in each sex and age class) and environmental factors (Table 1). A GLMM allows us to detect effects of specific environmental factors while including location variables (Beach Locality and Habitat Site) as random factors to control for spatial autocorrelation. Models were fit using the “meglm” STATA command and a negative binomial distribution (to account for overdispersion of count data) and log link through STATA 15, and following the general strategy of Wolf et al. (2005). One model was fit at a large spatial scale (whole beaches) but still accounted for each environmental variable, as well as temporal variation across censuses (Table 1). Another model was fit at a fine spatial scale (per habitat site) that grouped environmental variables into distinct habitat types (Table 2). Results were obtained for both standardized and unstandardized variables.

Variables with high levels of collinearity were omitted from the final models. Thus, while sand and air temperatures were measured in both shade and sun, we omitted sun measurements due to collinearity with their shade counterparts). As both shade and sun measurements could not be kept in the model, we decided to keep shade measurements, based on the demonstrated ecological importance of shade in sea lion behavioral ecology (Wolf *et al.* 2005).

As a robustness check, we fit additional models that included dummy variables for each beach. These variables were included to absorb time-invariant factors that differ among beaches and so might be confounded with other variables of interest. In particular, we wanted to distinguish apparent effects of human presence from other factors that

might vary among beaches (see Results). Due to collinearity, these models omitted Access Line and Tidal Variability as explanatory variables. In addition, collinearity between Oro Beach and Marinos Beach meant that both dummy variables could not be included at the same time, so, we fit one model that omitted Oro Beach and another that omitted Marinos Beach (to account for both options).

Next, to determine which model compositions perform best and which factors held particular usefulness in the models, we conducted a Model Averaging and Model selection analysis. This was performed only for the large-scale analysis, since the fine-scale model had only a single fixed predictor (habitat type). To prevent overloading the model and to facilitate analysis, only the significant variables obtained from the previous GLMM results were included in the model averaging/selection analysis. This approach also served to maximize parsimony while simplifying the model (Burnham et al. 2011a, Burnham et al. 2011b, Symonds and Moussalli 2011). The MIINC package in STATA 15 (Luchman 2014) was used to conduct the Model Averaging & Model Selection Analysis.

Fine-scale Models

To determine the effects of fine-scale (spatial-based) variation within beaches on sea lion behavioral habitat choice, we first classified beach zones into discrete habitat types (Tables 2 & 3). To define habitat types, various habitat factors were combined and aggregated. First, we combined beach quadrants were combined into 149 “habitat sites” such that each site contained ~50 observations and had homogenous environmental traits within the site (Figure 3). Thus, a “habitat site” is defined as a delineated subset area on a

beach (depicted in Figure 3). By equalizing the number of observations in each site, the density (number of observations/sq m of area) was of relative habitat type use between sites was able to be compared (Wolf et al. 2005). Second, to determine habitat type, we condensed the environmental factors (water accessibility, surface type, tide pool presence, inclination, anthropogenic shade, vegetation shade, structural complexity, and Tidal Variability) into six discrete habitat types through a K-Means Clustering analysis. The K-Means Clustering analysis was conducted using the “Multivariate Clustering” Geoprocessing tool in ArcGIS Pro, with the specifications of “6” as a cluster number restraint (similar to Wolf *et al.* 2005) and “Optimized Seeds” for starting seeds (Table 3). Our initial choice of six as the number of habitat types stemmed from previous results of Wolf et al. (2005); subsequent examination of the spatial and visual results showed that the resulting clusters effectively delineated discrete habitat types, thus we opted to keep these six final habitat types.

We used GLMMs to model the relationships between each social metric and habitat type (Table 2). Unlike the large-scale analysis, we did not perform model selection, since the fine-scale model had only a single fixed predictor (habitat type).

Table 1. Description of GLMM Model at large spatiotemporal scale (per census).

Generalized Linear Mixed Model		
Response Variables (Social Metrics)	Explanatory Variables (Environmental Factors)	Variable Measurement Unit
<ul style="list-style-type: none"> - Number of Females - Number of Juveniles - Number of Males - Number of Pups - Number of Subadult Males - Number of Groups - Number of Dyads - Number of Female-Juvenile Dyads - Number of Female-Pup Dyads 	Beach Access Length	Meters
	Beach Tidal Variability	Area (m ²)/Length (m)
	Count of People Present*	Count
	Human Activity Level*	Categories (0,1,2)
	Sand Surface Temperature	Degrees Celsius
	Air Temperature	Degrees Celsius
	Weather Conditions	Categories (Sunny, Rainy, Cloudy)
	Tide Level	Categories (High, Low)
	Wave Height	Categories (0, 1, 2, 3)
	Time of Day	Categories (Morning, Midday, Afternoon)
	Beach Location (Model Random Effect)	Categories (Carola, Mann, Oro, Marinos)

*Anthropogenic

Table 2. Description of GLMM Model at fine spatial scale (per habitat type).

Generalized Linear Mixed Model		
Response Variables (Social Metrics)	Explanatory Variables (Environmental Factors)	Variable Measurement Unit
<ul style="list-style-type: none"> - Number of Females - Number of Juveniles - Number of Males 	Habitat Type	Categories (1, 2, 3, 4, 5, 6)
<ul style="list-style-type: none"> - Number of Pups - Number of Subadult Males - Number of Groups - Number of Dyads - Number of Female-Juvenile Dyads - Number of Female-Pup Dyads 	Habitat Site (Model Random Effect)	Categories (Habitat Site ID)

Table 3. (a) Definitions of specific habitat traits. **(b)** Definitions of habitat types determined through spatial K-Means Clustering analysis. Six distinct habitat types were defined and identified (methodologies and definitions adapted from Wolf et al. 2005).

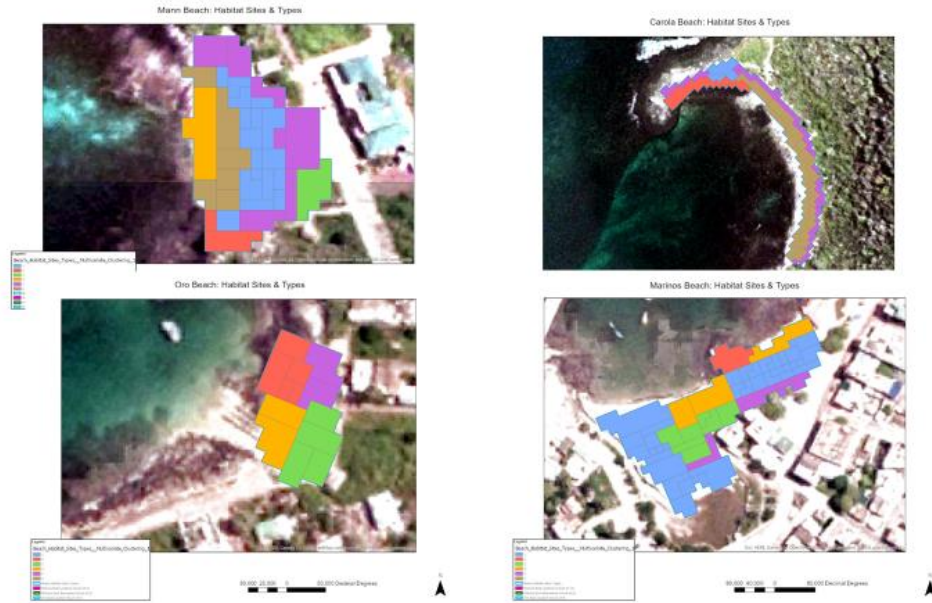
(a)

Habitat Trait	Description	Trait States
Water Accessibility	Relative distance to water's edge within the context of each beach	Direct / Close / Far
Surface	Predominant substrate type	Sand / rock
Tide Pools	Presence of tide pools formed at different tide levels	Yes / No
Inclination	Slope of beach site	Flat / Steep
Anthropogenic Shade	Presence of man-made shade (i.e. buildings, boats, etc.)	Yes / No
Vegetation Shade	Presence of shade from vegetation (i.e. saltbush, shrubs, trees, etc.)	Yes / No
Structural Complexity	Visual estimation of terrain relief variation within a beach habitat site	Simple / Complex
Tidal Variability	(Beach Area at Low tide (m ²) - Beach Area at High Tide (m ²))/Beach Length (m)	Low / High (Low (>10); High (<10))

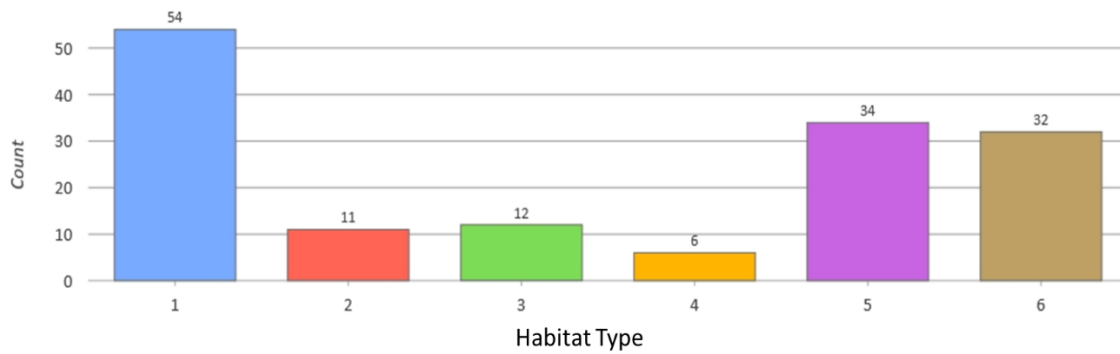
(b)

HABITAT TYPE	HABITAT SUBTYPE	WATER ACCESSIBILITY	SURFACE	TIDE POOLS	INCLINATION	ANTHROPOGENIC SHADE	VEGETATION SHADE	STRUCTURAL COMPLEXITY	TIDAL VARIABILITY TYPE	BEACH NAME
1	1a	direct/close	sand	no	flat	no	no	complex	high	Marinos, Mann, Carola
	1b	direct/close	sand	no	flat	no	yes	complex	high	
	1c	direct/close	sand	no	flat	no	no	simple	high	
	1d	direct/close	sand	no	flat	no	no	complex	low	

	1e	direct/close	sand	no	flat	no	no	simple	low	
	1f	far	sand	no	flat	no	no	simple	low	
	1g	far	sand	no	flat	no	no	simple	high	
2	2a	direct/close	rock	yes	flat	no	no	complex	low	Marinos, Mann, Oro, Carola
	2b	direct/close	rock	yes	flat	no	no	complex	high	
	2c	direct/close	rock	no	flat	no	yes	complex	low	
	2d	direct/close	rock	no	flat	no	no	complex	low	
3	3a	far	sand	no	flat	yes	no	simple	high	Marinos, Oro, Mann
	3b	far	sand	no	flat	yes	yes	simple	low	
	3c	far	sand	no	flat	yes	no	simple	low	
4	4a	direct/close	sand	yes	flat	no	no	simple	high	Marinos, Oro, Mann
	4b	direct/close	sand	yes	flat	yes	no	complex	high	
	4c	direct/close	sand	yes	flat	yes	yes	complex	low	
	4d	direct/close	sand	yes	steep	no	no	complex	low	
5	5a	direct/close	sand	no	flat	no	yes	complex	low	Marinos, Oro, Mann, Carola
	5b	far	sand	no	steep	no	yes	simple	low	
	5c	far	sand	no	steep	no	yes	simple	low	
	5d	far	sand	no	steep	no	yes	complex	low	
	5e	far	sand	no	steep	no	yes	simple	low	
6	6a	direct/close	sand	no	steep	no	no	simple	low	Mann, Carola
	6b	direct/close	sand	no	steep	no	no	complex	low	
	6c	far	sand	no	steep	no	no	complex	low	



(a)



(b)

Figure 3. (a) Identification of six distinct habitat types on four beaches (Carola, Mann, Oro, and Los Marinos) on the Shipwreck Bay of San Cristóbal island, in the Galápagos islands. (b) Legend of beach habitat type and count of habitat sites per type.

Results

Large-scale Models

The length of the beach Access Line had a strong positive relationship with all social metrics except males and female/pup dyads (Table 4). Longer access lines provide more usable space and the likelihood of more diverse habitats for sea lions. Low Tidal Variability was also significantly associated with higher counts for all categories of sea lion, except for female/pup dyads. Low Tidal Variability is a positive indicator of beaches where available sand/rock area is minimally impacted by changing tide levels, showing high beach slope (i.e. topography inclination).

Air Temperature significantly influenced the occurrence of most sea lion social metrics. Male sea lions, pups, and female-pup dyads “preferred” higher air temperatures, while all other groups occurred more at lower temperatures.

The four beaches varied in observed level of anthropogenic use; their ranking from lowest to highest was Carola, Mann, Oro, and Marinos. The beach with the lowest Tidal Variability (Carola) also presented the least anthropogenic alteration and human visitor presence, perhaps encouraging more sea lion presence and haul-off sites. Nevertheless, count of people present was found to have a significant and positive relationship to many of the same social metrics: number of males, number of total sea lions, number of groups, and number of dyads.

In instances of High Anthropogenic Use (different from Count of People of Present), groups and dyads were less likely to form. Other individuals with lower social ranking and group acceptance, such as subadult males and bachelor males, may still use these habitats as daytime haul outs.

We fit additional models to test the robustness of the apparent effects of human metrics (i.e., count of people present and anthropogenic use level). These models included beach identity as dummy variables, to detect correlations across beaches between human metrics and other time-invariant factors of importance to the Sea Lions. The overall strength and direction of effects remained the same as the global model, but a few environmental variables previously significant at $\alpha = 0.05$, were now found to be only significant at $\alpha = 0.1$ or wholly insignificant (Tables 4a & 4c). Count of People Present had a significant relationship to two social metrics: males and groups (Table 4b & 4c), in comparison to five social metrics in the global model (Table 4a). There were no significant relationships detected between the Low Anthropogenic Use level and any of the sea lion metrics ($\alpha=0.05$), similar to the global model. However, High Anthropogenic Use remained significantly (and negatively) related with number of groups ($\alpha=0.05$). This same measure of human presence went from being significantly related with number of sea lion dyads at $\alpha=0.05$ (Table 4a) to $\alpha=0.1$ (Table 4b).

The averaged model results, based on significant variables from the GLMM, largely supported the original global GLMM: Access line, High Tidal Variability, and Air

Temperature were found to be consistently strong variables (Table 5). The Appendix contains further details on model selection, including the top 10 best models and results with standardized coefficients.

In terms of model fit by AIC (Akaike Information Criterion), the global model consistently outperformed the selected best model (Table 6). These results may be reflective of the original narrow composition of the model selection analysis (only significant variables stemming from the global GLMM were included in the model selection analysis). As all models with $\Delta AIC < 2$ relative to the best model are found to have similar performance, only the results from the top model were included in the results (Burnham et al. 2011b) (A full set of best models is included in the Appendix). The social metrics with the most model similarities between the global model and the best model were males and female-juvenile dyad ($\Delta AIC < 5$). For these two social metrics, the global and best models may be interchangeably applied in active conservation management practices, as they yield the same approximate performance. The social metrics with the highest differences between the global and the best model were subadult males, total number of sea lions, and number of groups ($\Delta AIC > 20$). The high discrepancy between the two models indicates that global models are the optimal choice towards identifying and quantifying environmental factors crucial to those three population segments' wellbeing.

Fine-scale Models

At the fine-scale level, Habitat Types 2, 5, and 6 were found to have the most significant relationships with Galápagos Sea Lion social metrics (Table 7; habitat types are defined in Table 3b). Specifically, Habitat Type 2 was positively associated with number of males and negatively associated with number of juveniles, dyads, and groups. Habitat 2 was characterized by direct, closer access to water, flat slope, with rock substrate, little shade and complex vegetation.

Habitat Type 5 (habitat types are defined in Table 3b) also strongly estimated 4 out of 10 social metrics; it was positively linked to number of males and negatively linked to numbers of juveniles, dyads, and females (Table 7; habitat types are defined in Table 3b). Habitat 5 was characterized by farther access to water, steep slope, sandy substrate, slightly more shade and less complex vegetation.

Habitat Type 6 had significant relationships with six of the ten social metrics. (Table 7; habitat types are defined in Table 3b). It was positively associated with number of males and negatively associated with numbers of juveniles, dyads, groups, pups, and total number of sea lions. Habitat 6 was similar to habitat 5, but with no shading and areas of more direct water access.

Table 4. (a) Generalized linear mixed model results- unstandardized effects of a suite of environmental variables and subtypes on Galápagos Sea Lion social metrics on San Cristóbal Island. (Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1; significant values in red for p<0.05 or p<0.01). **(b)** Robustness check with three beach dummy variables (Oro Beach, access line and Tidal Variability excluded) **(c)** Robustness Check with three beach dummy variables (Marinos Beach excluded).

(a)

ENVIRONMENTAL VARIABLES	Females	Juveniles	Males	Pups	Subadult Males	Total	Groups	Dyads	Female-Juvenile Dyads	Female-Pup Dyads
Access Line (m)	1.320*** (0.134)	1.499*** (0.0970)	0.182 (0.145)	1.394*** (0.201)	0.573*** (0.136)	1.154*** (0.0808)	1.276*** (0.215)	1.232*** (0.262)	1.491*** (0.305)	0.786 (0.587)
Low Tidal Variability	11.34*** (1.081)	12.27*** (0.783)	2.630** (1.154)	11.20*** (1.630)	5.238*** (1.090)	9.822*** (0.646)	10.85*** (1.711)	10.43*** (2.088)	12.39*** (2.439)	6.767 (4.682)
Count of People Present	0.00973 (0.00692)	0.0103** (0.00527)	0.0190** (0.00740)	-0.000853 (0.0112)	0.00815 (0.00771)	0.0103** (0.00447)	0.0142** (0.00585)	0.0129** (0.00641)	0.0149* (0.00878)	-0.00141 (0.0150)
Low Anthropogenic Use	0.250 (0.212)	0.281* (0.171)	-0.0376 (0.278)	-0.211 (0.382)	0.422* (0.248)	0.203 (0.150)	0.0877 (0.181)	-0.0116 (0.200)	0.263 (0.253)	-1.001 (0.636)
High Anthropogenic Use	-0.209 (0.137)	-0.185 (0.107)	0.0943 (0.158)	0.134 (0.228)	-0.128 (0.155)	-0.148 (0.0908)	-0.337*** (0.125)	-0.285** (0.139)	-0.246 (0.184)	-0.0132 (0.333)
Sand Temperature	-0.0470 (0.0302)	-0.0403* (0.0241)	-0.0284 (0.0375)	-0.0861 (0.0563)	-0.0719** (0.0351)	-0.0500** (0.0211)	-0.0490* (0.0293)	-0.0409 (0.0325)	-0.0267 (0.0419)	-0.155* (0.0908)
Air Temperature	-0.132*** (0.0406)	-0.0786** (0.0328)	0.144*** (0.0436)	0.241*** (0.0702)	-0.0360 (0.0445)	-0.0359 (0.0281)	-0.107*** (0.0363)	-0.109*** (0.0399)	-0.216*** (0.0568)	0.250*** (0.0958)
Rainy Weather Conditions	-0.222 (0.155)	-0.246* (0.133)	-0.550** (0.218)	0.303 (0.290)	-0.389** (0.192)	-0.251** (0.114)	-0.274* (0.140)	-0.195 (0.154)	-0.279 (0.197)	0.207 (0.376)
Sunny Weather Conditions	-0.238* (0.145)	-0.336*** (0.123)	-0.541*** (0.186)	-0.234 (0.272)	-0.466*** (0.179)	-0.326*** (0.104)	-0.264 (0.141)	-0.252 (0.155)	-0.386* (0.210)	-0.255 (0.382)
Low Tide Level	-0.0873 (0.130)	-0.131 (0.110)	0.109 (0.167)	-0.404 (0.233)	0.152 (0.160)	-0.0509 (0.0945)	0.0277 (0.125)	-0.00535 (0.137)	-0.0755 (0.177)	-0.509 (0.337)
Medium Tide Level	-0.264* (0.141)	-0.197* (0.117)	0.163 (0.174)	-0.360 (0.242)	-0.153 (0.101)	-0.160 (0.101)	-0.222* (0.130)	-0.235 (0.144)	-0.344* (0.189)	-0.228 (0.336)
Wave Height Level 1	-0.0402 (0.164)	0.116 (0.132)	0.511** (0.199)	0.300 (0.284)	0.0341 (0.184)	0.0848 (0.111)	-0.108 (0.147)	-0.184 (0.162)	0.0212 (0.214)	-0.369 (0.413)
Wave Height Level 2	0.0237 (0.185)	0.103 (0.153)	0.522** (0.228)	0.145 (0.337)	0.208 (0.214)	0.150 (0.127)	0.0543 (0.165)	-0.00678 (0.181)	-0.0193 (0.247)	0.0683 (0.447)
Wave Height Level 3	0.129 (0.198)	0.333** (0.146)	0.615*** (0.223)	0.379 (0.317)	0.199 (0.210)	0.313** (0.126)	0.354** (0.176)	0.181 (0.193)	0.341 (0.261)	-0.180 (0.470)
Midday	-0.0216 (0.152)	0.219* (0.127)	-0.407** (0.182)	-0.573** (0.266)	-0.299 (0.184)	-0.0786 (0.106)	-0.158 (0.143)	-0.133 (0.157)	0.208 (0.219)	-0.577 (0.360)
Morning	-0.0221 (0.180)	0.0190 (0.152)	0.537** (0.235)	0.720** (0.339)	-0.138 (0.210)	0.0858 (0.130)	0.0475 (0.155)	-0.0103 (0.171)	-0.0967 (0.218)	0.323 (0.460)
Constant	-7.050*** (1.688)	-10.48*** (1.209)	-3.348 (1.785)	-17.49*** (2.622)	-1.589 (1.758)	-6.406*** (1.032)	-7.690*** (2.490)	-7.495** (3.014)	-8.865** (3.572)	-10.41 (6.890)

Observations	100	100	100	100	100	100	93	93	93	93
Number of groups	4	4	4	4	4	4	4	4	4	4

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

(b)

ENVIRONMENTAL VARIABLES	Females	Juveniles	Males	Pups	Subadult Males	Total	Groups	Dyads	Female-Pup Dyads	Female- Juvenile Dyads
Count of People Present	0.00612 (0.00635)	0.00812 (0.00544)	0.0161** (0.00770)	-0.00414 (0.0115)	0.00849 (0.00803)	0.00796* (0.00459)	0.0124** (0.00564)	0.0111* (0.00619)	-0.00480 (0.0143)	0.0119 (0.00843)
Low Anthropogenic Use	0.176 (0.200)	0.243 (0.171)	-0.0877 (0.279)	-0.278 (0.381)	0.431* (0.255)	0.153 (0.150)	0.0543 (0.176)	-0.0441 (0.194)	-1.125* (0.627)	0.216 (0.244)
High Anthropogenic Use	-0.150 (0.128)	-0.144 (0.110)	0.136 (0.161)	0.179 (0.230)	-0.133 (0.158)	-0.110 (0.0918)	-0.313** (0.122)	-0.260* (0.135)	0.0251 (0.325)	-0.204 (0.179)
Sand Temperature	-0.0392 (0.0290)	-0.0347 (0.0242)	-0.0209 (0.0377)	-0.0774 (0.0562)	-0.0727** (0.0356)	-0.0439** (0.0210)	-0.0429 (0.0285)	-0.0345 (0.0315)	-0.135 (0.0879)	-0.0173 (0.0406)
Air Temperature	-0.129*** (0.0395)	-0.0790** (0.0325)	0.147*** (0.0434)	0.244*** (0.0697)	-0.0356 (0.0446)	-0.0356 (0.0277)	-0.107*** (0.0355)	-0.110*** (0.0389)	0.250*** (0.0931)	0.217*** (0.0552)
Rainy Weather Conditions	-0.219 (0.152)	-0.235* (0.133)	-0.532** (0.218)	0.315 (0.290)	-0.390** (0.192)	-0.243** (0.113)	-0.266* (0.137)	-0.186 (0.151)	0.223 (0.365)	-0.257 (0.191)
Sunny Weather Conditions	-0.227 (0.141)	-0.324*** (0.122)	-0.533*** (0.185)	-0.251 (0.270)	-0.469*** (0.180)	-0.318*** (0.102)	-0.248* (0.139)	-0.236 (0.152)	-0.252 (0.378)	-0.354* (0.205)
Low Tide Level	-0.0837 (0.127)	-0.131 (0.109)	0.108 (0.166)	-0.389* (0.233)	0.151 (0.161)	-0.0452 (0.0932)	0.0279 (0.122)	-0.00498 (0.134)	-0.522 (0.329)	-0.0738 (0.173)
Medium Tide Level	-0.235* (0.136)	-0.184 (0.117)	0.192 (0.174)	-0.321 (0.243)	-0.156 (0.174)	-0.139 (0.0997)	-0.203 (0.127)	-0.217 (0.140)	-0.179 (0.327)	-0.318* (0.184)
Wave Height Level 1	-0.108 (0.155)	0.0759 (0.134)	0.463** (0.202)	0.238 (0.290)	0.0398 (0.188)	0.0431 (0.112)	-0.153 (0.142)	-0.230 (0.156)	-0.504 (0.394)	-0.0575 (0.204)
Wave Height Level 2	-0.0363 (0.178)	0.0643 (0.154)	0.488** (0.229)	0.114 (0.338)	0.213 (0.216)	0.114 (0.128)	0.0220 (0.161)	-0.0407 (0.176)	-0.0105 (0.432)	-0.0752 (0.238)
Wave Height Level 3	0.00649 (0.176)	0.257* (0.154)	0.510** (0.238)	0.265 (0.332)	0.211 (0.224)	0.230* (0.131)	0.284* (0.167)	0.110 (0.184)	-0.390 (0.446)	0.230 (0.246)

Midday	-0.0353 (0.149)	0.211* (0.126)	-0.423** (0.181)	-0.568** (0.265)	-0.299 (0.184)	-0.0879 (0.105)	-0.165 (0.140)	-0.140 (0.154)	-0.585* (0.350)	0.191 (0.214)
Morning	0.00164 (0.175)	0.0344 (0.151)	0.554** (0.235)	0.736** (0.338)	-0.140 (0.210)	0.0996 (0.128)	0.0570 (0.152)	0.000108 (0.167)	0.327 (0.453)	-0.0793 (0.212)
Carola Beach	1.973*** (0.174)	1.525*** (0.153)	1.421*** (0.203)	1.261*** (0.315)	1.075*** (0.201)	1.562*** (0.120)	1.857*** (0.168)	1.799*** (0.186)	1.777*** (0.499)	1.982*** (0.271)
Mann Beach	1.085*** (0.168)	0.998*** (0.150)	0.327 (0.206)	1.048*** (0.302)	0.274 (0.209)	0.807*** (0.116)	1.230*** (0.168)	1.321*** (0.186)	1.906*** (0.499)	1.598*** (0.272)
Marinos Beach	1.843*** (0.157)	2.043*** (0.136)	0.291 (0.193)	1.935*** (0.279)	0.746*** (0.187)	1.566*** (0.107)	1.792*** (0.159)	1.747*** (0.175)	1.366*** (0.499)	2.171*** (0.256)
Oro Beach (omitted)	-	-	-	-	-	-	-	-	-	-
Constant	6.097*** (0.953)	4.698*** (0.808)	-1.809 (1.247)	-3.589** (1.728)	4.321*** (1.133)	5.215*** (0.696)	5.052*** (0.883)	4.742*** (0.978)	-3.416 (2.418)	5.860*** (1.301)
Observations	100	100	100	100	100	100	93	93	93	93
Number of groups	4	4	4	4	4	4	4	4	4	4

Standard errors in
parentheses
*** p<0.01, **
p<0.05, * p<0.1

(c)

ENVIRONMENTAL VARIABLES	Females	Juveniles	Males	Pups	Subadult Males	Total	Groups	Dyads	Female-Pup Dyads	Female- Juvenile Dyads
Count of People Present	0.00612 (0.00635)	0.00812 (0.00544)	0.0161** (0.00770)	-0.00414 (0.0115)	0.00849 (0.00803)	0.00796* (0.00459)	0.0124** (0.00564)	0.0111* (0.00619)	-0.00480 (0.0143)	0.0119 (0.00843)
Low Anthropogenic Use	0.176 (0.200)	0.243 (0.171)	-0.0877 (0.279)	-0.278 (0.381)	0.431* (0.255)	0.153 (0.150)	0.0543 (0.176)	-0.0441 (0.194)	-1.125* (0.627)	0.216 (0.244)
High Anthropogenic Use	-0.150 (0.128)	-0.144 (0.110)	0.136 (0.161)	0.179 (0.230)	-0.133 (0.158)	-0.110 (0.0918)	-0.313** (0.122)	-0.260* (0.135)	0.0251 (0.325)	-0.204 (0.179)
Sand Temperature	-0.0392 (0.0290)	-0.0347 (0.0242)	-0.0209 (0.0377)	-0.0774 (0.0562)	-0.0727** (0.0356)	-0.0439** (0.0210)	-0.0429 (0.0285)	-0.0345 (0.0315)	-0.135 (0.0878)	-0.0173 (0.0406)
Air Temperature	-0.129*** (0.0395)	-0.0790** (0.0325)	0.147*** (0.0434)	0.244*** (0.0697)	-0.0356 (0.0446)	-0.0356 (0.0277)	-0.107*** (0.0355)	-0.110*** (0.0389)	0.250*** (0.0931)	0.217*** (0.0552)
Rainy Weather Conditions	-0.219 (0.152)	-0.235* (0.133)	-0.532** (0.218)	0.315 (0.290)	-0.390** (0.192)	-0.243** (0.113)	-0.266* (0.137)	-0.186 (0.151)	0.223 (0.365)	-0.257 (0.191)
Sunny Weather Conditions	-0.227 (0.141)	-0.324*** (0.122)	-0.533*** (0.185)	-0.251 (0.270)	-0.469*** (0.180)	-0.318*** (0.102)	-0.248* (0.139)	-0.236 (0.152)	-0.252 (0.378)	-0.354* (0.205)
Low Tide Level	-0.0837 (0.127)	-0.131 (0.109)	0.108 (0.166)	-0.389* (0.233)	0.151 (0.161)	-0.0452 (0.0932)	0.0279 (0.122)	-0.00498 (0.134)	-0.522 (0.328)	-0.0738 (0.173)
Medium Tide Level	-0.235* (0.136)	-0.184 (0.117)	0.192 (0.174)	-0.321 (0.243)	-0.156 (0.174)	-0.139 (0.0997)	-0.203 (0.127)	-0.217 (0.140)	-0.179 (0.327)	-0.318* (0.184)
Wave Height Level 1	-0.108 (0.155)	0.0759 (0.134)	0.463** (0.202)	0.238 (0.290)	0.0398 (0.188)	0.0431 (0.112)	-0.153 (0.142)	-0.230 (0.156)	-0.504 (0.394)	-0.0575 (0.204)
Wave Height Level 2	-0.0363 (0.178)	0.0643 (0.154)	0.488** (0.229)	0.114 (0.338)	0.213 (0.216)	0.114 (0.128)	0.0220 (0.161)	-0.0407 (0.176)	-0.0106 (0.432)	-0.0752 (0.238)
Wave Height Level 3	0.00649 (0.176)	0.257* (0.154)	0.510** (0.238)	0.265 (0.332)	0.211 (0.224)	0.230* (0.131)	0.284* (0.167)	0.110 (0.184)	-0.390 (0.446)	0.230 (0.246)

Midday	-0.0353 (0.149)	0.211* (0.126)	-0.423** (0.181)	-0.568** (0.265)	-0.299 (0.184)	-0.0879 (0.105)	-0.165 (0.140)	-0.140 (0.154)	-0.585* (0.350)	0.191 (0.214)
Morning	0.00164 (0.175)	0.0344 (0.151)	0.554** (0.235)	0.736** (0.338)	-0.140 (0.210)	0.0996 (0.128)	0.0570 (0.152)	0.000108 (0.167)	0.327 (0.453)	-0.0793 (0.212)
Carola Beach	0.130 (0.149)	-0.519*** (0.125)	1.131*** (0.188)	-0.674*** (0.258)	0.329* (0.182)	-0.00421 (0.110)	0.0643 (0.132)	0.0521 (0.147)	0.411 (0.371)	-0.189 (0.190)
Mann Beach	-0.758*** (0.139)	-1.046*** (0.118)	0.0368 (0.188)	-0.888*** (0.245)	-0.472*** (0.179)	-0.759*** (0.102)	-0.562*** (0.127)	-0.427*** (0.139)	0.540 (0.357)	0.573*** (0.179)
Oro Beach	-1.843*** (0.157)	-2.043*** (0.136)	-0.291 (0.193)	-1.935*** (0.279)	-0.746*** (0.187)	-1.566*** (0.107)	-1.792*** (0.159)	-1.747*** (0.175)	-1.366*** (0.499)	2.171*** (0.256)
Constant	7.940*** (0.971)	6.742*** (0.823)	-1.518 (1.279)	-1.654 (1.738)	5.067*** (1.148)	6.781*** (0.708)	6.844*** (0.885)	6.489*** (0.978)	-2.051 (2.391)	8.031*** (1.295)
Observations	100	100	100	100	100	100	93	93	93	93
Number of groups	4	4	4	4	4	4	4	4	4	4

Standard errors in
parentheses
*** p<0.01, **
p<0.05, * p<0.1

Table 5. Results of averaged models of unstandardized effects of a suite of environmental variables on Galápagos Sea Lion social metrics on San Cristóbal Island. (Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1; significant values in red for p<0.05 or p<0.01).

ENVIRONMENTAL VARIABLES	Females	Juveniles	Males	Pups	Subadult Males	Total	Groups	Dyads	Female-Juvenile Dyads	Female-Pup Dyads
Tidal Variability	10.96***	11.87***	1.215***	12.13***	4.760***	9.646***	8.760**	7.211	7.981	
	(2.859)	(2.161)	(0.184)	(2.039)	(1.348)	(1.810)	(3.993)	(5.187)	(6.611)	
Count of People Present			0.0202**			0.000986	0.00698	0.00287		
			(0.00792)			(0.00284)	(0.00737)	(0.00540)		
Air Temperature	-0.162***	-0.0584**	0.0937***	0.0830			-0.145***	-0.159***	-0.211***	-
	(0.0220)	(0.0241)	(0.0324)	(0.0632)			(0.0233)	(0.0242)	(0.0291)	0.00136
Rainy Weather Conditions		-0.0202	-0.649***		-0.187	-0.196				
		(0.0759)	(0.251)		(0.209)	(0.150)				
Sunny Weather Conditions		-0.337***	-0.531**		-0.590***	-0.444***				
		(0.127)	(0.230)		(0.169)	(0.0952)				
Wave Height Level 1		0.000747	0.499*			-0.0227	-0.0479			
		(0.0551)	(0.288)			(0.0718)	(0.108)			
Wave Height Level 2		-0.0261	0.415			0.0626	0.00706			
		(0.0775)	(0.303)			(0.104)	(0.0813)			
Wave Height Level 3		0.0541	0.563*			0.102	0.383**			
		(0.0995)	(0.299)			(0.123)	(0.176)			

Midday			-0.227	-0.267						
			(0.227)	(0.303)						
Morning			0.532**	0.628**						
			(0.246)	(0.299)						
Access Line	1.275***	1.449***	1.509***	0.519***	1.131***	1.024**	0.825	0.949		
	(0.351)	(0.268)	(0.254)	(0.167)	(0.223)	(0.489)	(0.634)	(0.816)		
Sand Temperature				-0.0589*	-0.0629***					
				(0.0334)	(0.0179)					
Low Anthropogenic Use						-0.0200	-0.00410			
						(0.102)	(0.0975)			
High Anthropogenic Use						-0.425***	-0.159			
						(0.141)	(0.150)			
Constant	-7.269*	-11.42***	-0.716	-17.15***	-2.185	-6.634***	-5.380	-3.143	-3.953	-0.0663
	(3.863)	(2.968)	(0.783)	(3.099)	(1.952)	(2.463)	(5.366)	(6.967)	(8.953)	(1.221)
Observations	102	101	101	102	106	103	94	95	95	95
Number of groups	4	4	4	4	4	4	4	4	4	4

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table 6. Comparative Global Model (GM) & Best Model (BM) components (regression coefficients & AICc-weight posterior inclusion probabilities (PIP)) for *Z. wollebaeki* social metrics. Dash marks represent variables excluded from the model in the model selection process. The regression coefficients show the relationship between each social metric and environmental factor. The AICc-weight PIP values show differential use for each explanatory environmental variable, depending on social metric. Overall, “Access Line” and “Low Tidal Variability” are found to have strong PIP values (between 0.5 and 1) (** $p < 0.01$, * $p < 0.05$, * $p < 0.1$; significant values in red for $p < 0.05$ or $p < 0.01$). Note - Female-Pup Dyads did not have a Best Model analysis, as only one factor was found to be significant in the original Global Model GLMM.

Estimated Social Metric	Model Type	Access Line (m)	Low Tidal Variability	Count of People Present	Low Anthropogenic Use	High Anthropogenic Use	Sand Temperature	Air Temperature	Rainy Weather Conditions	Sunny Weather Conditions	Wave Height Level 1	Wave Height Level 2	Wave Height Level 3	Midday	Morning	Constant (Intercept Term)	AICc	Δ AICc
Females	GM Regression Coefficients	1.32***	11.34***	0.01	0.25	-0.21	-0.05	-0.13***	-0.22	-0.24*	-0.04	0.02	0.13	-0.02	-0.02	-7.05***	720.5241	0
	BM Regression Coefficients	1.34	11.51	-	-	-	-	-0.16	-	-	-	-	-	-	-	-8	733.0	12.4759
	Best Model PIP	0.96	0.97	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--
Juveniles	GM Regression Coefficients	1.50***	12.27***	0.01*	0.281*	-0.19*	-0.04*	-0.08**	-0.25*	-0.34***	0.12	0.10	0.33**	0.22*	0.02	-10.48***	706.9762	0
	BM Regression Coefficients	1.49	12.21	--	--	--	--	-0.06	--	-0.34	--	--	--	--	--	-11.88	715.3	8.3238
	Best Model PIP	0.98	0.98	--	--	--	--	0.96	0.27	0.97	0.24	0.29	0.39	--	--	--	--	--
Males	GM Regression Coefficients	0.18	2.63*	0.02*	-0.0376	0.09	-0.03	0.14***	-0.55**	-0.54***	0.51**	0.52**	0.62***	-0.41**	0.54**	-3.35*	623.291	0
	BM Regression Coefficients	--	1.22	0.02	--	--	--	0.1	-0.65	-0.55	0.6	0.52	0.64	-0.31	0.5	-0.84	627.9	4.609
	Best Model PIP	--	0.99	0.97	--	--	--	0.99	0.96	0.95	0.89	0.78	0.91	0.64	0.93	--	--	--
Pups	GM Regression Coefficients	1.39***	11.20***	0	-0.211	0.13	-0.09	0.24***	0.30	-0.23	0.30	0.15	0.38	-0.57**	0.72**	-17.49***	542.4776	0

FINE-SCALE RESULTS

Table 7. GLMM Model Results of unstandardized effects of a suite of six distinct habitat types (HT) on Galápagos Sea Lion social metrics on San Cristóbal Island. HT1 is the reference group used for comparison to other habitat types, and is thus omitted from the final results. (Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1; significant values in red for p<0.05 or p<0.01).

Habitat Type	Females	Juveniles	Males	Pups	Subadult Males	Total	Groups	Dyads	Female-Pup Dyads	Female-Juvenile Dyads
HT2	0.0400 (0.141)	-0.347** (0.168)	0.708*** (0.233)	0.0296 (0.231)	0.296 (0.197)	0.0267 (0.0985)	-0.600*** (0.177)	-0.528*** (0.190)	-1.182 (1.103)	-0.877* (0.475)
HT3	-0.285** (0.132)	-0.106 (0.147)	0.304 (0.225)	0.109 (0.200)	0.311* (0.176)	-0.0558 (0.0879)	-0.155 (0.137)	-0.0740 (0.146)	-0.380 (0.717)	-0.124 (0.342)
HT4	-0.0565 (0.179)	-0.0544 (0.203)	0.327 (0.306)	0.0214 (0.288)	0.150 (0.254)	0.0261 (0.123)	-0.138 (0.194)	-0.0742 (0.207)	0.419 (0.801)	0.245 (0.447)
HT5	-0.222** (0.0892)	-0.356*** (0.104)	1.035*** (0.149)	-0.214 (0.148)	0.0559 (0.129)	0.00234 (0.0602)	-0.105 (0.0929)	-0.205** (0.103)	0.125 (0.430)	-0.441* (0.248)
HT6	-0.0713 (0.0849)	-0.436*** (0.103)	0.640*** (0.153)	-0.494*** (0.153)	-0.144 (0.131)	-0.136** (0.0593)	-0.289*** (0.0936)	-0.351*** (0.104)	-0.407 (0.471)	-0.333 (0.236)
Constant	0.521***	0.683***	-0.656***	-0.869***	-0.665***	1.654***	0.118**	-0.129**	-3.213***	-1.572***

	(0.0543)	(0.0626)	(0.104)	(0.0889)	(0.0833)	(0.0378)	(0.0572)	(0.0623)	(0.277)	(0.144)
Observations	1,354	1,354	1,354	1,354	1,354	1,354	1,354	1,354	1,354	1,354
Number of groups	148	148	148	148	148	148	148	148	148	148

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Discussion

Large-scale Galápagos Sea Lion Habitat Use

Our large-scale analyses shed some light on the environmental features that influence terrestrial habitat choice by sea lions. We found that beach Access Line and low Tidal Variability had the highest number of significant relationships with most Galápagos sea lion social metrics (Table 4). The importance of these two variables is logical, due the demonstrated linear spread of sea lion colonies along the beach (Wolf and Trillmich 2007). A longer Access Line provides more space for sea lions to use, indicating good habitat quality, as longer beach lengths are likely to have more diverse habitat types for sea lion occupation. Low Tidal Variability is indicative of beaches where available sand/rock area is minimally impacted by changing tide levels, showing high beach slope. Past studies on islands devoid of human presence have shown that *Z. wolfebaeki* nurseries and female-young dyads prefer habitats with a low slope, higher Tidal Variability and tide pools (Wolf et al. 2005). However, the results of our study show an opposite relationship: beaches with low Tidal Variability show significant and positive relationships to number of females, juveniles, males, pups, subadult males, total number of sea lions, groups, dyads, and female-juvenile dyads.

It is interesting to note that Access Line had a strong positive relationship with all social metrics except males and female/pup dyads (Table 4). In addition, low Tidal Variability was also significantly associated with higher counts for all categories of sea

lion, except for female/pup dyads. While it may be expected that longer access lines provide more usable space and beach access opportunity, the needs of very young pups (with distinctive darker coats and raised fur texture) are distinct. For example, young pups have been observed and documented in somewhat isolated and seemingly unlikely locations such as water culverts, lighthouses, buildings, underneath boats and kayak racks, etc. Because females form nursery groups to facilitate the care of their young, it is possible that females place a higher emphasis on isolated, somewhat unexplored sites for the placement of young pups. This may also facilitate pup retrieval once females are back on land. In general, males may try to increase their social ranking and social acceptance through proximity to females, female-young dyads or nursery groups. In addition, female choice dictates male territory placement and male attendance suggests that males maintaining a close physical proximity to sea lions to increase chances of breeding success, even superseding male dominance status (Wolf et al. 2007, 2007a, 2007b, 2008). As a result, it is possible that due to their social associations with females and pups and possible physical proximity, males may also have a negative relationship with “access line,” as a reflection of their associations with females and young. It is also possible that males are often relegated to creative use of isolated, lower-quality areas with smaller “access line” lengths because of their lower social acceptance and competition from dominant males with established territories.

These different behavioral ecology and habitat use dynamics may be linked to human presence, which distinguishes this study from previous research. Human presence may explicitly influence sea lion habitat use through human behavioral impacts, including altering of habitat landscape (e.g. humans may show preferential use of similar substrate types and modify substrate use through consistent use, and also increase coexistence with sea lions; modification of vegetation presence, provision of additional shade sources, etc.). The beach with the lowest Tidal Variability also showed the least amount of anthropogenic alterations and human visitor presence, perhaps encouraging more sea lion presence and haul-off sites (Table 7). Nevertheless, count of people present was found to have a significant and positive relationship to many of the same social metrics: number of males, number of total sea lions, number of groups, and number of dyads. These results seem to support the hypothesis that human presence, along with alteration of habitat landscape, may present some advantages to sea lion habitat occupancy, through byproducts such as shade from anthropogenic structures. Interestingly, a high level of anthropogenic disturbance has been shown to have a significant and negative relationship with number of groups and dyads. For highly social animals, group formation (especially dyads, as the most frequent group unit) is important for social cohesion and regulating perceived threats (Acevedo-Gutierrez et al. 2010, Acevedo-Gutierrez et al. 2011). Thus, while it seems that human visitor count does not necessarily decrease habitat quality and may actually indicate preferred habitat, different types of anthropogenic activity can have negative impacts on sea lion grouping. At high

anthropogenic activity levels, such as construction, boat repair, machinery and chemical product usage, (Appendix A; Table 2) groups and dyads are less likely to form.

Individuals with lower social ranking and group acceptance, such as subadult males and bachelor males, may still use these sub-prime habitats as daytime haul outs.

The robustness check (Table 4b & 4c) (to account for beach specific variation and thus to isolate the relationships between sea lion metrics and human presence, as represented by “Count of People Present” and “Anthropogenic Use Level”), showed a coefficient pattern in agreement with the global model. The results suggest that beach-specific dummy variables may be a more parsimonious approach to including spatial variation (perhaps in the stead of beach access length, Tidal Variability, etc.) for sea lion habitat use. Perhaps due to the restrictions imposed on the model due to the use beach dummy variables, a few previously significant environmental were no longer significant. For example, less observed variables such as number of groups, dyads, and female-young dyads, may be more likely to drop to a lower significant state due to a consistently lower frequency of observation, reflected in the dataset. Nevertheless, crucial variables, such as “Count of People Present,” levels of anthropogenic use (low and high), sand temperature, air temperature, and rainy and sunny weather conditions, maintained significant relationships to specific sea lion metrics at $\alpha=0.05$. In particular, air temperature was shown to significantly impact almost all sea lion social classes, except for subadult males and total sea lions (Table 4b). Both rainy and sunny weather conditions also significantly

related with sea lion social metrics (3 significant relationships for rainy weather- males, subadult males, and total sea lions; four significant relationships for sunny weather- juveniles, males, subadult males, and total sea lions). This suggests the ambient conditions and thermoregulatory costs/benefits, as indicated by weather conditions, may mediate sea lion habitat choice and occupancy (perhaps superseding human presence benefits/costs). This analysis is helpful as it suggests that some of the effects of humans (Count of People Present and Anthropogenic Activity Level) in the global model are due to other differences among beaches that also happen to be correlated with human metrics. However, the fact that most of these significant effects still persist (though weakened) indicate evidence of human impacts on the social metrics.

In general, the averaged model results, based on significant variables from the previous GLMM analysis, supported the previous findings, albeit with a “stricter” selection of significant variables (Table 5). This suggests the usefulness of providing a “standard” to complement the global GLMM analysis, and to perhaps highlight certain variables as particularly significant or valuable by review of all model combinations.

Surprisingly, the global model (including all variables) outperformed the best model (based on significant variables), indicating that other “non-significant” variables may actually play a strong role in estimating social metrics through underlying dynamics (Table 6). While choosing significant variables may provide a standardized and systematic approach towards variable selection, these results suggest that a holistic

approach beyond “significance” may be more appropriate. For example, factors such as posterior inclusion probabilities (PIP), may complement significance-based results and help select variables with high contributions in the global model (Table 6). Variable inclusion based on strong ecological reasoning and logic should also be considered (Anderson et al. 2001, Burnham and Anderson 2001, Burnham 2002).

Fine-Scale Galápagos Sea Lion Habitat Use

At the fine-scale level, Habitat Type 2 (habitat types are defined in Table 3b) characteristics (e.g. direct/close access to water, rocky substrate, tide pools, flat inclination, shade from vegetation, complex structures and both high and low Tidal Variability) are negatively linked to juvenile, group, and dyad occurrences, while having a positive relationship with males (Table 7). While this habitat presents various advantages which may be otherwise appealing to other social metrics such as non-dominant males and subadult males, rocky substrates are not optimal to locomotion, thermoregulation, and group aggregation (Wolf et al. 2005, Wolf and Trillmich 2007). Thus, males, which are characterized by lower social acceptance, may be more likely to occupy these peripheral subprime spaces while other more social populations segments may avoid them (Porschmann et al. 2010).

Females, juveniles, and dyads are less likely to use Habitat Type 5 (habitat types are defined in Table 3b) (distant access to water, sand substrate, lack of tide pools, steep inclination, shade from vegetation, simple structures, and low Tidal Variability).

However, similar to Habitat Type 2, males have a positive and significant relationship with this habitat profile. Mainly, the lack of tide pools and steep inclination present disadvantages to young sea lions practicing play behaviors. Easily accessible tide pools, at gentle slopes, are important to young-rearing and nursery group formation (Wolf et al. 2005, Wolf et al. 2007a).

Habitat Type 6 (defined in Table 3b) (direct/close access to water, sand substrate, lack of tide pools, steep inclination, lack of shade, complex structure, and low Tidal Variability) is also negatively associated with juveniles, pups, groups, and dyads. However, in contrast, males are more likely to occupy habitat type 6. Due to its lack of tide of pools, steep inclination and complex structure, this is likely a lower quality habitat type similar to Habitat Type 5.

In brief, Habitat Types 2, 5 and 6 are advantageous or “preferred” by male sea lions (not females, pups or dyads). In general, females, juveniles, and males are the main determinant social metrics for habitat types, and may be the most discriminatory social segments for habitat choice. As individuals with the ability to participate in various territories and harems, females have the ability to choose higher quality habitats for themselves and their young (Wolf et al. 2007a). While pups are more location-bound due to their higher vulnerability and limited mobility both on land and in water, juveniles are more exploratory, and may be more likely to follow their mothers or initiate independent trips while their mothers forage. Juveniles may stay with their mothers until two years of

age, providing ample time to learn independent behaviors, accompany their mothers for more extended distance on land, and to replicate habitat choices in the absence of their mothers (Trillmich and Wolf 2008).

Conclusion and Recommendations

This study aimed to elucidate the relationships between environmental factors and Galápagos Sea Lion demographic and group behavioral metrics during the non-reproductive season. Results should inform long-term conservation strategies and management of the species, in an inclusive manner that accounts for human presence as well. Previous research has indicated the differential behavioral ecology of Galápagos Sea Lions in different social classes (Wolf et al. 2005). However, prior research did not address the potential influence of anthropogenic factors, which are crucial for an endemic species where 90% of the population resides on 9 islands, 4 of which are human-inhabited (Schramm et al. 2009).

In 2011, the Galápagos National Park tried to implement a conservation approach by providing additional near-shore habitats to *Z. wollebaeki* through floating platforms (“Plataformas”/ “Balsas flotantes”) (the locations of the original “Plataformas” points are labeled in Figure 2) (Murillo 2009, Montero Serra 2012, DPNG 2014). One of the objectives of the initiative was to present sea lion rookeries with additional territories, and to lessen sea lion-human interactions on beaches during the day by providing

alternate areas to the sea lions. The initiative was eventually abandoned, due to lack of use by sea lions. Dominant sea lion males with territories on nearby beaches “annexed” the platforms as additional territories, and actively patrolled and defended the platforms. Females and young sea lions were able to use the platforms, but non-dominant males and sub-adult males were effectively barred from these areas and unable to establish them as their own territories. By establishing new territories and harems, new males could have expanded the local sea lion population and increased genetic diversity as well. This past conservation initiative demonstrates the importance of including comprehensive behavioral ecology knowledge of the species into conservation plans. Strategic placement of floating platforms in different zones and areas (i.e. close to specific habitat types) might have targeted specific population segments (ex. non-dominant males and subadult males), promoting conservation goals.

In terms of future study, air temperature shows strong potential for future investigation, as it significantly influenced the occurrence of most sea lion social metrics. Only male sea lions “prefer” higher air temperatures, while all other groups showing significant effects occurred at lower temperatures. This indicates the importance of ambient temperature for terrestrial thermoregulation. Nuances of this variable may show potential for future investigation in air-related characteristics, such as humidity, wind speed, pollution levels, etc.

For example, a study conducted with harbor seals (*Phoca vitulina*) to determine the potential impacts of human presence on haul-out animal presence densities showed a relationship between airborne noise pollution levels and time of day (Acevedo-Gutierrez & Cendejas-Zarelli, 2011). Season, tide level, time of day, precipitation presence and levels, air temperature and wind speed influenced harbor seal haul-out timing and place. The results showed that interactions between time of day and tide level, and noise level and tide level respectively impact haul out time preference, with a bias towards nighttime. To prioritize sea lion conservation and investigate airborne and linked variables, future studies may explore additional air-based data, and apply systematic sampling for densely packed beaches and sites through a priori selected sampling squares on each beach. This approach would maximize environmental and *Z. wolfebaeki* social measurements, while minimizing sampling and follow up analysis effort.

In sum, previous studies and this study's results indicate that human presence, directly and indirectly, may impact Galápagos Sea Lion behavioral ecology. As 90% of the Galápagos Sea lion population occurs on only 9 islands (including the only 4 islands occupied by humans in the archipelago) out of a total of 125 islets and islands, human presence and coexistence may actually be an advantage to the Galápagos Sea Lion (Schramm et al. 2009). Humans and sea lions may coincide in habitat choice and preferences by choosing habitat with advantageous factors such as easily accessible beaches (amenable to haul-out for sea lions and easy construction for docks and

recreational activities for humans). However, humans may improve these habitats by providing structures with shade (small buildings, lighthouses, small boats, etc.) and modified beach structures that sea lions incorporate into their range of habitat choices. However, caution must be exercised in terms of human activity levels. Activities with high impact such as long-term construction, pollution products, and complete restructuring of habitats can negatively affect sea lion grouping behavior and could be minimized by selectively choosing activity sites and periods.

In the case of the Galápagos Islands, where a 6% population growth rate remains the highest in South America, the impacts of human population growth, development and urbanization processes remain poorly explicitly documented (Quiroga, 2009). Despite their localized endemic status and limited geographic range, Galápagos Sea Lions are capable of long-range movement. Vagrant individuals are occasionally reported off the Central and South American coasts as far as 1,570 km (~976 miles) from their home range (Schramm et al. 2009). In 2010, a colony of about 30 Galápagos Sea Lions and Galápagos Fur Seals was documented on Foca Island of Peru, a location 1,000 miles southeast of their Galápagos Islands home range (Wade 2010). This documented potential range migration is important to note, as the species is generally geographically endemic to the Galápagos Islands. The establishment of a new colony so far from the usual occurrence range is hypothesized to be primarily linked to warming sea temperatures (Wade 2010). The average water temperature off Foca Island has increased

from 17 to 23 degrees Celsius over the past 10 years, matching the sea lions home sea surface temperature of 25 degrees Celsius in the Galápagos (2010, Kurczy 2010, PUCP 2010, Wade 2010). Other climate-change associated factors, such as prey availability and migration, pollution, and ocean acidification, may also be linked to the new colony establishment (Wade 2010). The Organization for Research and Conservation of Aquatic Animals predicts that, based on the ambient surface water temperature, more Galápagos sea lion colonies are expected to radiate towards northern Peru and other locales in the Eastern Tropical Pacific Seascape (2010).

Within this changing context, documenting habitat use preferences and colony behavioral dynamics is crucial towards prioritizing the wellbeing of the Galápagos Sea Lion as an iconic touristic species and an ecological sentinel organism.

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CHAPTER 2

GUIANA DOLPHIN CONSERVATION: HABITAT PREFERENCES AT DIFFERENT SCALES

Introduction

Currently, at the global level, marine mammal megafauna are facing conservation challenges from habitat loss, chemical pollution, and accidental human-environment interactions such as bycatches and overfishing (Azevedo et al. 2002, Azevedo et al. 2004, Azevedo et al. 2005, Jablonski et al. 2006, Azevedo et al. 2007, Dorneles et al. 2008, Azevedo et al. 2009, Bisi et al. 2012, Lailson-Brito et al. 2012, Bisi et al. 2013, Bittencourt et al. 2014). The widespread coastal distribution of species such as bottlenose dolphins, combined with their role as apex predators, suggest certain marine mammals are important indicator species for biomonitoring of spatial and temporal trends in contaminants and other factors, making them “sentinel species” (Bossart 2006, Bossart 2010). An ecosystem sentinel is a species able to respond to ecosystem variability and/or change in a timely and measurable way, with the capability to indicate an otherwise unobserved change in ecosystem function (Hazen et al. 2019). In the case of the completely aquatic cetaceans, particular challenges apply- due to their aquatic nature and usual research limitations to staying above water, it is difficult to pursue accurate population counts of individuals at rest state, and further observe individuals in their social groups (IBJ 2016). Further, data on animal presence and human activity are often missing, making it harder to explore these ecological dynamics, hindering efforts to

extend conservation practices for these marine species. This study aims to fill this gap by using a long-term dataset on both animal presence and human activity, and by focusing on coastal habitat use patterns at varying spatio-temporal scales, in a marine mammal apex predator, the Guiana Dolphin (*Sotalia guianensis*).

Marine mammal social clustering behavior and grouping patterns have been studied and documented in terms of habitat use, group membership, size, and nearest neighbor proximity (Acevedo-Gutierrez 2009b, Acevedo-Gutierrez 2009a). For example, among other marine mammal social hierarchy systems, dolphin pods are delimited by individuals within 10m of each other and New Zealand fur seals significantly alter their behavior when a nearby individual or human presence comes within 10 m (Acevedo-Gutierrez et al. 2010, Acevedo-Gutierrez et al. 2011). However, in relation to long-term datasets and environmental factors, there are often data or analysis results missing on marine mammal megafauna habitat use within specific locales, and implications for conservation.

The Guiana Dolphin is listed as “data-deficient” by the International Union for the Conservation of Nature (IUCN), meaning that further studies are currently required to determine its conservation status (Azevedo et al. 2009). The Federal Brazilian Environmental Agency (Ministério do Meio Ambiente) in 2014 has listed the Guiana Dolphin as vulnerable, based upon several research studies that have shown the negative impacts of anthropogenic activities such as fisheries bycatch and environmental

degradation (i.e. pollution) on the species (Azevedo et al. 2009). Additional data linking Guiana Dolphin behavioral ecology to environmental factors may help to establish an accurate IUCN listing for the species. Towards this goal, identifying the mechanistic links and relationships between Guiana Dolphins and environmental factors is crucial for understanding how environmental factors may impact populations and broader environmental health as well.

The Guiana Dolphin, despite being completely aquatic, is a coastal species and prefers shallow waters, similar to its sister freshwater species (*Guiana fluviatilis*) which dwells in the Amazon river. The geographic distribution of the species ranges along the widely human-occupied coast of Brazil, northern South America, and Central America (specifically, throughout the Caribbean Sea until Honduras) (da Silva et al. 2010). The two sister species were identified through a relatively recent phylogenetic reclassification between riverine (*Sotalia fluviatilis*) and marine species (*Sotalia guianensis*) variants (Cunha et al. 2005). At the national level in Brazil, environmental agencies classify the species as “threatened” with a need for further research to obtain baseline information for the species. These coastal individuals usually prefer saline habitats but may explore as well and capitalize on adjacent estuarine and river habitats, depending on social and resource needs. As a highly mobile aquatic marine mammal species, Guiana Dolphins (*Sotalia guianensis*) are a vital keystone and sentinel species in their coastal habitats (Bisi et al. 2013). Because this species prefers waters of shallow depth with habitat preferences

varying across different sex and age groups, *S. guianensis* transports nutrients across the coastline ecosystems, including mangroves, fishery zones, and select open-ocean and pelagic areas (Azevedo et al. 2007, Bisi et al. 2013). Similar to sea lions, dolphins translate nutrients and play a crucial role in energy flow across the ecosystem webs.

As a highly social species, the behavior of resident Guiana Dolphin populations mediates their environmental roles: their temporal and spatial use patterns may impact nutrient use, uptake, and deposition (Azevedo et al. 2005, Azevedo et al. 2007, de Oliveira and Monteiro-Filho 2008, Bisi et al. 2013). These effects are also likely strongly determined by group formations and aggregations. Thus, studying the behavioral ecology of the species and obtaining further insights into behavioral patterns could help us form a basis for understanding broader ecological patterns, and the potential ramifications stemming from dolphin behavior change. Habitat fidelity and recurrent use provides further information about potential connections between dolphin ecology and habitats (Cantor et al. 2012a & 2012b).

Behavioral adaptations, exhibited through changes in site fidelity and habitat use over time, can impact both individual and group population fitness, as the animals can spend less time on resting and foraging, and more time towards developing mitigating behavioral responses to external stimuli. Similarly, heightened stress as demonstrated by elevated cortisol levels may lessen body condition as well and lead to lower reproductive rates (Filby *et al.* 2014). However, in the case of the Cassurubá Extractive Reserve

(RESEX), previous research on Guiana Dolphin local habitat use and behavioral ecology was based upon 3 years of data, prompting the authors to suggest further research in the future on a larger and longer-term dataset to accurately understand local behavioral ecology dynamics (Rossi-Santos et al. 2010).

Further, due to their preference for coastal habitats, Guiana Dolphin populations often encounter human population, resulting in interactions which may be positive or negative for the species. Thus far, past research indicates that human-dolphin interactions likely depend on specific contexts and locales. In the specific case of the Cassurubá RESEX in northeastern Brazil, Guiana Dolphin contend with two main human activities: small-scale subsistence-based artisanal fisheries and harvesting, and a yearly seasonal dredging regime and frequent barge passage on boating routes (IBJ 2016, Nobre et al. 2017).

Because of the complex dynamics of a socio-environmental ecosystem, it can be hard to distinguish specific relationships between different human activities and dolphin wellbeing. However, past ecological research suggests analysis avenues through modelling to represent relationships and provide results-based evidence for navigating different stakeholder positions in such a dynamic ecosystem (Anderson et al. 1999, Anderson et al. 2001, Jablonski et al. 2006, Nobre et al. 2017).

Therefore, this case study research proposes to better understand the relationship between habitat use, site-fidelity, and group vs. individual behavior, through analyses of

Guiana dolphin behavioral data collected over distinct transect routes in the Cassurubá RESEX area of Brazil (Figure 4).

Our objective was to explore the patterns of habitat use by different sex/age and social categories, through a long-term 15-year dataset at different scales, **under the hypothesis that** environmental factors are associated with specific Guiana Dolphin social metrics. These results may help contribute to an accurate IUCN conservation status for the Guiana Dolphin.

Methods and Materials

Study Site

The Cassurubá Extractive Reserve (RESEX) is a 100,767 ha (1007.67 square km) area composed of coastal, estuarine and freshwater riverine ecosystems across the neighboring municipalities of Caravelas, Nova Viçosa, and Alcobaça. The Caravelas River Estuary system and its neighboring coastal areas are linked to and impacted by the second largest (66 km²) estuarine-mangrove system of the north-eastern coast of Brazil (Rossi-Santos *et al.* 2007).

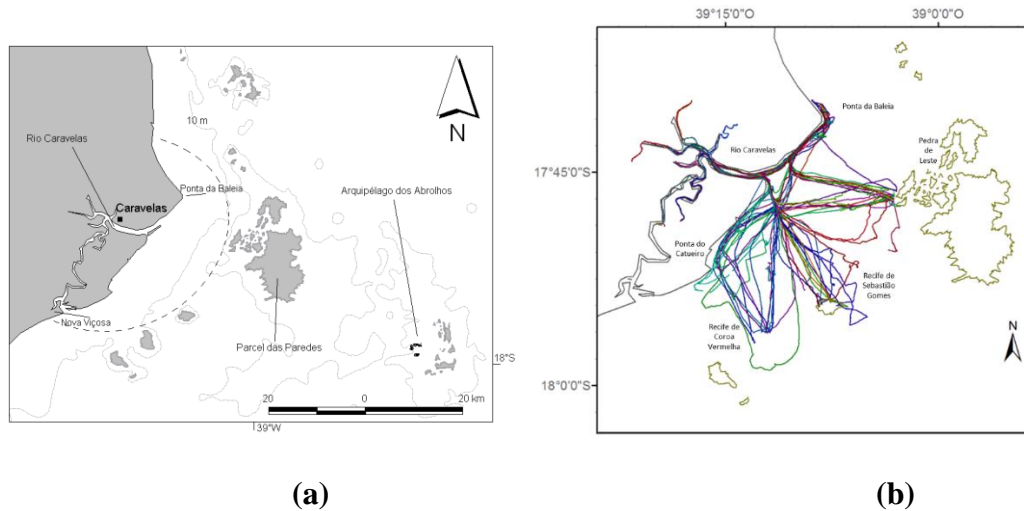


Figure 1. (a) Map illustration of the Cassurubá RESEX study area for sampling and monitoring a population of *Sotalia guianensis* between 2002 and 2015 (Rossi-Santos et al. 2007). (b) Research survey routes and transects used for data collection in the Cassurubá RESEX territory in 2015 (IBJ 2016).

The Cassurubá Extractive Reserve (RESEX) was established in 2009 as protection from a large-scale shrimp farming proposal in the area (Nobre et al. 2017). Through grassroots mobilization efforts and local NGO partnerships, who produced foundational scientific studies, local residents and stakeholders successfully petitioned the creation of the RESEX. The reserve is home to 300 families who practice local artisanal fishing, river/estuary/sea resource harvesting, and agriculture and livestock (Nobre et al. 2017). 2000 additional families reside in urban areas outside official RESEX delineations, but also utilize resources stemming from the interior of the RESEX boundaries, mainly through fishing and harvesting at sea (Nobre et al. 2017).

The strategic placement of the Canal de Tomba within the RESEX allows for commercial and industrial transport of eucalyptus lumber and timber from nearby land plantations to barges for transfer to other distribution points (Rossi-Santos et al. 2006, Rossi-Santos et al. 2007, Rossi-Santos et al. 2010, Cantor et al. 2012a, Cantor et al. 2012b, IBJ 2016). As a result of ongoing industrial barge traffic in the Canal de Tomba, the area constitutes an excluded area from the RESEX designation. Further, to maintain optimal depth and width in the Canal to allow barge passage, since 2002 a eucalyptus company with local operations conducts yearly seasonal dredging regime (January-March) to dredge the canal.

Field Data Collection

During a time period of 15 years (2002-2016), Guiana Dolphin data were collected using standard marine mammal methodology of observation cruises, with 4-6 volunteers trained to detect surface dolphin movement in the form of dorsal fin surfacing and other environmental detection clues (IBJ 2016). Methods for Guiana Dolphin individual and group presence, habitat use, and grouping formations data collection were modified from previous studies by Rossi-Santos et al. (2010) (IBJ 2016, Filby et al. 2017) (Figure 4) (See Appendix).

Between April 2002 and December 2016, an average of 5 days/month were spent censusing various routes within the Cassurubá RESEX, with aims of covering the whole study area each month. Data collection through boat cruises to survey different routes

involved two separate motorboats departing from the same point at the port of the town Caravelas at 6 am and returning at 1 pm (IBJ 2016). In the first 14 years of data collection, about half (46%) of field outings reported zero dolphin sightings, while about 33% of outings reported sightings ranging from 2 to 6 dolphin individuals. The total dataset for this study contained ~825 census observations (IBJ 2016).

In addition to data on individuals, groups and formations, additional environmental variables were recorded during observations (Tables 1 & 2). Tide level, moon phase, wind speed, cloud cover, dredge status, and wave height were recorded at the start of each census. Water salinity, water temperature, water depth, and water transparency were measured through regular stops and at dolphin group sightings throughout each census. Census duration, group observation duration, boat velocity, and census distance were calculated at the end of each census. Due to their highly visible dorsal fin, always shown as the dolphins surface, it is relatively easy to obtain individual-specific identification and data over time. Through photo-identification of dorsal fins, a relatively non-invasive method, we are able to gather data on specific individuals, definitive group clusters, and general animal movement (IBJ 2016). The current Cassurubá population of Guiana Dolphins is about 100 individuals in total (Cantor et al. 2012a, Cantor et al. 2012b, IBJ 2016). Between 2002 and 2016, a total of 188 dolphins have been identified through dorsal fin photo-identification and cataloguing (IBJ 2016).

While it is difficult to reliably identify the sex and age of each sighted individual, catalogued individuals can be identified as females and calves due to the constant grouping and tandem surfacing of females with their calves. In addition, calf sightings also indicate the presence of at least one female within the observed dolphin group. Thus, dolphin metrics on re-sightings that include calves as a group member may be used as a proxy for dolphin female number and population composition (IBJ 2016).

Table (1). (a) Guiana Dolphin social and behavioral data collected from 2002-2017 on distinct transect routes. (b) Guiana Dolphin environmental data, collected 2002-2017 on distinct transect routes

(a)

Social Metric	Description	Measurement Units/Categories
Maximum Group Size	Variable counting the maximum number of dolphins in a group per census	Discrete count number
Range of Group Size	A measure of discrepancy in the group sizes sighted per scan sampling period. Also serves as proxy for accuracy of observed group size during scan sampling, calculated as: <i>(Max Group Size – Min Group Size)</i>	Discrete count number
Maximum Number of Adults Sighted	Variable counting the maximum number of adult dolphins in a group per census	Discrete count number
Number of calves	Variable counting the presence and number of observed calves	Discrete count number
Number of females	Variable counting the presence and number of observed females	Discrete count number
Number of Re-sightings	Variable counting observations of dolphin individuals previously identified and/or previously sighted	Discrete count number
Maximum Group Size per Re-sighting	Variable counting the maximum number of dolphins in a group which included a previously identified and/or previously sighted individual	Discrete count number
Maximum Number of Calves per Re-sighting	Variable counting the maximum number of calves in a group which included a previously identified and/or previously sighted individual	Discrete count number

(b)

Environmental Variable	Description	Measurement Units/Categories
Census Duration	Time elapsed between survey start and survey end	Minutes
Group Observation Time	Time elapsed observing dolphin groups	Minutes

Boat Velocity	Average boat speed during census	Nautical miles/hr
Census Distance	Distance covered during census	Nautical miles
Dredge Status	Indicator of non-active vs. active dredging period at time of census	Categories (No Dredging, Active Dredging)
Sky coverage	Sky overcast level as determined categories defined <i>a priori</i>	Percentage of sky cloud coverage (%)
Wave Height	Beaufort categories of different wave height levels	Categories (0, 1, 2, 3, 4)
Air Temperature	Air temperature measured by a standard thermometer	Degrees Celsius (°)
Moon Phase	Stage of Moon phase as observed and categorized by <i>a priori</i> listed	New, Waxing, Full, Waning
Tide Level	Variable measuring level of tide as predicted by charts	Low, Medium, High
Water Visibility	Measured by visibility, according to a Secchi desk	Secchi Disk Measurement (Meters (m))
Water Depth	Variable measuring water depth	Meters (m)
Water Temperature	Variable measuring water temperature as measured by a standard thermometer	Degrees Celsius (°)
Water Salinity	Variable measuring water salinity as per a standard salinity meter	ppm
GPS Route of survey trajectory	Spatial line of each survey route travelled per outing, recorded using a standard GPS	Longitude & Latitude Coordinates (Nautical miles measurement of route)
GPS Point of dolphin sighting location	Spatial points of each dolphin sighting location, recorded using a standard GPS	Longitude & Latitude Coordinates (ArcGIS Polygon georeferenced spatial layers)

Data Analysis

Data Spatial Referencing

To place dolphin behavioral data on spatial maps of the study sites, standard spatial analysis and data preparation was conducted using a suite of geospatial and statistical software, following reference studies (Wolf et al. 2005, Rossi-Santos et al. 2010). The study area polygon (representing the Cassurubá RESEX) was georeferenced to UTM 1984 Zone 15S and overlaid on areal imagery, line layers and point locations of the region. In addition to water depth measurements taken by hand, water depth data was also calculated by converting bathymetric raster data to TIN (triangular Irregular Networks) format, which were then converted to surface contour lines with measurement points spaced at 5-meter intervals (Rossi-Santos et al. 2010). Microsoft Excel was used for data editing. Spatial analysis of feature (polygon shapes, line and point files) and raster (imagery) layers was conducted through ArcGIS 10.6.1 and ArcGIS Pro.

Large-scale Data Models

To determine the effects of large-scale (temporal-based) factors for Guiana Dolphins, we summarized environmental data by census (Table 1). We used present study area data to calculate derived and composite variables describing location-based environmental factors for each beach.

The Guiana Dolphin social metric variables (Table 2 & Table 3) of maximum group size, range of group size, maximum number of adults, number of re-sightings, maximum group size per re-sighting, and maximum number of adults per re-sighting were calculated using the “Spatial Join” and “Summarize” Geoprocessing tools in ArcGIS Pro, to create metrics that provide additional information about dolphin detectability and accuracy of observation data.

We used Generalized Linear Mixed Model regressions (GLMM) to investigate the relationships between Guiana Dolphin social metrics (i.e., group size and other associated and derived grouping dynamic metrics) and environmental factors (Table 2). A GLMM allows us to detect effects of specific environmental factors while including location variables (Census Name and Habitat Site) as random effects to control for spatial autocorrelation. Models were fit using the “meglm” STATA command and a negative binomial distribution (to account for overdispersion of count data) and log link through STATA 15, and following the general strategy of Wolf et al. (2005). One model was fit at a large spatial scale (whole censuses) but still accounted for each environmental variable, as well as temporal variation across censuses (Table 2). Another model was fit at a fine spatial scale (per habitat site) that grouped environmental variables into distinct habitat types (Table 3). Results were obtained for both standardized and unstandardized variables. Results were obtained for both standardized and unstandardized variables.

Next, to determine which model compositions perform best and which factors held particular usefulness in the models, we conducted a Model Averaging and Model selection analysis. This was performed only for the large-scale analysis, since the fine-scale model had only a single fixed predictor (habitat type). To prevent overloading the model and to facilitate analysis, only the significant variables obtained from the previous GLMM results were included in the model averaging/selection analysis. This approach also served to maximize parsimony while simplifying the model (Burnham et al. 2011a, Burnham et al. 2011b, Symonds and Moussalli 2011). The MIINC package in STATA 15 (Luchman 2014) was used to conduct the Model Averaging & Model Selection Analysis.

Fine-scale Models

To determine the effects of fine-scale (spatial-based) habitat traits for the chosen population of dolphins, we needed to first determine and classify distinct and discrete habitat types (Tables 3 & 4). To calculate composite habitat types, various habitat factors were combined and aggregated. First, the study area polygon (the Cassurubá RESEX area) was converted into 38 discrete 5kmX5km quadrants parallel to the coastline using the ArcGIS10.6.1 Extension Repeating Shapes Tool (Version 1.5.152) (Jenness 2012).

The study area polygon (representing the Cassurubá RESEX) was converted into discrete 5kmX5km quadrants using the ArcGIS10.6.1 Extension Repeating Shapes Tool (Version 1.5.152) (Jenness 2012). Thus, a “habitat site” is defined as a delineated subset area within the broader study area (depicted in Figure 2). Second, using the dataset of

~825 observations and accompanying GPS location data, dolphin observations (individuals and groups) were assigned to specific 5kmX5km quadrants. The variables of Water Salinity, Water Temperature, Water Depth, and Water Transparency were calculated as averages per number of recorded stops during each census per each respective habitat site. Third, for each habitat site, “Hui’s Contour Index” was calculated using the formula below:

$$\left(\frac{Max\ Depth - Min\ Depth}{Max\ Depth}\right) * 100$$

This metric also served as a proxy for sea floor slope (Rossi-Santos et al. 2010) (Table 3 a &b).

Next, to determine habitat type, we condensed the environmental factors (shrimping activity, ocean location, mangrove presence, canal location, dredging discard location, reef presence, single direction boating route presence, multiple direction boating route presence, RESEX exclusion area location, APA location, agriculture/livestock presence, shellfish presence, fishery presence, fish species present, Hui’s Contour Index level, water temperature level, water salinity level, water visibility level, and wind speed) into six discrete habitat types through a K-Means Clustering analysis (Table 4).

The K-Means Clustering analysis was conducted using the “Multivariate Clustering” Geoprocessing tool in ArcGIS Pro, with the specifications of “6” as a cluster number restraint (similar to Wolf *et al.* 2005) and “Optimized Seeds” for starting seeds

(Table 4). Our initial choice of six as the number of habitat types stemmed from previous results of Wolf et al. (2005); subsequent examination of the spatial and visual results showed that the resulting clusters effectively delineated discrete habitat types, thus we opted to keep these six final habitat types.

We used GLMMs to model the relationships between each social metric and habitat type (Table 3). Unlike the large-scale analysis, we did not perform model selection, since the fine-scale model had only a single fixed predictor (habitat type).

Table 2. Description of GLMM Model at large spatio-temporal scale (per census).

Generalized Linear Mixed Model		
Response Variables (Social Metrics)	Explanatory Variables (Environmental Factors)	Variable Measurement Unit
<ul style="list-style-type: none"> - Maximum Group Size - Range (Observability) of Group Size - Maximum Number of Adults Sighted - Number of Re-sightings - Maximum Group Size per Re-sighting - Maximum Number of Adults per Re-sighting - Maximum Number of Calves per Re-sighting 	Census Duration	Minutes
	Group Observation Duration	Minutes
	Boat Velocity*	Nautical miles/hr
	Census Distance	Nautical miles
	Dredge Status*	Categories (No Dredging, Active Dredging)
	Tide Level	Categories (Low, Medium, High)
	Moon Phase	Categories (New, Waxing, Full, Waning)
	Wind Speed	Meters/s
	Cloud Cover	Percentage (of sky covered by cloud)
	Wave Height	Categories (0, 1, 2, 3, 4)
	Water Salinity	ppm
	Water Temperature	Degrees Celsius (°)
	Water Depth	Meters
	Water Visibility	Meters
	Route ID (Model Random Effect)	26 Categories

***Anthropogenic**

Table 3. Description of GLMM Model at fine spatial scale (per habitat type).

Generalized Linear Mixed Model		
Response Variables (Social Metrics)	Explanatory Variables (Environmental Factors)	Variable Measurement Unit
<ul style="list-style-type: none"> - Maximum Group Size - Range (Observability) of Group Size - Maximum Number of Adults Sighted - Number of Re-sightings 	Habitat Type	Categories (1, 2, 3, 4, 5, 6)

Table 4. K-Means Clustering **(a)** Definitions of specific habitat traits. **(b)** Definitions of Habitat types determined through spatial K-Means Clustering analysis. Six distinct habitat types were defined and identified (methodologies and definitions adapted from Wolf et al. 2005 and Rossi-Santos et al. 2010).

(a)

Habitat Trait	Description	Trait States
Shrimping Activity	Presence of shrimping activities in habitat site	Yes / No
Ocean Location	Habitat site located in ocean	Yes / No
Mangroves Present	Presence of mangroves in habitat site	Yes / No
Canal Location	Habitat site located in canal	Yes / No
Dredging Discard Location	Dredging discard area present in habitat site	Yes / No
Reefs Present	Presence of reefs in habitat site	Yes / No
Single Direction Boating Route Present	Presence of single direction boating route in habitat site	Yes / No
Degraded Area Location	Presence of documented degradation in habitat site	Yes / No
RESEX Excluded Area Location	Presence of Area excluded from RESEX, in habitat site	Yes / No
APA (Área de Proteção Ambiental) Location	Presence of APA designation within the habitat site	Yes / No
Human Community Present	Presence of one or more human communities within the habitat site	Yes / No
Agriculture/Livestock Present	Presence of agriculture/livestock activities within the habitat site	Yes / No
Shellfish	Presence of shellfish gathering activities within habitat site	Yes / No
Fishery Present	Presence of fishery activities within habitat site	Yes / No
Fish Species Present	Presence of fish species within habitat site	Yes / No
Hui's Contour Index Level	Estimate of sea floor slope within habitat site, calculated as:	Low / High

	$((Max\ Water\ Depth\ m - Min\ Water\ Depth\ m) / Max\ Water\ Depth\ m) * 100$	(Low = 0 to 62.5 ; High = 62.5 to 100)
Water Temperature Level	Average water temperature documented in habitat site (°C)	Low / High (Low = 0 to 21.95; High = 21.95 to 43.90)
Water Salinity Level	Average water salinity documented in habitat site (ppm)	Low / High (Low = 0 to 61.41; High = 61.41 to 98.26)
Water Visibility Level	Average water visibility documented in habitat site (m)	Low / High (Low = 0 to 61.41; High = 61.41 to 98.26)
Wind Speed Level	Average wind speed documented in habitat site (m/s)	Low / High (Low = 0 to 62.5; High = 62.5 to 100)

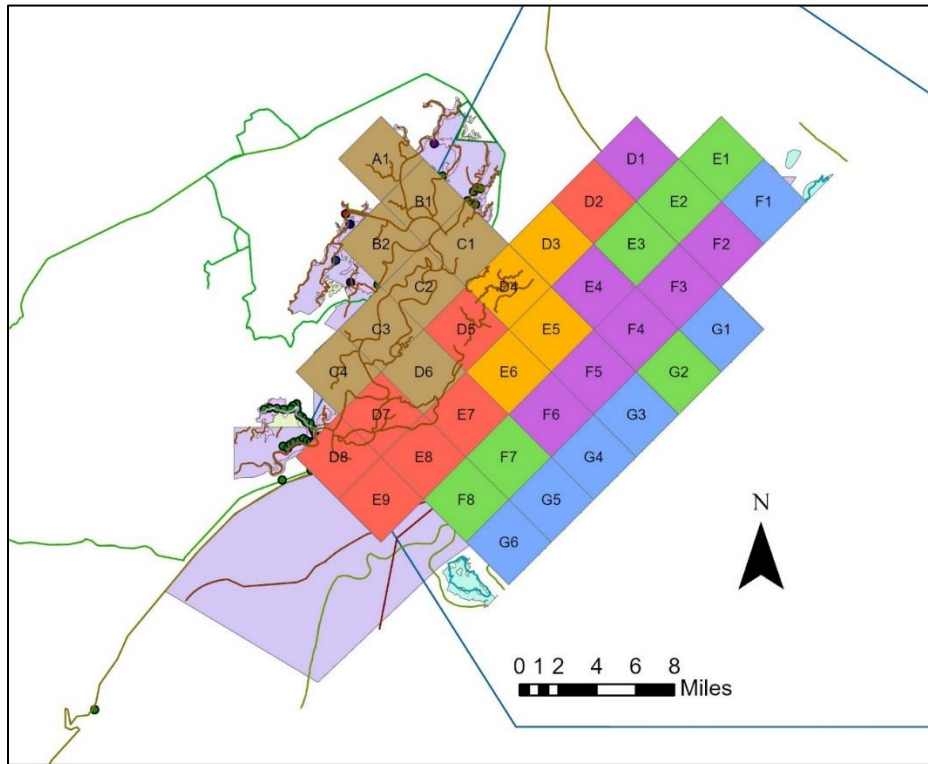
(b)

Habitat Type	Habitat Subtype	Shrimping Activity	Ocean Location	Mangroves Present	Canal Location	Dredging/ Discard Location	Reefs Present	Single Direction Boating Route Present	Multiple Direction Boating Route Present	Degraded Area Location	REEF Excluded Area Location	APA Location	Human Community Present	Agriculture/Livestock Present	Shellfish Present	Fishery Present	Fish Species Present	HUI Index Level	Water Temperature Level	Water Salinity Level	Water Visibility Level	Wind Speed Level	Total Number of Sites					
1	1a	No	Yes	No	No	No	Yes	No	No	No	No	Yes	No	No	No	Yes	Yes	Low	Low	Low	High	Low	6					
	1b	No	Yes	No	No	No	Yes	No	Yes	No	No	Yes	No	No	No	Yes	Yes	Low	Low	Low	Low	Low		6				
	1c	No	Yes	No	No	No	Yes	No	Yes	No	No	Yes	No	No	No	No	Yes	High	High	Low	High	High			6			
	1d	No	Yes	No	No	No	Yes	No	Yes	No	No	Yes	No	No	No	No	Yes	Low	High	Low	Low	High				6		
	1e	No	Yes	No	No	No	Yes	No	No	No	No	Yes	No	No	No	Yes	No	High	Low	Low	High	High					6	
	1f	No	Yes	No	No	No	Yes	No	No	No	No	Yes	No	No	No	Yes	Yes	High	Low	Low	Low	Low						6
2	2a	Yes	Yes	No	No	No	No	No	No	No	Yes	No	No	No	No	No	Yes	Low	High	High	High	High	7					
	2b	Yes	Yes	Yes	No	No	No	No	No	No	Yes	Yes	Yes	No	Yes	No	Yes	High	Low	Low	High	High		7				
	2c	Yes	Yes	Yes	No	No	No	No	No	No	Yes	No	No	No	Yes	Yes	Yes	High	Low	Low	High	High			7			
	2d	Yes	Yes	Yes	No	No	No	No	No	No	Yes	No	Yes	No	Yes	No	Yes	Low	High	High	High	High				7		
	2e	Yes	Yes	Yes	No	No	No	No	No	No	Yes	Yes	Yes	Yes	Yes	No	No	Low	Low	High	High	High					7	
	2f	Yes	Yes	Yes	No	No	No	No	No	No	No	Yes	No	Yes	Yes	No	Yes	Low	High	Low	High	High						7
	2g	Yes	Yes	No	No	No	No	No	No	No	No	Yes	No	No	Yes	No	Yes	High	High	High	High	High						
3	3a	No	Yes	No	No	No	No	No	No	No	No	Yes	No	No	No	No	No	High	Low	Low	Low	Low	6					
	3b	Yes	Yes	No	No	No	No	Yes	Yes	No	No	Yes	No	No	No	Yes	Yes	Low	Low	Low	Low	Low		6				
	3c	Yes	Yes	No	No	No	No	Yes	Yes	No	No	Yes	No	No	No	No	Yes	Low	High	Low	Low	High			6			
	3d	Yes	Yes	No	No	No	No	No	No	No	No	Yes	No	No	No	No	Yes	High	Low	Low	High	High				6		
	3e	Yes	Yes	No	No	No	No	Yes	Yes	No	No	Yes	No	No	No	Yes	Yes	High	Low	Low	Low	High					6	
	3f	Yes	Yes	No	No	No	No	Yes	Yes	No	No	Yes	No	No	No	No	Yes	High	Low	Low	Low	Low						6
4	4a	Yes	Yes	No	No	Yes	No	No	No	No	No	Yes	No	No	No	No	Yes	High	High	Low	High	High	4					
	4b	Yes	Yes	No	Yes	Yes	No	No	Yes	No	No	Yes	No	No	No	No	Yes	High	High	High	High	High		4				

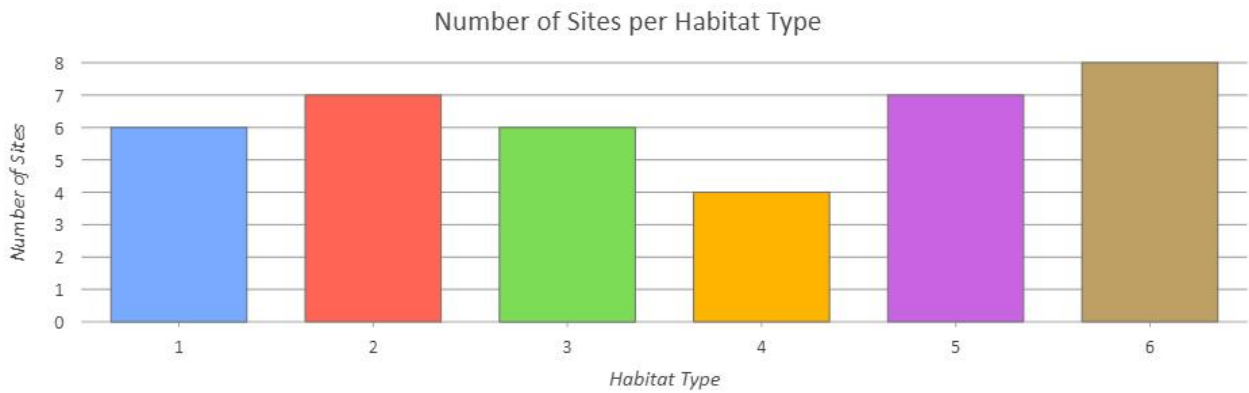
	4c	Yes	Yes	Yes	Yes	No	No	No	Yes	No	No	Yes	Yes	Yes	Yes	No	Yes	High	High	High	High	High
	4d	Yes	Yes	Yes	Yes	No	No	No	No	No	No	Yes	Yes	No	Yes	Yes	Yes	High	High	High	High	High
5	5a	Yes	Yes	No	No	No	No	Yes	Yes	No	No	Yes	No	No	No	No	No	Low	High	Low	High	High
	5b	No	Yes	No	No	No	No	Yes	Yes	No	No	Yes	No	No	No	Yes	No	Low	High	High	High	High
	5c	No	Yes	No	No	No	No	Yes	Yes	No	No	Yes	No	No	No	Yes	Yes	High	High	Low	High	High
	5d	No	Yes	No	No	No	No	Yes	Yes	No	No	Yes	No	No	No	Yes	Yes	High	High	Low	High	High
	5e	No	Yes	No	No	No	No	Yes	Yes	No	No	Yes	No	No	No	Yes	Yes	High	Low	Low	High	High
	5f	Yes	Yes	No	No	No	No	No	No	No	No	Yes	No	No	No	Yes	Yes	High	High	High	High	High
	5g	Yes	Yes	No	No	No	No	No	No	No	No	Yes	No	No	No	Yes	Yes	High	High	Low	High	High
6	6a	No	Yes	Yes	No	No	No	No	No	No	No	Yes	Yes	Yes	Yes	No	No	Low	Low	Low	Low	Low
	6b	No	No	Yes	No	No	No	No	No	No	No	No	Yes	Yes	Yes	No	No	High	Low	High	High	Low
	6c	No	No	Yes	No	No	No	No	No	No	No	No	Yes	Yes	Yes	No	No	Low	Low	Low	Low	Low
	6d	No	No	Yes	No	No	No	No	No	No	No	Yes	Yes	Yes	Yes	No	No	High	Low	Low	High	High
	6e	No	No	Yes	No	No	No	No	No	Yes	No	Yes	Yes	Yes	Yes	No	No	Low	High	High	High	High
	6f	No	No	Yes	No	No	No	No	No	No	No	No	Yes	No	Yes	No	No	Low	Low	Low	High	Low
	6g	No	No	Yes	No	No	No	No	No	Yes	No	No	Yes	Yes	Yes	No	No	High	High	High	High	High
	6h	No	No	Yes	No	No	No	No	No	No	No	No	Yes	No	Yes	No	No	Low	Low	Low	Low	Low

7

8



(a)



(b)

Figure 2. (a) Identification of 6 distinct habitat types in the Cassurubá Extractive Reserve (RESEX) study area in northeastern Brazil. (b) Legend of beach habitat type and count of habitat sites per each type.

Results

Previous results have shown that the current Cassurubá population of Guiana Dolphins is about 100 individuals in total (Cantor et al. 2012a, Cantor et al. 2012b, IBJ 2016). Between 2002 and 2016, a total of 188 dolphins have been identified through dorsal fin photo-identification and cataloguing (IBJ 2016). Among the identified and catalogued individual dolphins, 34% have been observed once, while 33% have been observed 2 to 3 times. 22 individuals (12% of catalogued individuals) were sighted more than 10 times. A lower percentage (1.5%), or 3 individual dolphins, were sighted very frequently, on more than 40 observations (IBJ 2016).

Large-scale Models

Only 4 out of 14 environmental variables (Group Observation Duration, Wind Speed, Cloud Cover, and Water Salinity) were to significantly estimate dolphin social metrics (Table 5). Dolphin group observation duration per census was found to be a strong significant and positively linked variable across all six social metrics (Table 5). Water Salinity was also a strong explanatory variable, with a significant relationship to 4 out of 14 (range of group size, number of re-sightings, group size per re-sighting, and maximum number of adults per re-sighting) social metrics (Table 5). Both Wind Speed and Cloud Cover significantly estimated a total of 2 (maximum group size and range of group size) and 1 (range of group size) social metrics, respectively (Table 5).

The averaged model results, based upon significant variables from the GLMM, largely provided the same results with the original global GLMM model: Group Observation Duration and Water Salinity were found to be consistently strong variables (Table 6). Appendix contains further details on model selection, including the top 10 best models and results with standardized coefficients.

In terms of model fit by AIC (Akaike Information Criterion), the global model consistently outperformed the selected best model (Table 7). Only the results from the best model were included in the results, as all models with $\Delta AIC < 2$ relative to the best model are found to have similar performances (Burnham et al. 2011b). The social metric with the most model similarities between the global model and the best model was number of re-sightings ($\Delta AIC < 150$). The social metrics with the highest differences between the global and the best model were maximum number of adults and maximum group size ($\Delta AIC > 500$).

Fine-scale Models

At the fine-scale level, only Habitat Type 6 was found to have significant relationships with any of the Guiana Dolphin social metrics (habitat types are defined in Table 4b; see Table 8). Specifically, Habitat Type 6 showed strong estimating ability only towards only 1 out of 4 social metrics: range of group size. In sites labelled as Habitat Type 6, range of group is likely to be lower, leading to lower discrepancies among various observations from a single scan sampling episode.

Table 5. Generalized Linear Mixed Model Results- Unstandardized Effects of environmental variables and subtypes on Guiana Dolphin social metrics in the Cassurubá RESEX. (Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1; significant values in red for p<0.05 or p<0.01).

EXPLANATORY VARIABLES	Maximum Group Size	Range of Group Size	Maximum Number of Adults	Number of Re-sightings	Group Size in Re-sighting	Maximum Number of Adults per Re-sighting	Maximum Number of Calves per Re-sighting
Census Duration	0.00397 (0.00451)	-0.00339 (0.00867)	0.00501 (0.00475)	0.000869 (0.0161)	-0.0105 (0.0144)	-0.0100 (0.0144)	0.0138 (0.0419)
Group Observation Duration	0.0150** (0.00207)	0.0258*** (0.00381)	0.0144** (0.00215)	0.0418** (0.00923)	0.0361** (0.00845)	0.0355** (0.00837)	0.0357 (0.0305)
Boat Velocity	0.341 (0.309)	0.0962 (0.583)	0.389 (0.327)	-0.519 (1.141)	-1.098 (1.002)	-1.064 (1.001)	0.136 (2.763)
Census Distance	-0.0513 (0.0516)	0.0189 (0.0959)	-0.0624 (0.0544)	-0.00781 (0.187)	0.110 (0.165)	0.104 (0.165)	0.0928 (0.473)
Active Dredging Period	0.146 (0.0994)	0.000524 (0.165)	0.133 (0.103)	0.446 (0.340)	0.207 (0.287)	0.203 (0.284)	0.0328 (1.342)
Medium Tide Level	0.110 (0.0917)	0.125 (0.153)	0.0934 (0.0950)	0.108 (0.321)	0.0124 (0.294)	0.0115 (0.288)	0.1678 (1.128)
High Tide Level	0.0150 (0.104)	0.196 (0.173)	-0.0145 (0.109)	-0.348 (0.384)	-0.544 (0.366)	-0.572 (0.360)	0.5848 (1.158)
New Moon Phase	-0.164 (0.123)	-0.120 (0.217)	-0.150 (0.130)	0.377 (0.528)	0.401 (0.460)	0.363 (0.455)	0.5290 (1.220)
Waning Moon Phase	-0.183* (0.106)	-0.0136 (0.194)	-0.146 (0.110)	-0.140 (0.415)	0.0333 (0.381)	0.0368 (0.373)	2.250 (1.452)
Waxing Moon Phase	-0.0913 (0.114)	0.149 (0.203)	-0.0610 (0.118)	0.809* (0.425)	0.656 (0.401)	0.647* (0.393)	1.1718 (1.228)
Wind Speed	0.0360** (0.0177)	-0.0934*** (0.0292)	-0.0330* (0.0185)	0.00905 (0.0629)	0.0415 (0.0564)	0.0388 (0.0566)	0.2629 (0.219)

					-	-	-
Cloud Cover	0.00104 (0.00123)	0.00426** (0.00205)	0.00126 (0.00128)	0.000903 (0.00434)	0.000394 (0.00397)	0.000242 (0.00393)	0.0156 (0.0143)
Low Wave Height	0.143 (0.102)	0.220 (0.172)	0.152 (0.106)	0.0535 (0.409)	0.335 (0.349)	0.311 (0.348)	0.306 (1.221)
Low/Medium Wave Height	-0.155 (0.406)	-0.405 (0.805)	-0.115 (0.410)	0.0623 (1.183)	0.0320 (1.134)	0.0814 (1.113)	28.65 (3.112e+06)
Medium Wave Height	-	-	-	-	-	-	-
High Wave Height	-	-	-	-	-	-	-
Water Salinity	-0.00212 (0.00594)	0.0326*** (0.00998)	-0.00122 (0.00618)	0.0565** (0.0280)	0.0532** (0.0217)	0.0520** (0.0217)	0.112 (0.0705)
Water Temperature	0.00677 (0.0167)	0.0452 (0.0285)	0.0121 (0.0173)	-0.0121 (0.0636)	-0.0398 (0.0520)	-0.0325 (0.0519)	0.380 (0.229)
Water Depth	-0.00442 (0.00728)	-0.00184 (0.0106)	-0.00586 (0.00768)	-0.0616 (0.0471)	-0.0103 (0.0300)	-0.0130 (0.0306)	0 (0.0752)
Water Transparency	-0.0182 (0.0501)	0.0550 (0.0858)	-0.0123 (0.0515)	-0.273 (0.231)	-0.212 (0.205)	-0.221 (0.204)	0.409 (0.802)
Route ID (Random Effect)	0 (0)	0.0421 (0.0834)	0 (0)	0.139 (0.184)	0.303 (0.292)	0.234 (0.238)	1.627 (3.483)
Constant	-0.640 (1.841)	-2.361 (3.418)	-1.144 (1.946)	4.606 (6.796)	7.706 (6.036)	7.367 (6.023)	6.248 (16.69)
Observations	155	155	152	155	155	155	155
Number of groups	19	19	17	19	19	19	19

Standard errors in parentheses
 *** p<0.01, ** p<0.05, * p<0.1

Table 6. Results of Averaged Models of Unstandardized effects of environmental variables on Guiana Dolphin social metrics in the Cassurubá RESEX. NOTE - "Maximum Number of Adults" features only one variable in the best model, since only one variable was found to be significant in the previous GLMM analysis. "Number of Calves" was excluded from model selection as no variables were found to be significant in the previous GLMM analyses (Standard errors in parentheses; *** p<0.01, ** p<0.05; significant values in red for p<0.05 or p<0.01).

EXPLANATORY VARIABLES	Maximum Group Size	Range of Group Size	Maximum Number of Adults	Number of Re-sightings	Maximum Group Size per Re-sighting	Maximum Number of Adults per
Group Observation Duration	0.0581*** (0.00415)	0.0678*** (0.00577)	0.0569*** (0.00414)	0.0763*** (0.00724)	0.0694*** (0.00804)	0.0688** (0.00781)
Wind Speed	-0.0173 (0.0244)	-0.0180 (0.0322)	--	--	--	--
Salinity	--	--	--	-0.0281** (0.0136)	-0.0337** (0.0136)	0.0341* (0.0133)
Constant	-0.571*** (0.156)	-1.925*** (0.351)	-0.656*** (0.121)	-1.484*** (0.446)	-0.927** (0.453)	0.936** (0.442)
Observations	378	378	385	386	386	386
Number of groups	22	22	21	22	22	22

Standard errors in parentheses
 *** p<0.01, ** p<0.05, * p<0.1

Table 7. Comparative Global Model & Best Model components (Regression Coefficients & AICc-Weight Posterior Inclusion Probabilities (PIP)) for *Z. wollebaeki* social metrics. Dash marks represent variable exclusion from the model as a result of the model selection process. The regression coefficients show the relationship between each social metric and environmental factor. The AICc-Weight PIP values show differential use for each explanatory environmental variable, depending on social metric. Overall, access line and low tidal variability are found to have strong PIP values (between 0.5 and 1) (***) p<0.01, ** p<0.05; significant values in red for p<0.05 or p<0.01).

Estimated Social Metric	Model Type	Census Duration	Group Observation Duration	Boat Velocity (nau mi/hr)	Census Distance	Active Dredging Period	Medium Tide Level	High Tide Level	New Moon Phase	Waning Moon Phase	Waxing Moon Phase	Wind Speed	Cloud Cover	Low Wave Weight	Low/Medium Wave Height	Water Salinity	Water Temperature	Water Depth	Water Transparency	Constant (Intercept Terms)	AICc	ΔAICc
Maximum Group Size	GM Regression Coefficients	0.00	0.02***	0.34	-0.05	0.15	0.11	0.02	-0.16	-0.18*	-0.09	-0.04**	0.00	0.14	-0.16	-0.00	0.01	-0.00	0.02	-0.64	685.8997	0
	BM Regression Coefficients	--	0.06	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	-0.65	1199.5	513.6003
	Best Model PIP	--	1.00	--	--	--	--	--	--	--	--	0.50	--	--	--	--	--	--	--	--	--	--
Range of Group Size	GM Regression Coefficients	-0.00	0.03***	0.10	0.02	0.00	0.13	0.20	-0.12	-0.01	0.15	-0.09***	0.00**	0.22	-0.41	0.03***	0.05	-0.00	0.06	-2.36	666.5232	0
	BM Regression Coefficients	--	0.07	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	-2.02	907.7	241.1768
	Best Model PIP	--	1.00	--	--	--	--	--	--	--	--	0.41	--	--	--	--	--	--	--	--	--	--
*Maximum Number of Adults	GM Regression Coefficients	0.01	0.01***	0.39	-0.06	0.13	0.09	-0.01	-0.15	-0.15	-0.06	-0.03*	0.00	0.15	-0.12	-0.00	0.01	-0.01	0.01	-1.14	668.8003	0
	BM Regression Coefficients	--	0.06***	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1211.27	542.4707
	Best Model PIP	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Number of Re-sightings	GM Regression Coefficients	-0.00	0.04***	-0.52	0.01	0.45	0.11	-0.35	0.38	-0.14	0.81*	0.01	0.00	0.05	0.06	-0.06**	-0.01	-0.06	0.27	4.61	521.6206	0
	BM Regression Coefficients	--	0.08	--	--	--	--	--	--	--	--	--	--	--	--	-0.03	--	--	--	-1.42	655.3	133.6794
	Best Model PIP	--	1.00	--	--	--	--	--	--	--	--	--	--	--	--	0.93	--	--	--	--	--	--
Maximum Group Size	GM Regression Coefficients	-0.01	0.04***	-1.10	0.11	0.21	0.01	-0.54	0.40	0.033	0.66	0.04	-0.00	0.34	0.032	-0.05**	-0.04	-0.01	0.21	7.71	542.8163	0

per Re-sighting	BM Regression Coefficients	--	0.07	--	--	--	--	--	--	--	--	--	--	--	--	-0.03	--	--	--	-0.89	716.5	173.6837			
	Best Model PIP	--	1.00	--	--	--	--	--	--	--	--	--	--	--	--	0.97	--	--	--	--	--	--			
Maximum Number of Adults per Re-sighting	GM Regression Coefficients	-0.01	0.04***	-1.06	0.10	0.20	0.01	-0.57	0.36	0.037	0.65*	0.039	-0.00	0.31	0.08	-0.05**	-0.03	-0.01	-	0.22	7.37	537.39	0		
	BM Regression Coefficients	--	0.07	--	--	--	--	--	--	--	--	--	--	--	--	-0.04	--	--	--	--	-0.91	708.8	171.41		
	Best Model PIP	--	1.00	--	--	--	--	--	--	--	--	--	--	--	--	0.97	--	--	--	--	--	--	--		
Maximum Number of Calves per Re-sighting	GM Regression Coefficients	0.0138	0.0357	0.136	-	0.03	-	0.17	0.58	-	0.53	-2.25	-1.17	0.26	-0.02	0.31	-	28.65	-0.11	0.38*	0.058	0.41	6.25	104.3062	0
	BM Regression Coefficients	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	Best Model PIP	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--

FINE-SCALE RESULTS

Table 8. GLMM Model Results of Unstandardized effects of a suite of 6 distinct habitat types on Guiana Dolphin social metrics in the Cassurubá RESEX. HT1 is the reference group used for comparison to other habitat types, and is thus omitted from the final results. (Standard errors in parentheses; *** p<0.01, ** p<0.05; significant values in red for p<0.05 or p<0.01).

EXPLANATORY VARIABLES	Maximum Group Size	Range of Group Size	Maximum Number of Adults	Number of Re-sightings
HT2	-0.00317 (0.270)	-0.258 (0.497)	-0.000231 (0.263)	0.399 (0.628)
HT3	0.00694 (0.319)	-1.063* (0.631)	0.0149 (0.311)	0.325 (0.764)
HT4	0.0628 (0.286)	-0.200 (0.477)	0.0388 (0.280)	0.829 (0.612)
HT5	0.00874 (0.272)	-0.209 (0.507)	0.0206 (0.266)	0.122 (0.643)
HT6	-0.396 (0.291)	-1.835*** (0.524)	-0.472* (0.286)	-0.377 (0.657)
Habitat Site ID (Random Effect)	0.129*** (0.0403)	0.0833 (0.0689)	0.126*** (0.0390)	0.176* (0.104)
Constant	1.480*** (0.219)	0.628 (0.441)	1.422*** (0.213)	-0.384 (0.560)
Observations	1,085	1,085	1,081	1,082
Number of groups	38	38	38	38

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Discussion

Large-scale Guiana Dolphin Habitat Use

In the context of the Cassurubá RESEX, our results indicate differential habitat use by the local Guiana Dolphins, at large-scale (temporal) vs. fine-scale (spatial). The life history of Guiana Dolphins facilitates animal detection, as the species commonly inhabits the coastal waters of South and Central America, with a preference for shallow waters at a depth of about 5m (da Silva et al. 2010). However, at the large-scale level, few environmental variables were found to have significant relationships with Guiana Dolphin social metrics (Table 5). It is logical that Group Observation Duration is significantly and positively associated with all observed social metrics. In essence, the more time can be spent with a particular group of dolphins, the higher the likelihood of observing more individuals as they surface and demonstrate behaviors.

Wind Speed has a significant yet inverse relationship to maximum group size and range of group size. Higher wind speed may link to dynamics below surface which may lead to smaller group formations and thus more accurate detection at the water surface when it comes to group size. Higher wind speeds may create underwater conditions such as ocean currents which are more easily navigable by small dolphin groups. It is also possible that days with particularly high winds created inhospitable conditions for boat censuses and accurate detection of dolphin group size, perhaps leading to underestimation of group sizes on days with high wind speeds.

Water Salinity is a strong explanatory environmental factor as well. Higher water salinity is associated with lower number of re-sightings, group size per re-sighting, maximum number of adults per re-sighting (Table 5). In general, this finding corroborates past research showing that Guiana Dolphins avoid extreme salinities and deeper ocean waters with higher salinities, preferring coastal, estuarine, and even freshwater areas with low to medium salinity ranges (Rossi-Santos et al. 2010). Perhaps due to small group size found in areas of high salinity, group size detection accuracy is associated with higher water salinity. Small groups of dolphins are easier to accurately observe and document, once sighted.

Surprisingly, the yearly dredging regime did not seem to have a significant impact on Guiana Dolphin social metrics. Per the local human community dynamics, stakeholder interests, and anecdotal reports, we expected to find differences in Guiana Dolphin behavioral ecology in dredging periods vs. non-dredging periods. However, this was not the case, suggesting that temporal effects of dredging may simply be non-significant, or are better explored through a more spatially-explicit approach (i.e. comparing dolphin observations in the dredging zone vs. areas without dredging). However, the presence of confounding factors such as pervasive and ubiquitous sedimentation due to various dredging sediment deposit sites, water vessel passage, shifting water current conditions (direction, intensity, varying water depths...etc.) ...etc. further complicate the potential relationship between dredging and dolphin ecology. To partially account for vessel

traffic, future studies may include specific vessel type passage frequencies (Fliby *et al.* 2014).

In general, the averaged model results, based upon significant variables from the previous GLMM analysis, supported the previous findings, albeit with a “stricter” selection of significant variables (Table 5). For example, Wind Speed was not found to be significant once averaged across all model combinations, and cloud cover was completely dropped as a variable. This suggests that averaged models might be useful as providing a “standard” to complement the global GLMM analysis (a standardized comparison point to evaluate the magnitude and significance of specific variables), and to perhaps highlight certain variables as particularly significant or valuable by review of all model combinations.

Surprisingly, the global model (including all variables) outperformed the best model (based upon significant variables), indicating that other “non-significant” variables may actually play a strong role in estimating social metrics through underlying dynamics (Table 7). For the purposes of this analysis, we followed the convention of $p < 0.05$ to determine factor significance. However, other variables showed $p < 0.1$, perhaps suggesting a weaker yet present level of significant relationship to dolphin social metrics. Namely, Moon Phase (at the waning level and at the waxing level) and Wind Speed showed $p < 0.1$ as related respectively to maximum group size, maximum number of adults, and number of re-sightings (Table 7). All three explanatory environmental factors

have underlying ecological and biological links to dolphin ecology. Wind Speed significantly impacted two other social metrics (maximum group size and range of group size) (see above), and Moon Phase is linked to tide levels and ocean currents, which may impact the movement patterns of dolphins as well as prey movement (Bisi et al. 2012, Cantor et al. 2012a, Cantor et al. 2012b, Lailson-Brito et al. 2012, Bisi et al. 2013).

Fine-scale Guiana Dolphin Habitat Use

At the fine-scale level, only Habitat Type 6 (characterized by absence of shrimping activities, estuarine/freshwater location, mangrove presence, location outside of the canal, lack of dredging activity, presence of human communities, agriculture and livestock activities, shellfish harvesting, absence of other fishery types and fish species and a mix of low and high Hui's Contour Index, water temperature, water salinity, water visibility and wind speed) was found to have significant (and inverse) relationship to just one social metric: range of group size (Table 8; habitat types are defined in Table 4b). In sites with Habitat Type 6, overall group size is more accurately detected, suggesting perhaps smaller groups in these areas (even though group size was not found to be significantly different). Thus, as group sizes become smaller, range of group size is smaller as well, as there is less discrepancy in the group sizes sighting per scan sampling period. Additionally, the Habitat Type 6 profile presents various traits unsuitable to Guiana Dolphin occupancy, as per previous research (Rossi-Santos et al. 2010). Namely, despite the lack of potential disturbing activities such as shrimping and other fisheries,

this particular habitat profile indicates a highly and heterogenous ocean floor structure, opposite to the flat bottoms that the dolphins have been shown to prefer (habitat types are defined in Table 4) (Rossi-Santos et al. 2010). This suggests that despite the lack of ideal geophysical features (i.e. sea floor slope), other factors such as the presence of mangroves and small-scale human activities may actually compensate and be a draw for Guiana Dolphins.

This study's results can help fill in gaps within the body of literature for long-term marine mammal behavioral ecology. Marine mammal social clustering behavior and grouping patterns have been studied and documented in terms of habitat use, group membership, size, and nearest neighbor proximity (Acevedo-Gutierrez 2009b, Acevedo-Gutierrez 2009a). For example, among other marine mammal social hierarchy systems, dolphin pods are delimited by individuals within 10m of each other and New Zealand fur seals significantly alter their behavior when a nearby individual or human presence comes within 10 m (Acevedo-Gutierrez et al. 2010, Acevedo-Gutierrez et al. 2011). However, in relation to long-term datasets and environmental factors, there are often data or analysis results missing on marine mammal megafauna habitat use within specific locales, and implications for conservation.

Findings from previous research on the Burrunan dolphin can both heavily serve to inform both *a priori* hypotheses and to evaluate findings on Guiana dolphin behavior. In support of studying marine mammal behavior, past studies of delphinid species

document predictable behavioral changes in both individual, group, and population response to environmental changes and social shifts. Due to various commonalities with Guiana Dolphins, the case of the Burrunan dolphins is especially relevant to the study of the Guiana dolphins in extreme southern Bahia in Brazil. Both species were recently identified as unique species separate both genetically and morphologically from another species. The Burrunan dolphin is classified as a genetically and morphologically isolated species of bottlenose dolphin, and as such endemic, with two resident populations. Similar to Guiana dolphins, the species exhibits high site fidelity and a preference for coastal waters year-round. In parallel to the Guiana dolphin, which is listed as a threatened species, the Burrunan dolphin is also considered threatened by the Brazilian Institute of the Environment and Renewable Natural Resources. The extreme south Bahia Guiana Dolphin population is estimated at 120 individuals, which is the same population size for the Burrunan dolphin. Both species are in close proximity to human settlement and development, and exposed to human pressures such as vessel (recreational and commercial) activity, as well as local tourism (Filby et al. 2014).

This research can also provide a practical framework towards collecting and analyzing cetacean datasets. Marine mammal species present data collection and research methodology challenges. These species are generally highly mobile and hard-to-observe animals, mainly due to their water habitat requirements and dependence on aquatic resources for survival. However, due to differential physiological and behavioral

needs, pinnipeds generally spend more time on land, facilitating terrestrial behavior observation and population counts (Wolf & Trillmich, 2007). Due to sheer population density and haul-out space overcrowding, it may be hard to employ non-invasive technique to mark and identify specific individuals to maintain long-term panel data on behavior dynamics. Even when successfully identified with pectoral fin tags, these tags may be hard to identify as the sea lions form social groups and cluster together (Montero Serra 2011). Further, discoloration and damage over time may lessen the identifying capabilities of the tags. Successfully tagging and subsequently monitoring a pinniped population is time and resource intensive, often requiring sizeable teams of researchers. However, photo identification of dorsal fins is a viable option for fully aquatic species such as the Guiana Dolphin. This presents opportunity for individual recognition and tracking, presenting an advantage for research.

In the case of the Cassurubá population of Guiana dolphins, previous studies have shown that the species prefer certain habitat trait characteristics such as coastal shallow waters in proximity to sand banks, areas for gentle ocean floor slopes, and salinity ranging from 35 to 38 ppm (Rossi-Santos et al. 2010). Due to the ongoing human-dolphin interactions and environmental changes due to various anthropogenic activities, it is now important to include human factors as well in Guiana Dolphin behavioral ecology. In short, building a more comprehensive model by inclusion of anthropogenic factors and defining habitat type profiles, may help build upon previous research. Further, additional

analyses may help clarify the potential mechanistic links between dolphin social metrics and environmental factors.

The Guiana Dolphin is a coast dwelling species with preference for shallow waters, leading to frequent interactions with various human communities, such as the Cassurubá RESEX. These dynamics often create ground for conflict, such as conflicting opinions about the causes of environmental degradation that impact wildlife (Jablonski et al. 2006, Alves et al. 2012, Nobre et al. 2017). In contexts with various stakeholder opinions and perspectives, coupling GLMM with model selection and averaging can provide more direct insights into which models most accurately represent current ecological dynamics, and may illustrate which perspectives are most supported by results-driven evidence (Anderson et al. 1999, Anderson et al. 2001). In the case of the Cassurubá RESEX, at the large-scale level, the global GLMM showed that seasonal dredging activities do not significantly affect Guiana Dolphin social metrics (Table 4 & Table 6). However, at the fine-scale level, Guiana Dolphin social metrics respond significantly to sites with localized low-impact anthropogenic activities and presence such as shellfish harvesting, livestock keeping, and agriculture (habitat type 6; see Table 3b for definitions of habitat types). These results at large-scale vs. fine-scale suggest the need for further research to isolate and specify potential human impacts on Guiana Dolphin ecology.

In general, the population appears to be steady over time, hovering at about ~100 individuals since data collection began in 2002 (IBJ 2016). Between 2002 and 2016, a total of 188 dolphins (including transient individuals or individuals from another population in the Abrolhos archipelago) have been identified through dorsal fin photo-identification and cataloguing (IBJ 2016). In the first 14 years of data collection, about half (46%) of field outings reported zero dolphin sightings, while about 33% of outings reported sightings ranging from 2 to 6 dolphin individuals (IBJ 2016). These results indicate considerable sample effort and use of human and monetary resources to effectively monitor and census the local population of *S. guianensis* in the Cassurubá RESEX, highlighting the importance of accurately assessing habitat use by the species and identifying key environmental traits and habitat types important to the long-term survival of the Cassurubá dolphin population. By focusing on and prioritizing specific habitat characteristics and habitat types (such as habitat type, which incorporates mangroves and small-scale harvesting activities) especially important to key social metrics (group size, re-sightings, females, and calves), the Cassurubá RESEX may be able to design a more targeted approach to the long-term conservation of the Guiana Dolphin locally. Specifically, focus on environmental factors and habitat types important to range of group size and re-sighting metrics may effectively target female and calf populations, promoting long term reproduction success and population wellbeing for the species.

Conclusions and Recommendations

This study aimed to elucidate the relationships between environmental factors and Guiana Dolphin demographic and group behavioral metrics. Our goal was to contribute to the long-term conservation strategies and management of the species, in an inclusive manner that accounts for human presence as well. Previous research has indicated the differential behavioral ecology of Guiana Dolphins across various categories of environmental factors (Rossi-Santos et al. 2006, Rossi-Santos et al. 2007, Rossi-Santos et al. 2010, Cantor et al. 2012a, Cantor et al. 2012b). In various locales and study sites, Guiana Dolphins have been shown to have complex relationships with nearby human communities and anthropogenic effects (Azevedo et al. 2004, Martin and Silva 2004, Azevedo et al. 2005, Azevedo et al. 2007, de Oliveira and Monteiro-Filho 2008, Dorneles et al. 2008, Marcos César de Oliveira and Rosso 2008, Azevedo et al. 2009, Espécie et al. 2010, Flores et al. 2010, Rossi-Santos et al. 2010, Santos et al. 2010, Alves et al. 2012, Bisi et al. 2012, Cantor et al. 2012a, Cantor et al. 2012b, Costa et al. 2012, Lailson-Brito et al. 2012, Bisi et al. 2013, Beirão et al. 2014, Lunardi and Ferreira 2014, Manzan and Lopes 2015, 2016). However, in the context of the Cassurubá Extractive Reserve, the past research has not addressed the potential influence of anthropogenic factors, a crucial factor for a coastal species with close and frequent interactions with humans and human-linked factors. Namely, small-scale subsistence fisheries and sea resource harvesting occur in the Cassurubá RESEX, as well as a yearly dredging regime to permit the

frequent passage of barges transporting eucalyptus (IBJ 2016, Nobre et al. 2017). Overall, our results show differential habitat use by the local Guiana Dolphins, at large-scale (temporal) vs. fine-scale (spatial), supporting the original exploratory hypothesis.

Currently, the local communities and stakeholders hold various viewpoints concerning the possible relationships between types of human activities and the population health status of important wildlife, such as fish species, the Guiana Dolphin, and Humpback whales. Namely, small-scale artisanal fishers and harvesters indicate dredging as a main cause of changing water quality and fish populations, while a local wood-harvesting and canal industry points to fishing and harvesting activities as a main cause of changing environmental conditions.

Thus, in terms of resolving and reconciling stakeholder positions relating to the impacts of different human activities on dolphin wellbeing, our results indicate that the yearly seasonal dredging regime may hold neutral or currently undetectable effects on Guiana Dolphin population behavioral ecology. However, small scale fisheries and harvesting may hold positive impacts on dolphin local habitat choice and use, as various social metrics positively associate with sites near human communities with mangroves and shellfish harvesting, agriculture and livestock activities. These nutrient-rich areas may serve as useful nurseries for the dolphins, especially for small groups consisting of female and a calf. This may explain the smaller group ranges and sizes observed in this habitat profile (6). Thus, small-scale human fishers/harvesters and dolphins may coincide

in habitat choice and successfully coexist due to the low-impact human activities.

Because these results are derived from a 15-year dataset, relative to past research based upon 3 years of data, we can recommend that these results are fairly reliable and may represent ongoing behavioral ecology and human-dolphin dynamics in the Cassurubá RESEX (Rossi-Santos et al. 2010).

Conservation management strategies have used stakeholder meetings and groups to conduct different versions of models, adapted to each stakeholder viewpoint (Anderson et al. 1999, Anderson et al. 2001). By holistically comparing the resulting metrics of each model between stakeholders, the community could then obtain statistical results to choose the best model and make informed decisions in an inclusive yet objective manner.

In addition to choosing the best model, we propose presenting various versions of the best model, that may yield the same performance metrics but differ in composition (Appendix; Supplementary Materials). Thus, communities may adapt ecological management practices to their own present resources, and take an active and proprietary role in local ecological governance. Using $\Delta AICc$ to compare relative model performance, it has been shown that models with $\Delta AICc > 2$ (and even $\Delta AICc \Rightarrow 7$) perform similarly to the best model (Anderson et al. 1994, Anderson et al. 1999, Anderson et al. 2001, Burnham and Anderson 2001, Burnham and Anderson 2001, Burnham 2002, Burnham and Anderson 2004, Burnham et al. 2011a, Burnham et al. 2011b, Luchman 2014). Thus, we recommend providing a list of best models (i.e. top 10

best models) falling within a range of $\Delta AICc > 2$ or up to $\Delta AICc \Rightarrow 7$, to provide choices and agency to the concerned community decision-makers (see Supplementary Materials in Appendix). As an additional advantage, providing management options to the local communities may enable stakeholder participation at each stage of the research process: project design, data collection, results presentation, and results implementation. Often, local communities highlight a need for better science communication and direct involvement in conservation management, especially if community members have directly contributed to the research process through participatory methods. Using model selection and providing a variety of solutions for the communities to choose from, may provide the added benefit of facilitating longer-term partnerships between communities and stakeholders.

In terms of future study, wind speed shows potential for future investigation, and may be combined with other factors such as wind direction. Water Salinity is clearly as well an important variable, and may be combined with prey habitat salinity preferences to better understand the driving pressures leading dolphins to occupy areas with lower salinity ranges. To prioritize Guiana dolphin conservation, there is a clear need for more follow up research investigating air and water-related factors, such as wind speed, wind direction, water salinity, and solute concentrations. Future studies may explore additional air-based data, and explore different habitat profiles under more categories to elucidate the potential effects of specific spatial variables. This approach would maximize

environmental and *S. guianensis* social measurements, providing more data and analysis results towards the correct conservation status for the Guiana Dolphin species at the IUCN level.

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CHAPTER 3

GUIANA DOLPHINS (*SOTALIA GUIANENSIS*) AS SENTINELS OF ECOLOGICAL AND ENVIRONMENTAL CHANGE: A CASE STUDY OF THE CASSURUBÁ RESERVE

Introduction

Sentinel species, defined as organisms able to respond to ecosystem variability and/or change in a timely and measurable way to nowcast or forecast otherwise potentially unobserved environmental changes, can help mitigate or even avoid changes deleterious to both wildlife and human communities (Hazen et al. 2019). Worldwide, coastal zones face degradation challenges due to impacts from human presence, including the increased frequency and intensity of harmful algal blooms, overfishing, loss of critical habitats, and the spread of persistent chemical pollutants (Aguirre and Tabor 2004). As such, scientists have recognized and documented observations of species sensitive to harmful environmental conditions to inform future population outcomes (Simeone 2018). Several previous studies have identified these links between behavioral change and environmental fluctuations (Erfteimeijer et al. 2012, Kimura et al. 2012, Pirotta et al. 2013, Todd et al. 2015, Marley et al. 2017).

An ecosystem sentinel holds the capability to indicate an otherwise unobserved change in ecosystem function (Hazen et al. 2019). Marine apex species, especially socially complex marine mammals, are often valuable sentinel species due to their large-scale movements across ocean basins and resulting ability to magnify trends in trophic

information across multiple spatiotemporal scales (Figure 1). Past research has shown that marine mammals respond behaviorally in tandem to external changes and stimuli. Similarly, accounting for various time lags, marine mammal behavioral ecology may indicate early stages of broader external changes, thus presenting the opportunity to remedy or stave off bigger scale deleterious external changes before they escalate both in terms of scale and ecologically (Reed 2002).

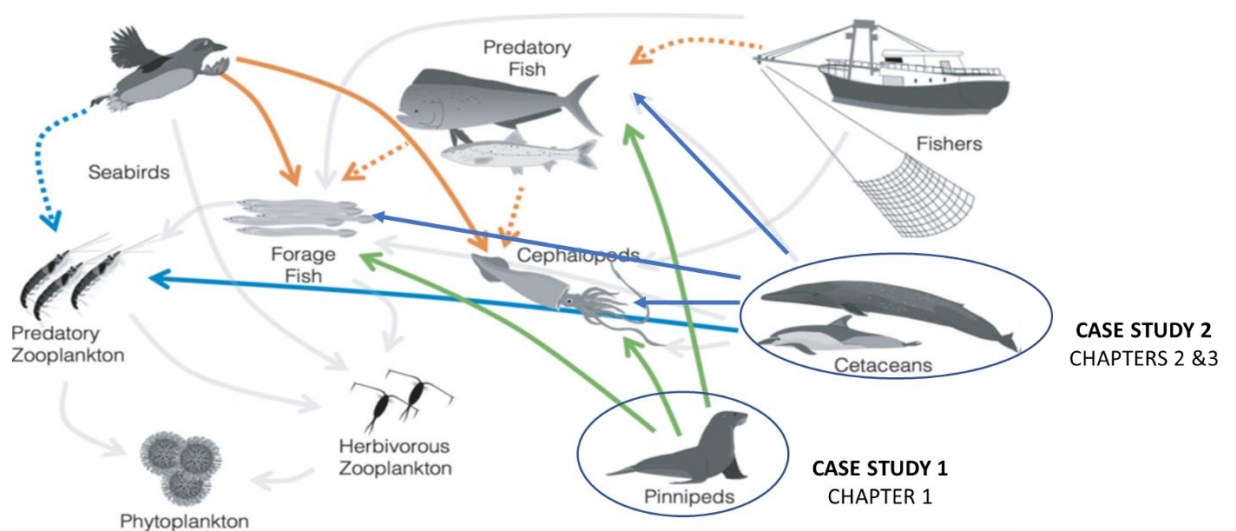


Figure 1. Selection of two case studies in a sample marine ecosystem with trophic linkages (Figure adapted from Hazen *et al.* 2019). Trophic linkages (gray and colored arrows) show a generic pelagic food web. Gray arrows represent a trophic linkage outside of the sentinel relationship, with colors referring to a specific example. Solid colored lines represent a direct relationship between a sentinel via the metric measured and an ecosystem component. Dotted colored arrows represent the ecosystem component that may be forecasted by a leading sentinel (Hazen et al. 2019).

Sentinel species generally provide information related to their environment through one or both of two functionalities. **Elucidating sentinels** respond to past or ongoing changes in unobserved ecosystem components for nowcasting (explaining current, very recently passed or future events), while **leading sentinels** “predict” or estimate future environment change for forecasting (concerning future events) (Hazen et al. 2019). Several previous studies have identified links between behavioral change and environmental fluctuations (Erftemeijer et al. 2012, Kimura et al. 2012, Pirotta et al. 2013, Todd et al. 2015, Marley et al. 2017).

To begin identification of a sentinel species, the first step is to establish boundaries for acceptable behavior, in order to identify behavioral profiles that significantly deviate from the established naturally occurring foundations (Reed 2002, Simeone 2018). Behavioral changes such as altered time budgets for foraging can indicate external changes, such as increased competition for high quality prey due to overfishing, pollution, or other factors; or more specific individual symptoms such as tremors in limbs, altered time/energy budgets, disrupted motor and sensory functions, and decreased performance in learned tasks (Reed 2002). However, sometimes it is difficult to pinpoint the source of specific problems, especially as these factors can be intrinsically interrelated in a web of biotic/abiotic feedback systems.

In 2017, the Marine Mammal Center (MMC) of California released various scientific publications and public communications highlighting the importance and

categorization of marine mammals as “sentinels of the sea”, which can be interpreted through “zoognosis,” a concept based on the mutual transfer of knowledge from animals to humans. In this sense, “zoognosis” places added focus on the monitoring of animal behavior as clues to inform broader environmental status and human health. The transfer of information can occur through steps such as direct adaptive behaviors or similar responses to environmental stimuli such as water temperature shifts and susceptibility to algal blooms (Simeone 2018). As apex and keystone species, marine mammals transfer biological information as they regulate ecosystem balance and nutrient and energy flow within their environment (Paez-Rosas and Aurióles-Gamboa 2010, Páez-Rosas et al. 2012, Páez-Rosas et al. 2014, Hazen et al. 2019).

Although prior studies have defined sentinel species and outlined important criteria, there remains a need for a unifying data analysis and evaluation methodology for identifying potential sentinel species (Hazen et al. 2019). This chapter draws upon the work of Hazen et al. (2019) to present a broader framework and more detailed approach for identifying marine mammal sentinel species. In doing so, this approach explores methods and data that can be used to identify sentinel species for either nowcasting or forecasting specific environmental changes. A case study of the Guiana Dolphin (*Sotalia guianensis*) in the Cassurubá Extractive Reserve in northeastern Brazil provides an example of analytical methods that can be used to test the strengths of relationships among changes in animal behavior and environmental variables over time.

Specifically, this case study explores how patterns of observed dolphin behavior over 15 years may be indicative of ecological changes in local food webs from decreased water quality and increased sedimentation from localized dredging in the Reserve. Namely, sedimentation may have distinct effects on Guiana Dolphin behavioral ecology. Research has shown that some dolphin species, such as a population of Bottlenose dolphins in Florida, may intentionally agitate the ocean floor to create water cloudiness to confuse and trap their prey (e.g. mud ring feeding), which they then detect through movement and electrical impulse detection (Engleby and Powell 2019). Thus, sedimentation could encourage behavioral adaptation and increased foraging for the local Guiana Dolphins. However, on a broad ecological scale, increased sedimentation can reduce food efficiency of primary filter feeders, increase shading and reduce photosynthesis for species such as zooplankton (Figure 1). In the long term, these changes may impact primary production and reduce fish populations in the area, which in turn may decrease the local Guiana Dolphin resident population numbers as food resources diminish.

Our overall research hypothesis proposes that decreases in dolphin abundance, or specific group types such as the number of calves, in the Cassurubá Extractive Reserve area over time may be indicative of increased sedimentation impacts on local food webs.

However, this case study also illustrates the difficulty of data collection for marine organisms, as well as the major lack of environmental and behavioral datasets that

may be most relevant for understanding how sentinels can inform on environmental change over time. Specifically in the case of sedimentation, the appropriate data in terms of water sediment load, particle concentration, etc. may not readily available. Therefore, in this case study, we employ proxy variables regarding water quality (water transparency, water temperature, water salinity, etc.) to evaluate potential and possible sedimentation effects.

This research aims to further contribute to the field of conservation science from the growing field of documenting “zoognosis,” by examining the transfer of (environmental) knowledge through monitoring of sentinel marine mammal behavior, in order to promote longer term physiological and population health for humans and wildlife.

Methods: A Case Study of the Guiana Dolphin

Background:

The Cassurubá Extractive Reserve (RESEX) is a 100,767 ha (1007.67 square km) area composed of coastal, estuarine and freshwater riverine ecosystems across the neighboring municipalities of Caravelas, Nova Viçosa, and Alcobaça. The Caravelas River Estuary system and its neighboring coastal areas are linked to and impacted by the second largest (66 km²) estuarine-mangrove system of the north-eastern coast of Brazil (Rossi-Santos *et al.* 2007).

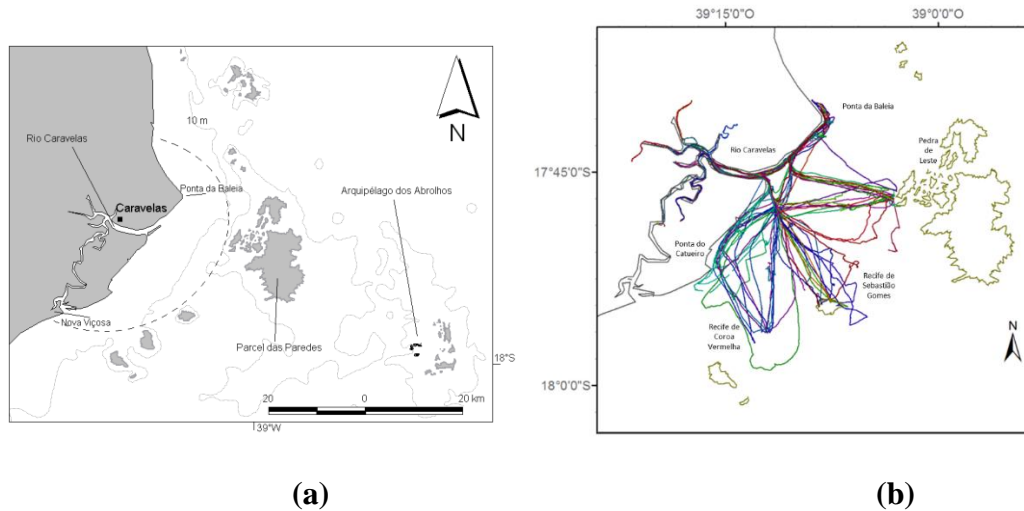


Figure 2. (a) Map illustration of the Cassurubá RESEX study area for sampling and monitoring a population of *Sotalia guianensis* between 2002 and 2015 (Rossi-Santos et al. 2007). (b) Research survey routes and transects used for data collection in the Cassurubá RESEX territory in 2015 (IBJ 2016).

The Cassurubá RESEX was established in 2009 as protection from a large-scale shrimp farming proposal in the area (Nobre et al. 2017). Through grassroots mobilization efforts and local NGO partnerships, who produced foundational scientific studies, local residents and stakeholders successfully petitioned the creation of the RESEX. The reserve is home to 300 families who practice local artisanal fishing, river/estuary/sea resource harvesting, and agriculture and livestock (Nobre et al. 2017). Two thousand additional families reside in urban areas outside official RESEX delineations, but also utilize resources stemming from the interior of the RESEX boundaries, mainly through fishing and harvesting at sea (Nobre et al. 2017).

The strategic placement of the Canal de Tomba within the RESEX allows for commercial and industrial transport of eucalyptus lumber and timber from nearby land plantations to barges for transfer to other distribution points (Rossi-Santos et al. 2006, Rossi-Santos et al. 2007, Rossi-Santos et al. 2010, Cantor et al. 2012a, Cantor et al. 2012b, IBJ 2016). As a result of ongoing industrial barge traffic in the Canal de Tomba, the area constitutes an excluded area from the RESEX designation. Further, to maintain optimal depth and width in the Canal to allow barge passage, since 2002 a eucalyptus company with local operations conducts yearly seasonal dredging regime of the canal (January- March).

Between April 2002 and December 2016, an average of 5 days/month were spent censusing various routes within the Cassurubá RESEX, with aims of covering the whole study area each month. Data collection through boat cruises to survey different routes involved two separate motorboats departing from the same point at the port of the town Caravelas at 6 am and returning at 1 pm (IBJ 2016). In the first 14 years of data collection, about half (46%) of field outings reported zero dolphin sightings, while about 33% of outings reported sightings ranging from 2 to 6 dolphin individuals (Tables 1 & 2). The total dataset for this study contained ~825 census observations (IBJ 2016) (See Chapter 2 for further details). The current Cassurubá population of Guiana Dolphins is about 100 individuals in total (Cantor et al. 2012a, Cantor et al. 2012b, IBJ 2016).

Between 2002 and 2016, a total of 188 dolphins have been identified through dorsal fin photo-identification and cataloguing (IBJ 2016).

While it is difficult to reliably identify the sex and age of each sighted individual, catalogued individuals can be identified as females and calves due to the constant grouping and tandem surfacing of females with their calves. In addition, calf sightings also indicate the presence of at least one female within the observed dolphin group. Thus, dolphin metrics on re-sightings that include calves as a group member may be used as a proxy for dolphin female number and population composition (IBJ 2016).

Table 1. (a) Guiana Dolphin social and behavioral data collected from 2002-2017 on distinct transect routes. **(b)** Guiana Dolphin environmental data, collected 2002-2017 on distinct transect routes

(a)

Social Metric	Description	Measurement Units/Categories
Maximum Group Size	Variable counting the maximum number of dolphins in a group per census	Discrete count number
Range of Group Size	A measure of discrepancy in the group sizes sighted per scan sampling period. Also serves as proxy for accuracy of observed group size during scan sampling, calculated as: <i>(Max Group Size – Min Group Size)</i>	Discrete count number
Maximum Number of Adults Sighted	Variable counting the maximum number of adult dolphins in a group per census	Discrete count number
Number of calves	Variable counting the presence and number of observed calves	Discrete count number
Number of females	Variable counting the presence and number of observed females	Discrete count number
Number of Resightings	Variable counting observations of dolphin individuals previously identified and/or previously sighted	Discrete count number

Maximum Group Size per Resighting	Variable counting the maximum number of dolphins in a group which included a previously identified and/or previously sighted individual	Discrete count number
Maximum Number of Calves per Resighting	Variable counting the maximum number of calves in a group which included a previously identified and/or previously sighted individual	Discrete count number

(b)

Environmental Variable	Description	Measurement Units/Categories
Dredge Status	Indicator of non-active vs. active dredging period at time of census	Categories (No Dredging, Active Dredging)
Wave Height	Beaufort categories of different wave height levels	Categories (0, 1, 2, 3, 4)
Wind Speed	Measurement of wind speed	Meters/s
Tide Level	Variable measuring level of tide as predicted by local weather charts	Low, Medium, High
Water Transparency	Measured by water transparency, according to a Secchi desk	Secchi Disk Measurement (Meters (m))
Water Depth	Variable measuring water depth	Meters (m)
Water Temperature	Variable measuring water temperature as measured by a standard thermometer	Degrees Celsius (°)
Water Salinity	Variable measuring water salinity as per a standard salinity meter	ppm
GPS Route of survey trajectory	Spatial line of each survey route travelled per outing, recorded using a standard GPS	Longitude & Latitude Coordinates (Nautical miles measurement of route)
GPS Point of dolphin sighting location	Spatial points of each dolphin sighting location, recorded using a standard GPS	Longitude & Latitude Coordinates (ArcGIS Polygon georeferenced spatial layers)

Data Analysis

We used Generalized Linear Mixed Model regressions (GLMM) to investigate the relationships between Guiana Dolphin social metrics (i.e., group size and other associated and derived grouping dynamic metrics) and environmental factors (Table 1) (refer to Chapter 2 for detailed spatial and summarizing methodology). A GLMM allows us to detect effects of specific environmental factors while including location variables (Census Name and Habitat Site) to control for spatial autocorrelation. Models were fit using the “meglm” STATA command and a negative binomial distribution (to account for overdispersion of count data) and log link through STATA 15, and following the general strategy of Wolf et al. (2005). The model was fit at a large spatial scale (whole censuses) but still accounted for each environmental variable, as well as temporal variation across censuses (Table 1 and Table 2).

Next, to determine which model compositions perform best and which factors held particular usefulness in the models, we conducted a Model Averaging and Model selection analysis. To prevent overloading the model and to facilitate analysis, only the significant variables obtained from the previous GLMM results were included in the model averaging/selection analysis. This approach also served to maximize parsimony while simplifying the model (Burnham et al. 2011a, Burnham et al. 2011b, Symonds and Moussalli 2011). The MIINC package in STATA 15 (Luchman 2014) was used to conduct the Model Averaging & Model Selection Analysis.

Logistic Models

In the case of categorical variables, logistic models were run for each variable category as binary variables (i.e. wave height levels...etc.). To account for spatial auto-correlation, “census ID” was included as a random effect variables. The following software was used for data editing, spatial analyses, and statistical analyses: ArcGIS 10.6.1, ArcGIS Pro, ArcGIS 10.6.1 Extension Repeating Shapes Tool (Version 1.5.152) (Jenness 2012), Polygon to Centerline Tool for ArcGIS (Version 9_3_10_1) (Dilts 2015), and the MIINC package in STATA 15 (Luchman 2014).

Model Testing (Crossfold Analysis)

In addition to the standard GLMM, Model Averaging and Model Selection, we tested the estimating ability of each social metric using the Crossfold (K= 5) method, to compare the global GLMM model vs. the refined Best Model (as determined from the Model selection analysis). We specifically chose Crossfold among other model validation methods to reduce result variations and biases (due to data samples included data training sets vs. data testing sets). The Crossfold package in STATA produced a Root Mean Square Error (RMSE) metric and a R^2 metric for each model (Daniels 2012).

Model Performance Metrics for Factors Relevant to Environmental Drivers (Sedimentation)

For model testing and sentinel evaluation, we selected a set of environmental variables that demonstrated links to pressing environmental changes such as

sedimentation in other studies (Acevedo-Gutierrez and Cendejas-Zarelli 2011, Hazen et al. 2019). Overall model performance (estimating ability of the explanatory variables) is judged by a suite of metrics, following the standard recommendations of Burnham and Anderson (2004) and supporting articles (Anderson et al. 1999, Anderson et al. 2001a, Anderson et al. 2001b, Burnham and Anderson 2001, Burnham 2002, Burnham and Anderson 2004, Burnham et al. 2011b, Luchman 2014). The Global Model (including all explanatory variables) is presented in contrast to the best model as determined by the Model Selection Analysis.

In addition to the AIC (Akaike Information Criterion) and $\Delta AICc$ (change in corrected Akaike Information Criterion) metrics, the models are also evaluated by RMSE (Root Mean Square Error) and R^2 values, derived from a Crossfold analysis to directly gauge the estimating ability and strength of each model (sentinel performance of the included social metrics towards a targeted environmental factor).

We only tested the specific performance of the first best model, as our prior analyses and supporting articles showed that all models with $\Delta AICc \leq 2$ (differences between 0 and 2 from the smallest information criterion producing/best model) show similar results in RMSE and R^2 values. As Burnham and Anderson (2004) note that models with $\Delta AICc \leq 2$ are similar in performance and validity, for the sake of simplicity, only the best model (with $\Delta AIC = 0$) specifications are reported here, with other supporting best models separately provided (see Appendix).

Table 2. Description of GLMM Model at large spatio-temporal scale (per census).

Generalized Linear Mixed Model		
Response Variables (Environmental Factors)	Explanatory Variables (Social Metrics)	Variable Measurement Unit (Standardized)
<ul style="list-style-type: none"> - Dredge Status* - Tide Level - Wind Speed - Wave Height - Salinity - Water Temperature - Water Depth - Water Transparency 	Maximum Group Size	Count
	Range (Observability) of Group Size	Count
	Maximum Number of Adults Sighted	Count
	Number of Resightings	Count
	Route ID (Model Random Effect)	26 categories

***Anthropogenic**

Results

In summary, maximum group size, range of group size, maximum group size per resighting, maximum number of adults per resighting, and maximum number of calves per resighting all had significant relationships with different environmental factors (Table 3). Range of group size had the highest number of significant relationships to environmental factors (4 out of 8 environmental factors- wind speed, high wave height, water depth, and water transparency). Range of group size is negatively associated with wind speed, high wave height, and water depth, while being positively associated with water salinity, water transparency (Table 3).

Both maximum group size and maximum number of adults per resighting held significant relationships with environmental variables. Maximum group size is positively linked with water depth. Maximum number of adults per resighting is also significantly linked with water salinity, but through an inverse relationship. The same relationship applies to water transparency as well. Maximum group size per resighting and maximum number of calves per resighting held one significant relationship with an environmental variable (Table 3).

The averaged model results, based on significant variables from the GLMM, largely supported the original global GLMM model highlighting water salinity, wind speed, water depth, and water transparency as environmental variables important to most dolphin social metrics found to be consistently strong variables (Table 4).

Table 3. Large-scale GLMM Model Results- concerning the standardized effects of a suite of Guiana Dolphin social metrics on environmental factors. (Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1).

ESTIMATED VARIABLES	Active Dredge Status	High Tide	Wind Speed	High Wave Height	Water Salinity	Water Temperature	Water Depth	Water Transparency
Maximum Group Size	-0.162 (0.758)	-0.867 (0.948)	0.563 (1.200)	0.852 (1.847)	-6.094* (3.409)	0.573 (1.206)	10.14** (4.247)	-0.858 (0.537)
Range of Group Size	0.219 (0.157)	0.101 (0.188)	-0.621** (0.251)	0.827** (0.389)	2.644*** (0.642)	0.0265 (0.233)	2.491*** (0.787)	0.299*** (0.0982)
Maximum Number of Adults	0.136 (0.739)	0.569 (0.912)	-0.490 (1.172)	-0.341 (1.832)	4.700 (3.343)	-0.582 (1.182)	-7.791* (4.102)	0.643 (0.522)
Number of Resightings	0.118 (0.110)	-0.0427 (0.143)	0.0178 (0.193)	-0.108 (0.442)	0.286 (0.503)	-0.0994 (0.184)	-0.963 (0.647)	0.00359 (0.0879)
Maximum Group Size per Resighting	27.35 (938.7)	27.05 (1,376)	0.707 (1.954)	21.85 (1,519)	13.33*** (4.868)	-2.178 (1.791)	2.333 (5.638)	1.381* (0.718)
Maximum Number of Adults per Resighting	-24.99 (866.1)	-24.73 (1,269)	-0.617 (1.839)	-20.31 (1,402)	13.64*** (4.597)	2.876* (1.689)	-0.955 (5.299)	-1.403** (0.684)
Maximum Number of Calves per Resighting	-4.424 (145.1)	-4.475 (212.7)	-0.0905 (0.260)	-3.829 (234.8)	-1.526** (0.612)	-0.0459 (0.229)	0.379 (0.719)	-0.0525 (0.0717)
Constant	-1.223 (4.153)	-1.357 (6.088)	4.572*** (0.121)	-3.223 (6.724)	32.47*** (0.304)	26.83*** (0.113)	12.37*** (0.368)	1.033*** (0.0469)
Observations	822	436	788	802	663	667	635	439
R-squared			0.024		0.067	0.051	0.066	0.045

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table 4. Large-scale Averaged Model Results- Average of models concerning the standardized effects of a suite of Guiana Dolphin social metrics on environmental factors. (Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1).

EXPLANATORY VARIABLES	Active Dredging Period	High Tide	Wind Speed	High Wave Height	Water Salinity	Water Temperature	Water Depth	Water Transparency
Maximum Group Size	0.0164 (0.266)	-0.177 (0.478)	0.0633 (0.392)	0.114 (0.654)	-2.137 (2.985)	0.0236 (0.366)	9.727* (5.478)	-0.205 (0.338)
Range of Group Size	0.148 (0.145)	0.00451 (0.0947)	-0.562** (0.226)	-0.502 (0.452)	2.516*** (0.707)	0.00395 (0.0961)	2.701*** (0.864)	0.264** (0.114)
Maximum Number of Adults	0.0376 (0.262)	0.0590 (0.448)	-0.0466 (0.379)	0.0878 (0.633)	0.954 (2.806)	-0.0243 (0.362)	-7.199 (5.219)	0.0242 (0.313)
Number of Resightings	0.0572 (0.0995)	0.00941 (0.0791)	0.0110 (0.0915)	0.0701 (0.247)	0.0780 (0.307)	-0.0314 (0.110)	-0.409 (0.642)	-0.00394 (0.0475)
Maximum Group Size per Resighting	8.143 (744.5)	3.819 (578.4)	0.0601 (0.421)	0.604 (413.0)	7.216 (7.014)	-1.149 (1.551)	1.340 (2.859)	0.223 (0.534)
Maximum Number of Adults per Resighting	-7.256 (686.9)	-3.369 (533.7)	-0.0222 (0.402)	-0.692 (381.1)	-7.750 (6.613)	1.832 (1.488)	-0.459 (2.620)	-0.290 (0.523)
Maximum of Calves per Resighting	-1.453 (115.1)	-0.918 (89.41)	0.00546 (0.0819)	-0.332 (63.84)	-1.013 (0.871)	-0.0944 (0.174)	0.329 (0.518)	-0.00569 (0.0385)
Constant	-1.142 (3.294)	-1.309 (2.563)	4.571*** (0.121)	3.079* (1.837)	32.49*** (0.306)	26.83*** (0.113)	12.39*** (0.371)	1.027*** (0.0472)
Observations	822	436	788	802	663	667	635	439

Standard errors in parentheses
 *** p<0.01,
 ** p<0.05, * p<0.1

LARGE-SCALE MODEL PERFORMANCE METRICS

S. guianensis social metrics show a low performance ability for estimating wind speed, water salinity, water depth, and water transparency (Table 4). The models with the most similarities between the global model and the best model, estimated the following factors: the active dredging period, high tide, water salinity, water depth, and water transparency ($\Delta\text{AIC} < 7$) (Burnham et al. 2011b) (Table 5). The environmental factor with the highest differences between the global and the best model was wind speed ($\Delta\text{AIC} > 10$) (Table 5).

As the Best Model consistently outperforms the Global Model (per RMSE and R^2 value), Table 5 shows detailed components and regression coefficients of the Best Model (Table 6). The AICc-Weight PIP (Posterior Inclusion Probability) value is a "weight of evidence" metric to show a level of confidence for inclusion of the independent variable in the model. These PIP values are relative to the best model under consideration and do not guarantee that the inclusion of highly likely variables are necessarily in the true model (Luchman 2014). PIP values suggest the usefulness of each independent variable in the represented model, which is which is sometimes interpreted as an indication of a variable's importance, while the regression coefficients show the relationship between each social metric and environmental factor. Overall, range of group size, maximum number of adults per resighting, and maximum number of calves per resighting are found

to have strong PIP values (between 0.5 and 1), suggesting strong model usefulness and emphasis for future model inclusion.

Table 5. Comparative model performance metrics for environmental factors. For each environmental factor, two model options are provided: Global model with all explanatory variables included vs. the best selected factor based on $\Delta AICc$. The mean RMSE and R^2 show relative model performance. While all R^2 values are very low, *S. guianensis* social metrics show a slightly higher relative performance ability for estimating water salinity, water depth, and water transparency.

Estimated Environmental Factor	Model Type	AICc	$\Delta AICc$	Mean RMSE	Mean R^2 Value
Active Dredging Period	Global Model	915.27	4.77	0.43 \pm 0.02	0.02 \pm 0.01
	Best Selected Model	910.50	0.00	0.43 \pm 0.01	0.04 \pm 0.02
High Tide	Global Model	447.43	6.63	0.40 \pm 0.02	0.01 \pm 0.01
	Best Selected Model	440.80	0.00	0.40 \pm 0.02	0.02 \pm 0.01
Wind Speed	Global Model	4167.90	11.10	3.43 \pm 0.16	0.01 \pm 0.01
	Best Selected Model	4156.80	0.00	3.38 \pm 0.25	0.02 \pm 0.01
High Wave Height	Global Model	324.06	7.56	0.22 \pm 0.02	0.01 \pm 0.02
	Best Selected Model	316.50	0.00	0.22 \pm 0.01	0.01 \pm 0.01
Water Salinity	Global Model	4608.02	1.62	7.90 \pm 0.90	0.04 \pm 0.03
	Best Selected Model	4606.40	0.00	7.83 \pm 1.25	0.03 \pm 0.02
Water Temperature	Global Model	3324.51	9.41	9.19 \pm 1.54	0.04 \pm 0.03

	Best Selected Model	3315.10	0.00	2.86 ± 0.55	0.07 ± 0.06
Water Depth	Global Model	4618.32	3454.03	9.19 ± 1.54	0.06 ± 0.08
	Best Selected Model	4615.40	0.00	9.15 ± 1.22	0.08 ± 0.05
Water Transparency	Global Model	1164.29	4.19	0.93 ± 0.10	0.03 ± 0.03
	Best Selected Model	1160.10	0.00	0.89 ± 0.18	0.04 ± 0.02

Table 6. Comparative selected best model components (AICc-weight posterior inclusion probabilities (PIP) & regression coefficients) for environmental factors. The AICc-Weight PIP values show that differential use for each explanatory social metric, depending on environmental variable. Overall, range of group size, maximum number of adults per resighting, and maximum number of calves per resighting are found to have strong PIP values (between 0.5 and 1). The regression coefficients show the relationship between each social metric and environmental factor. Dash marks represent variable exclusion from the model through the analysis.

Estimated Environmental Factor	Model Component	Maximum Group Size	Range of Group Size	Maximum Number of Adults	Number of Resightings	Maximum Group Size per Resighting	Maximum Number of Adults per Resighting	Maximum Number of Calves per Resighting	Constant (Intercept Term)
Active Dredging Period	PIP	0.35	0.67	0.35	0.43	0.66	0.64	0.85	NA
	Regression Coefficients	--	0.22	--	--	0.35	--	-0.27	-1.11
High Tide	PIP	0.40	0.29	0.36	0.29	0.52	0.51	0.86	NA
	Regression Coefficients	--	--	--	--	0.16	--	-0.39	-1.36
	Regression Coefficients (Best Model 2)	--	--	--	--	0.11	--	--	-1.31
Wind Speed	PIP	0.30	0.96	0.30	0.28	0.29	0.29	0.27	NA
	Regression Coefficients	--	-0.54	--	--	--	--	--	4.57
High Wave Height	PIP	0.37	0.73	0.36	0.32	0.37	0.35	0.46	NA
	Regression Coefficients	--	-0.47	--	--	--	--	-0.43	-3.10
Water Salinity	PIP	0.64	1.00	0.49	0.30	0.78	0.84	0.74	NA
	Regression Coefficients	-1.43	2.73	--	--	11.54	-11.65	-1.59	32.49
Water Temperature	PIP	0.27	0.27	0.27	0.30	0.69	0.87	0.47	NA
	Regression Coefficients	--	--	--	--	-2.26	2.87		26.82
Water Depth	PIP	0.94	0.99	0.83	0.47	0.52	0.45	0.47	NA
	Regression Coefficients	12.17	-2.56	-9.74	-0.96	1.55			12.39
Water Transparency	PIP	0.57	0.97	0.45	0.29	0.48	0.54	0.29	NA
	Regression Coefficients	-0.31	0.33	--	--	--	--	--	1.01

Discussion

To evaluate sentinel species capability, we presented the example case study of the Guiana Dolphin to estimate if these social metrics can estimate environmental factors that may impact long-term environmental changes and conservation outcomes associated with increased dredging activities in the Reserve. Referring to the hypothesis stating that dolphin group dynamics may estimate environmental drivers such as sedimentation (potentially linked to dredging and other human activities), the results show that none of the dolphin group types estimated active dredging periods.

However, the dolphin group types did significantly relate with variables associated to water quality and linked to sedimentation (water salinity, water depth, and water transparency). Our results show that range of group size is negatively associated with wind speed, high wave height, and water depth, while being positively associated with water salinity, and water transparency (Table 4). This indicates that detection of group is more accurate as water salinity and water transparency decrease, perhaps due to small groups in these ranges of values (*S. guianensis* usually prefer a lower profile of water salinity and mid-range to upper water visibility) (Rossi-Santos et al. 2010). Thus, per the relationship to specific environmental factors, range of group size is an important social metric towards estimating environmental factors, and should be prioritized in nowcasting models using Guiana Dolphin social metrics as estimators. However, maximum group size is positively linked to water depth, indicating that dolphins may

form larger group in deeper waters (Cunha et al. 2005, de Oliveira and Monteiro-Filho 2008).

The averaged model results corroborated the original global GLMM model, showing that only the range of range group size significantly estimates water salinity, wind speed, water depth, and water transparency (Tables 3 and 4). This suggests that repeated observation of a group of dolphins, such as scan sampling, coupled with additional variables pertaining to sedimentation and water conditions, may be an effective approach towards estimating environmental factors. It may be especially helpful to investigate how the potential usefulness of variation in dolphin pod size, and how it may estimate and “predict” specific environmental conditions.

In terms of model estimating ability, we found that the best model consistently outperformed the global model. The most distinct model differences were observed by $\Delta AICc$ (Table 5), while RMSE and R^2 yielded results more similar to each other. Ideally, a strong performing model, should show low RMSE values (close to 0) and a high R^2 value (R^2 values range from 0 to 1; a strong R^2 should be >0.5). *S. guianensis* social metrics show a strong performance ability for estimating water salinity, water depth, water temperature, and water transparency (Table 4). These results are expected, all four variables change frequently with time and are sensitive to other weather/climate conditions. Further, as factors linked to water conditions, these variables also hold ramifications for human communities such as fisheries, subsistence activities, tourism,

and recreational activities. These are important variables to note for inclusion in environmental monitoring efforts. Further, these variables hold clear ramifications for climate change documentation.

In terms of model composition and social metric usefulness, overall, range of group size, maximum number of adults per resighting and maximum number of calves per resighting are found to have strong PIP values (between 0.5 and 1), suggesting strong model usefulness and emphasis for future model inclusion (Table 6). Range of group size is a logical significant variable, as it has also been highlighted in the previous analyses. Maximum number of adults per resighting and maximum number of calves per resighting, these two social metrics represent numerous population segments, as most identified and resighted individuals are females (identified through the companionship of their calf). Thus, both resighting-based variables represent female occurrence as habitat fidelity for all resighted individuals. Throughout the Guiana Dolphin mass mortality event in 2017 in Brazil, it was surmised that changing observation frequencies of calves may have indicated an ongoing change in the population, due to unobserved environmental disturbances (Groch et al. 2018). These results confirm that the number of calves present in each resighting occurrence hold high importance in contributing towards models estimating environmental change. We recommend the inclusion of maximum number of calves (per scan sampling period) in nowcasting model for environmental change. Females as well are important in dolphin social structure, and may

prioritize certain environmental states to optimize their wellbeing and offspring survivorship (Cantor et al. 2012b).

The dolphin group dynamics did not significantly estimate dredging periods. Rather, the dolphin social metrics significantly related with variables associated to water quality and linked to sedimentation (water salinity, water depth, and water transparency). Therefore, we hypothesize that other temporal, spatial and ecological variables may impact any potential dredging effects. Regardless, water transparency is important ecologically, as increased water turbidity has clear documented links to increased sedimentation and dredging activities (Erfteimeijer et al. 2012). Water salinity as well responds to solute concentration(s), suspended particle presence, concentration gradients, and saturation rates (Pirodda et al. 2013, Marley et al. 2017). Both water transparency and water salinity can be impacted by water depth (proximity to the ocean floor), as thermal and water current dynamics influence sedimentation plume presence and size (Pirodda et al. 2013, Todd et al. 2015).

While the case of the Guiana Dolphin population in the Cassurubá Reserve remains to be further explored in relation to potential dredging effects, other dolphin species, (e.g. bottlenose dolphins) have shown significant behavioral and population changes from dredging (Erfteimeijer et al. 2012, Pirodda et al. 2013, Todd et al. 2015, Marley et al. 2017). At a primary ecological level, dredging has been found to impact corals through unmet light requirements (which affects the wellbeing of algal symbionts),

increased turbidity (which taxes energy budgets for filtering activity), and increased sensitivity to different types of sediment over periods of time (Erfteimeijer et al. 2012). Fine sediments have been documented to have worse effects than coarse sediments on coral wellbeing and survival. This may be because fine sediments remain suspended in the water column for a longer period of time (while coarse sediments percolate through faster and settle down faster on account of a larger size) and because fine sediments are harder for corals to effectively filter out. In the long term, this increased sedimentation may lead to the gradual smothering and burial of coral polyps, increased shade, tissue necrosis, and bacteria population blooms in coral mucus and other parts of the organism. Decreased coral, filter-feeding and primary producer population would eventually lead to lower water quality and decreased dolphin populations in the long-term, through venues like increased exposure to toxins and pathogens.

The applicability of sentinel species in real-world scenarios is highly dependent on the indicated species or environmental changes. Per the graphic linkages illustrated by Hazen *et al.* (2019) in Figure 1, the relationships between individual sentinel species depends on the nature of the sentinel species (elucidating vs. leading) and the ecological chain status of the target environmental changes (indicated by dotted, dashed, and solid arrows in Figure 1). An elucidating sentinel, such as cetaceans, may hold a direct relationship to an assemblage of prey (cephalopods, predatory fish, forage fish, and predatory fish). In turn, each of these prey items may hold an ecological connection to

other species such as predatory zooplankton, phytoplankton, herbivorous zooplankton. Thus, a sentinel's indicating abilities may be direct (e.g. prey items) or indirect (mediated through intermediary steps such as other species, environmental factors related to other species, etc.). As the foundations of dolphin social groups, females and calves are crucial towards linking dolphin social metrics to environmental change (Rossi-Santos et al. 2010, Santos et al. 2010, Cantor et al. 2012a, Cantor et al. 2012b). In conclusion, added emphasis should be placed on females and calves (particularly identified individuals) and scan sampling during population monitoring. We highly recommend including maximum number of adults per resighting and maximum number of calves per resighting in models seeking to estimate environmental factors in nowcasting efforts.

Because of the direct/indirect distinction, the individual nature of the relationship between a sentinel species and its target species/environmental change likely depends on a temporal factor. A direct relationship may represent fairly synchronized changes (or shortly lagged) in life cycles and population dynamics (e.g. predator-prey dynamics; species and environmental quality factors). However, indirect relationships may be once or many times "removed" from the original sentinel species signal, and may demand more contextual information to correctly interpret the conservation implications of sentinel species changes. For example, cetaceans such as the Guiana Dolphin may indicate changes in water temperature and salinity, which in turn may be linked to the habitat preferences (and thus prevalence and population status) of species such non-prey

fish, zooplankton, phytoplankton, vegetation habitats (mangroves). To this end, a longer-term continuous dataset, such as the 15-year Guiana Dolphin dataset in the Cassurubá Resex, may work best to analyze sentinel relationships.

In today's context, the Cassurubá Extractive Reserve may serve as a microcosm of global tensions currently at work when it comes to human subsistence and broader ocean environmental health (Small and Cohen 2004). Within its delineated 100,767 hectares of coastal, estuarine and freshwater riverine ecosystems, the reserve illustrates the tensions between human local subsistence-based livelihoods, industrial uses, and animal conservation (Nobre et al. 2017). The area is rich in natural resources and strategically located for manufacturing transport: it links across the neighboring municipalities of Caravelas, Nova Viçosa, and Alcobaça. Further, the Caravelas River Estuary system and its neighboring coastal areas are part of the second largest (66 km²) estuarine-mangrove system of the north-eastern coast of Brazil (Rossi-Santos *et al.* 2007). Within this context, human communities and stakeholders at all levels may benefit from timely information on environmental changes that may impact livelihoods and activities. A reliable elucidating sentinel species, such as the Guiana Dolphin, may provide these environmental informations through nowcasting models by including additional environmental variables, especially linked to water conditions such as sedimentation (Hazen et al. 2019).

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APPENDIX A
GALÁPAGOS SEA LION MATERIALS

GALÁPAGOS SEA LION DATA SETS

Table 1. Galápagos Sea Lion social and behavioral data, collected in 2011 and 2013 (N= ~9000 observations), corresponding to the temporal and spatial scales at which data was collected. All data were collected on four beach localities beaches (Carola, Mann, Oro, and Marinos) on Shipwreck Bay in Puerto Baquerizo Moreno, San Cristóbal, Galápagos, Ecuador.

Social Variable	Description	Measurement Units/Categories
Identification of sex/age category	Identification of females, males, sub-adult males, juveniles, and pups by physical characteristics	Female, Male, Sub-adult male, Juvenile, and Pup
Pre- research approach behavior	Observed behavior (s) of Sea Lion(s) prior to research approach, and selected from discrete behavioral categories defined <i>a priori</i>	Discrete Behavior categories
Post- research approach behavior	Observed behavior (s) of Sea Lion(s) after research approach, and selected from discrete behavioral categories defined <i>a priori</i>	Discrete Behavior category
Distance to nearest Sea Lion neighbor	Variable estimating distance between observed Sea Lion(s) and nearest Sea Lion neighbor	Meters (m)
Identification of sex/age category of nearest Sea Lion neighbor	Identification of females, males, sub-adult males, juveniles, and pups by physical characteristics	Female, Male, Sub-adult male, Juvenile, and Pup

Number of individuals in group	Variable counting the number of Sea Lions in a group	Discrete Count number
Group behavior	Observed behavior (s) of Sea Lion groups and selected from discrete behavioral categories defined <i>a priori</i>	Discrete Behavior categories

Table 2. Galápagos Sea Lion environmental data corresponding to the temporal and spatial scales at which data was collected. Data were collected in 2011 and 2013 on four beach localities beaches (Carola, Mann, Oro, and Marinos) on Shipwreck Bay in Puerto Baquerizo Moreno, San Cristóbal, Galápagos, Ecuador.

Environmental Variable	Description	Measurement Units/Categories
Start survey time	Time clocked at which the survey starts	Hr: Min
End survey time	Time clocked at which the survey ends	Hr: Min
Air temperature in shade	Air Temperature measured in a shade protected spot	Degrees Celsius (°)
Air temperature in sun	Air Temperature measured in a sun exposed spot	Degrees Celsius (°)
Sand substrate temperature in shade	Sand Temperature measured in a shade protected spot	Degrees Celsius (°)

Sand substrate temperature in sun	Sand Temperature measured in a sun exposed spot	Degrees Celsius (°)
Tide level	Level of tide as estimated by water level on the beach	Low, Medium, High
Wave Height	Wave height as estimated by the Beaufort scale	1,2, and 3
Presence of Shade	Binary variable noting presence of shade over observed Sea Lion (s)	Meters (m)
Distance to nearest source of shade	Variable estimating distance between observed Sea Lion (s) and nearest presence of shade	Meters (m)
Human Visit Frequency	Number of humans present on each beach at the start of sampling time	Discrete number
Human Activity Intensity Level	Type of human activity on beach at sampling time	Rank of 0, 1,2,3
GIS spatial layer of each beach site at low, medium, and high tide	ArcGIS layer files constructed from GPS points and routes collected	Polygons & lines measured by meters (m)
GIS spatial layer and aerial imagery of bathymetry characteristics offshore of each beach site	ArcGIS raster files constructed from collected aerial imagery and mapping information	Polygons & lines measured by meters (m)

Additional Model Results

Generalized Linear Mixed Models- Standardized Model Results using Environmental Variables to estimate Distinct Galápagos Sea Lion Social Metrics

Table 1. Generalized Linear Mixed Model Results- Standardized effects of a suite of environmental variables on Galápagos Sea Lion social metrics on San Cristóbal Island. (Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1).

ENVIRONMENTAL VARIABLES	Female s	Juvenile s	Males	Pups	Subadult Males	Total	Group s	Dyads	Female-Juvenile Dyads	Female- Pup Dyads
Access Line	4.381*** (0.532)	4.921*** (0.362)	0.870* (0.517)	4.885** * (0.715)	1.817*** (0.464)	3.832** * (0.267)	4.200** * (0.741)	4.022*** (0.852)	5.048*** (1.174)	2.302 (1.497)
Tidal Variability	4.747*** (0.539)	5.068*** (0.373)	1.339** (0.522)	4.938** * (0.730)	2.078*** (0.469)	4.107** * (0.270)	4.517** * (0.746)	4.317*** (0.857)	5.283*** (1.184)	2.594 (1.514)
Count of People Present	0.100* (0.0597)	0.127** (0.0572)	0.155** (0.0725)	0.00999 (0.103)	0.101 (0.0699)	* (0.0395)	0.132** (0.0534)	0.117** (0.0578)	0.143* (0.0760)	-0.00141 (0.147)
Anthropogenic Use	-0.0977 (0.0636)	-0.0981* (0.0594)	0.0342 (0.0835)	0.00481 (0.115)	-0.0846 (0.0775)	-0.0819* (0.0439)	0.159** * (0.0607)	-0.134** (0.0663)	-0.0969 (0.0865)	-0.0624 (0.167)
Sand Temperature	-0.0988 (0.0711)	-0.0926 (0.0634)	-0.102 (0.0996)	-0.283* (0.145)	-0.156* (0.0885)	-0.130** (0.0515)	-0.134* (0.0715)	-0.121 (0.0777)	-0.0294 (0.0990)	-0.563** (0.234)
Air Temperature	-0.397*** (0.0962)	-0.159* (0.0825)	0.269** (0.123)	0.362** (0.180)	-0.201* (0.116)	-0.141** (0.0683)	0.341** * (0.0895)	0.342*** (0.0960)	-0.536*** (0.131)	0.415* (0.238)
Weather Conditions	-0.123** (0.0620)	-0.139** (0.0549)	0.322** * (0.0898)	-0.221* (0.124)	-0.263*** (0.0814)	0.174** * (0.0456)	0.182** * (0.0617)	-0.161** (0.0669)	-0.183** (0.0881)	-0.137 (0.172)
Tide Level	-0.0811 (0.0496)	-0.0410 (0.0429)	0.0161 (0.0692)	-0.142 (0.0911)	-0.0653 (0.0642)	-0.0581 (0.0361)	-0.0926* (0.0474)	-0.0980 (0.0515)	-0.0998 (0.0668)	-0.144 (0.128)
Wave Height Level	0.0392 (0.0564)	0.0932* (0.0540)	0.242** * (0.0775)	0.232** (0.108)	0.0999 (0.0687)	* (0.0389)	* (0.0522)	0.0890 (0.0571)	0.0488 (0.0737)	0.191 (0.149)

Time of Day	-0.0294 (0.0632)	0.0157 (0.0566)	0.167* (0.0937)	0.107 (0.123)	-0.0829 (0.0792)	0.00563 (0.0469)	-0.0308 (0.0572)	-0.0494 (0.0623)	-0.0355 (0.0791)	-0.0385 (0.167)
Constant	2.734*** (0.0731)	2.856*** (0.0475)	2.222** (0.0678)	1.504** (0.0941)	1.787*** (0.0644)	4.008** (0.0359)	2.180** (0.104)	1.942*** (0.120)	1.191*** (0.165)	-0.182 (0.203)
Observations	100	100	100	100	100	100	93	93	93	93
Number of groups	4	4	4	4	4	4	4	4	4	4

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

GLMM Model Selection

10 Best Models for Fitting Regressions using Environmental Variables to estimate Distinct Galápagos Sea Lion Social Metrics

FEMALE GALÁPAGOS SEA LION MODELS

Table 3. Best Selected Model AICc-Weight Posterior Inclusion Probabilities (PIP) for *Z. wolfebaeki* females.

	Access Line	Low Tidal Variability	Air Temperature
r1	0.962174	0.966006	1

Table 3. Best 10 Selected Model based on $\Delta AICc$ for *Z. wolfebaeki* females.

Model Ranking	$\Delta AICc$	Access Line	Low Tidal Variability	Air Temperature	Constant (Intercept Term)
r1	0	4.423677	4.791921	-0.46377	2.762273
r2	7.469681			-0.46001	2.803854
r3	8.282573		0.407738	-0.46127	2.775582
r4	8.866959	-0.32011		-0.46092	2.783028
r5	42.29594	4.395033	4.713509		2.852228
r6	48.8682				2.890319
r7	49.90883		0.358773		2.866013
r8	50.4147	-0.27212			2.873024

JUVENILE GALÁPAGOS SEA LION MODELS

Table 4. Best Selected Model AICc-Weight Posterior Inclusion Probabilities (PIP) for *Z. wollebaeki* juveniles.

	Access Line	Tidal Variability	Air Temperature	Weather Conditions	Wave Height Level
r1	0.981216	0.981819	0.963493	0.964671	0.296841

Table 5. Best 10 Selected Model based on Δ AICc for *Z. wollebaeki* juveniles.

Model Ranking	ΔAICc	Access Line	Tidal Variability	Air Temperature	Weather Conditions	Wave Height Level	Constant (Intercept Term)
r1	0	4.893292	5.059119	-0.16946	-0.15787		2.864107
r2	1.698652	4.8863	5.045375	-0.17893	-0.15847	0.036893	2.863635
r3	6.325612	4.825542	4.972387		-0.23312		2.873804
r4	6.5206	5.092587	5.27318	-0.25491			2.869509
r5	8.25218	5.088599	5.262185	-0.2643		0.036021	2.869092
r6	8.49215			-0.16647	-0.16038		2.892872
r7	8.593983	4.823765	4.969222		-0.23402	0.006603	2.873781
r8	10.38261		0.209559	-0.16703	-0.16015		2.878172
r9	10.41379			-0.17309	-0.16086	0.02588	2.891838
r10	10.62987	-0.11486		-0.16677	-0.16026		2.885322

MALE GALÁPAGOS SEA LION MODELS

Table 6. Best Selected Model AICc-Weight Posterior Inclusion Probabilities (PIP) for *Z. wollebaeki* males.

	Tidal Variability	Count of People Present	Air Temperature	Weather Conditions	Wave Height Level	Time of Day
r1	0.992264	0.952652	0.910064	0.997509	0.966957	0.748194

Table 7. Best 10 Selected Model based on Δ AICc for *Z. wollebaeki* males.

Model Ranking	Δ AICc	Tidal Variability	Count of People Present	Air Temperatur e	Weather Conditions	Wave Height Level	Time of Day	Constant (Intercep t Term)
r1	0	0.463141	0.180227	0.198683	-0.33643	0.227123	0.19124	2.235761
r2	2.765735	0.467042	0.135344	0.183252	-0.41924	0.204696		2.245165
r3	5.575068	0.461582	0.145164		-0.34512	0.243283		2.256587
r4	5.720929	0.458691	0.188068		-0.25817	0.2652	0.181908	2.246053
r5	7.357363	0.487454		0.200315	-0.37537	0.178931		2.253183
r6	7.39411	0.4908		0.213724	-0.30985	0.188857	0.125965	2.246525
r7	7.500063	0.509683	0.116221	0.230123	-0.40871			2.266869

r8	8.81008	0.516922	0.154438	0.246461	-0.33437	0.15863	2.260932
	3					7	
r9	10.2661		0.171055	0.183608	-0.30276	0.232932	0.19763
	8						1
r10	10.3724	0.524879		0.240634	-0.37174		2.267331
	2						

PUP GALÁPAGOS SEA LION MODELS

Table 8. Best Selected Model AICc-Weight Posterior Inclusion Probabilities (PIP) for *Z. wollebaeki* pups.

	Access Line	Tidal Variability	Air Temperature	Time of Day
r1	0.993708	0.993809	0.32483	0.777118

Table 9. Best 10 Selected Model based on Δ AICc for *Z. wollebaeki* pups.

Model Ranking	Δ AICc	Access Line	Tidal Variability	Air Temperature	Time of Day	Constant (Intercept Term)
r1	0	5.18712 2	5.278203		0.19855 9	1.560114
r2	1.28128 6	5.20471 5	5.283912	0.110729	0.23177 2	1.555616
r3	2.23149 1	5.27435 2	5.374048			1.578209
r4	4.39381 8	5.27994 1	5.378024	0.018158		1.578034
r5	10.7146 7				0.21131 4	1.586639
r6	11.7202 7			0.124268	0.24812 5	1.578923

r7	12.7652		0.1419		0.21100	1.577143
	3				5	
r8	12.8947	-0.03988			0.21123	1.58414
	5				3	
r9	13.4454					1.610327
	4					
r10	13.8415		0.129907	0.123051	0.24745	1.570222
					4	

SUBADULT MALE GALÁPAGOS SEA LION MODELS

Table 10. Best Selected Model AICc-Weight Posterior Inclusion Probabilities (PIP) for *Z. wollebaeki* Subadult Males.

	Access Line	Tidal Variability	Sand Temperature	Weather Conditions
r1	0.978436	0.98399	0.885856	0.998238

Table 11. Best 10 Selected Model based on Δ AICc for *Z. wollebaeki* Subadult Males.

Model Ranking	Δ AICc	Access Line	Tidal Variability	Sand Temperature	Weather Conditions	Constant (Intercept Term)
r1	0	1.75523	2.028426	-0.17031	-0.2779	1.79912
r2	4.114086	1.690055	1.932511		-0.35074	1.810709
r3	8.598228		0.285524	-0.16589	-0.28831	1.809464
r4	9.660325	-0.25039		-0.16481	-0.28787	1.812192
r5	9.70934			-0.16147	-0.28631	1.826377
r6	12.21463		0.254422		-0.36076	1.82184
r7	12.42511	2.071177	2.377195	-0.27115		1.830432
r8	13.03857				-0.35704	1.836324
r9	13.19561	-0.22109			-0.35991	1.824262
r10	21.6219		0.323541	-0.26986		1.841706

TOTAL GALÁPAGOS SEA LION MODELS

Table 12. Best Selected Model AICc-Weight Posterior Inclusion Probabilities (PIP) for *Z. wollebaeki* Total numbers.

	Access Line	Tidal Variability	Count of People Present	Sand Temperature	Weather Condition	Wave Height Level
r1	0.985177	0.986535	0.339652	0.99703	0.999977	0.783596

Table 13. Best 10 Selected Model based on Δ AICc for *Z. wollebaeki* Total numbers.

Model Ranking	ΔAICc	Access Line	Tidal Variability	Count of People Present	Sand Temperature	Weather Condition	Wave Height Level	Constant (Intercept Term)
r1	0	3.790826	4.078161		-0.16872	-0.21447	0.088845	4.006951
r2	1.154843	3.777304	4.05881	0.042429	-0.17712	-0.22179	0.098949	4.006582
r3	2.359633	3.804597	4.106062		-0.14654	-0.20926		4.009826
r4	4.313959	3.798974	4.098046	0.023514	-0.14984	-0.21278		4.009665
r5	9.390957				-0.16184	-0.21741	0.078881	4.041838
r6	10.42772		0.321732		-0.16266	-0.21728	0.078223	4.019496
r7	10.87621				-0.14211	-0.2127		4.045902
r8	10.98297	-0.24728			-0.16242	-0.21732	0.078384	4.025737
r9	11.19841			0.025777	-0.16631	-0.22198	0.084058	4.040902
r10	11.80153		0.334041		-0.14319	-0.21252		4.022702

GROUP GALÁPAGOS SEA LION MODELS

Table 14. Best Selected Model AICc-Weight Posterior Inclusion Probabilities (PIP) for *Z. wollebaeki* Groups.

	Access Line	Tidal Variability	Count of People Present	Anthropogenic Use	Air Temperature	Wave Height Level
r1	0.866317	0.876924	0.703212	0.97499	0.999999	0.868008

Table 15. Best 10 Selected Model based on Δ AICc for *Z. wollebaeki* Groups.

Model Ranking	Δ AICc	Access Line	Tidal Variability	Count of People Present	Anthropogenic Use	Air Temperature	Wave Height Level	Constant (Intercept Term)
r1	0	4.116207	4.407522	0.126517	-0.23554	-0.42725	0.156882	2.212218
r2	2.473685	4.086872	4.399973		-0.16587	-0.39157	0.116274	2.220097
r3	4.789418	4.048169	4.389752		-0.14049	-0.36829		2.225258
r4	5.011956			0.108414	-0.22401	-0.42057	0.141453	2.244933
r5	5.379466	4.059181	4.393912	0.073688	-0.17528	-0.38491		2.221375
r6	6.297508		0.336105	0.107379	-0.2219	-0.42137	0.139426	2.221484
r7	6.393738				-0.16519	-0.38936	0.108525	2.254941
r8	6.789324	-0.25545		0.10756	-0.22242	-0.42111	0.1399	2.228194
r9	7.55433		0.352899		-0.16363	-0.39052	0.106803	2.230303
r10	8.057132	-0.27285			-0.16404	-0.39019	0.10719	2.237039

DYAD GALÁPAGOS SEA LION MODELS

Table 16. Best Selected Model AICc-Weight Posterior Inclusion Probabilities (PIP) for *Z. wollebaeki* Dyads.

	Access Line	Tidal Variability	Count of People Present	Anthropogenic Use Level	Air Temperature
r1	0.748344	0.768988	0.428556	0.676782	1

Table 17. Best 10 Selected Model based on Δ AICc for *Z. wollebaeki* Dyads.

Model Ranking	ΔAICc	Access Line	Tidal Variability	Count of People Present	Anthropogenic Use	Air Temperature	Constant (Intercept Term)
r1	0	4.055681	4.375506	0.088905	-0.14343	-0.45475	1.954798
r2	0.147071	4.042276	4.369923		-0.09976	-0.43623	1.959492
r3	0.859281	3.991216	4.33225			-0.47606	1.964531
r4	2.742921	3.987558	4.327883	0.033262		-0.48966	1.963577
r5	2.857283				-0.10062	-0.43556	1.99594
r6	3.116273			0.079	-0.13933	-0.4521	1.990493
r7	3.715286					-0.47571	2.001575
r8	3.947354		0.364254		-0.09915	-0.4372	1.970463
r9	4.271535		0.357832	0.07878	-0.13775	-0.45367	1.965455
r10	4.439335	-0.28517			-0.09953	-0.43678	1.977184

FEMALE-JUVENILE GALÁPAGOS SEA LION MODELS

Table 18. Best Selected Model AICc-Weight Posterior Inclusion Probabilities (PIP) for *Z. wolfebaeki* Female-Juvenile Dyads.

	Access Line	Tidal Variability	Air Temperature
r1	0.702452	0.714808	1

Table 19. Best 10 Selected Model based on Δ AICc for *Z. wolfebaeki* Female-Juvenile Dyads.

Model Ranking	ΔAICc	Access Line	Tidal Variability	Air Temperature	Constant (Intercept Term)
r1	0	5.026615	5.271467	-0.60467	1.204563
r2	2.200941			-0.60515	1.236309
r3	3.888039		0.29144	-0.60603	1.215707
r4	4.185178	-0.19396		-0.60572	1.2234
r5	40.93339	5.069073	5.270769		1.358827
r6	43.19026				1.385713
r7	44.96113		0.250238		1.368087
r8	45.20842	-0.15252			1.375588

APPENDIX B
GUIANA DOLPHIN MATERIALS

GUIANA DOLPHIN DATA COLLECTION METHODOLOGY

Between April 2002 and December 2016, an average of 5 days/month were spent censusing various routes within the Cassurubá RESEX, with aims of covering the whole study area each month. Data collection through boat cruises to survey different routes involved two separate motorboats departing from the same point at the port of the town Caravelas at 6 am and returning at 1 pm.

Variable Descriptions

Table 1. Guiana Dolphin social and behavioral data collected from 2002-2017 on distinct transect routes.

Social Metric	Description	Measurement Units/Categories
Maximum Group Size	Variable counting the maximum number of dolphins in a group per census	Discrete count number
Range of Group Size	A measure of discrepancy in the group sizes sighted per scan sampling period. Also serves as proxy for accuracy of observed group size during scan sampling, calculated as: <i>(Max Group Size – Min Group Size)</i>	Discrete count number
Maximum Number of Adults Sighted	Variable counting the maximum number of adult dolphins in a group per census	Discrete count number
Number of calves	Variable counting the presence and number of observed calves	Discrete count number
Number of females	Variable counting the presence and number of observed females	Discrete count number
Number of Re-sightings	Variable counting observations of dolphin individuals previously identified and/or previously sighted	Discrete count number
Maximum Group Size per Re-sighting	Variable counting the maximum number of dolphins in a group which included a previously identified and/or previously sighted individual	Discrete count number
Maximum Number of Calves per Re-sighting	Variable counting the maximum number of calves in a group which included a previously identified and/or previously sighted individual	Discrete count number

Table 2. Guiana Dolphin environmental data collected 2002-2017 on distinct transect routes.

Environmental Variable	Description	Measurement Units/Categories
Census Duration	Time elapsed between survey start and survey end	Minutes
Group Observation Time	Time elapsed observing dolphin groups	Minutes
Boat Velocity	Average boat speed during census	Nautical miles/hr
Census Distance	Distance covered during census	Nautical miles
Dredge Status	Indicator of non-active vs. active dredging period at time of census	Categories (No Dredging, Active Dredging)
Sky coverage	Sky overcast level as determined by percentage of sky covered by cloud	Percentage of sky cloud coverage (%)
Wave Height	Beaufort categories of different wave height levels	Categories (0, 1, 2, 3, 4)
Air Temperature	Air temperature measured by a standard thermometer	Degrees Celsius (°)
Moon Phase	Stage of Moon phase as observed and categorized by <i>a priori</i> categories	New, Waxing, Full, Waning
Wind Speed	Measurement of wind speed	Meters/s
Tide Level	Variable measuring level of tide as predicted by local weather charts	Low, Medium, High
Water Visibility	Measured by water transparency, according to a Secchi desk	Secchi Disk Measurement (Meters (m))
Water Depth	Variable measuring water depth	Meters (m)
Water Temperature	Variable measuring water temperature as measured by a standard thermometer	Degrees Celsius (°)
Water Salinity	Variable measuring water salinity as per a standard salinity meter	ppm
GPS Route of survey trajectory	Spatial line of each survey route travelled per outing, recorded using a standard GPS	Longitude & Latitude Coordinates (Nautical miles measurement of route)
GPS Point of dolphin sighting location	Spatial points of each dolphin sighting location, recorded using a standard GPS	Longitude & Latitude Coordinates (ArcGIS Polygon georeferenced spatial layers)

GPS Locations of fishing areas	Spatial points of each local fishing area, located and mapped using a standard GPS	Longitude & Latitude Coordinates (ArcGIS Polygon georeferenced spatial layers)
GPS Locations of areas associated with specific types of fisheries	Spatial Identification and labelling of the fisheries type associated with fishing areas	Longitude & Latitude Coordinates (ArcGIS Polygon georeferenced spatial layers)

Additional Models

Generalized Linear Mixed Models- Standardized Model Results using Environmental Variables to estimate Distinct Guiana Dolphin Social Metrics

Table 1. Generalized Linear Mixed Model Results- Standardized effects of a suite of environmental variables on Guiana Dolphin social metrics in the Cassurubá RESEX. (Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1).

EXPLANATORY VARIABLES	Maximum Group Size	Range of Group Size	Maximum Number of Adults	Number of Re-sightings	Group Size per Re-sighting	Maximum Group Size per Re-sighting	Maximum Number of Calves per Re-sighting
Census Duration	0.403 (0.442)	-0.279 (0.852)	0.489 (0.466)	-0.218 (1.638)	-1.178 (1.434)	-1.100 (1.437)	--
Group Observation Duration	0.619*** (0.0882)	1.104*** (0.162)	0.596*** (0.0912)	1.768*** (0.395)	1.557*** (0.358)	1.514*** (0.355)	--
Boat Velocity	0.725 (0.666)	0.248 (1.255)	0.806 (0.705)	-1.124 (2.530)	-2.474 (2.189)	-2.359 (2.185)	--
Census Distance	-0.606 (0.609)	0.159 (1.135)	-0.717 (0.643)	0.0133 (2.279)	1.480 (1.985)	1.366 (1.987)	--
Active Dredging Period	0.0495 (0.0426)	-0.0111 (0.0700)	0.0457 (0.0439)	0.146 (0.149)	0.0763 (0.125)	0.0726 (0.124)	--
Tide Level	0.0101 (0.0398)	0.0757 (0.0669)	-0.00102 (0.0415)	-0.146 (0.146)	-0.209 (0.138)	-0.214 (0.135)	--
Moon Phase	-0.0300 (0.0427)	0.0696 (0.0757)	-0.0170 (0.0442)	0.261* (0.158)	0.222 (0.149)	0.218 (0.146)	--
Wind Speed	-0.124** (0.0610)	-0.327*** (0.101)	-0.114* (0.0636)	0.0473 (0.213)	0.174 (0.190)	0.162 (0.191)	--
Sky Coverage	0.0296 (0.0374)	0.132** (0.0620)	0.0362 (0.0388)	0.00777 (0.134)	-0.0266 (0.121)	-0.0212 (0.120)	--
Wave Height	0.0762 (0.0581)	0.125 (0.0985)	0.0809 (0.0601)	0.0614 (0.219)	0.169 (0.194)	0.162 (0.193)	--
Salinity	-0.0192 (0.0476)	0.257*** (0.0789)	-0.0129 (0.0495)	-0.420* (0.222)	-0.421** (0.174)	-0.415** (0.175)	--
Water Temperature	0.0293 (0.0497)	0.139 (0.0854)	0.0442 (0.0516)	0.0120 (0.190)	-0.105 (0.156)	-0.0821 (0.156)	--
Water Depth	-0.0433	-0.0115	-0.0576	-0.609	-0.134	-0.159	--

	(0.0694)	(0.0990)	(0.0730)	(0.453)	(0.297)	(0.304)	--
Water Transparency	-0.00304	0.0557	0.00214	-0.282	-0.208	-0.209	--
	(0.0448)	(0.0756)	(0.0460)	(0.201)	(0.177)	(0.175)	--
var(_cons[z_route_group])	0	0.0559	0	0.155	0.369	0.290	--
	(0)	(0.0903)	(0)	(0.185)	(0.316)	(0.261)	--
Constant	1.472***	0.717***	1.429***	-0.615	-0.415	-0.438	--
	(0.0847)	(0.243)	(0.0900)	(0.379)	(0.364)	(0.353)	--
Observations	155	155	152	155	155	155	155
Number of groups	19	19	17	19	19	19	19

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table 2. Averaged Models Results- Standardized effects of a suite of environmental variables on Guiana Dolphin social metrics in the Cassurubá RESEX. (Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1).

EXPLANATORY VARIABLES	Active Dredging Period	High Tide	Full Moon	New Moon	Wind Speed	Cloud Cover	High Wave Height	Salinity	Water Temperature	Water Depth	Water Transparency
Maximum Group Size	0.0164 (0.266)	-0.177 (0.478)	0.414 (0.729)	-0.0327 (0.272)	0.0633 (0.392)	-0.339 (3.467)	0.114 (0.654)	-2.137 (2.985)	0.0236 (0.366)	9.727* (5.478)	-0.205 (0.338)
Range of Group Size	0.148 (0.145)	0.00451 (0.0947)	- (0.0954)	- (0.0740)	0.562* (0.226)	-0.675 (1.379)	-0.502 (0.452)	2.516*** (0.707)	0.00395 (0.0961)	-2.701*** (0.864)	0.264** (0.114)
Maximum Number of Adults	0.0376 (0.262)	0.0590 (0.448)	-0.346 (0.691)	0.0337 (0.265)	0.0466 (0.379)	-0.798 (3.469)	0.0878 (0.633)	0.954 (2.806)	-0.0243 (0.362)	-7.199 (5.219)	0.0242 (0.313)
Number of Re-sightings	0.0572 (0.0995)	0.00941 (0.0791)	0.0300 (0.0832)	0.00312 (0.0631)	0.0110 (0.0915)	-0.0396 (0.810)	0.0701 (0.247)	0.0780 (0.307)	-0.0314 (0.110)	-0.409 (0.642)	-0.00394 (0.0475)
Maximum Group Size per Re-sighting	8.143 (744.5)	3.819 (578.4)	-0.193 (0.708)	0.181 (0.569)	0.0601 (0.421)	0.116 (4.706)	0.604 (413.0)	7.216 (7.014)	-1.149 (1.551)	1.340 (2.859)	0.223 (0.534)
Maximum Number of Adults per Re-sighting	-7.256	-3.369	0.130	-0.112	0.0222	0.291	-0.692	-7.750	1.832	-0.459	-0.290

	(686.9)	(533.7)	(0.655)	(0.534)	(0.402)	(4.471)	(381.1)	(6.613)	(1.488)	(2.620)	(0.523)
Maximum of Calves per Re-sighting	-1.453	-0.918	0.0388	0.0221	0.0054 6 (0.081 9)	-0.612	-0.332	-1.013	-0.0944	0.329	-0.00569
	(115.1)	(89.41)	(0.109)	(0.0871)		(1.172)	(63.84)	(0.871)	(0.174)	(0.518)	(0.0385)
Constant	-1.142	-1.309	1.293* **	1.288** *	4.571* **	52.60***	3.079*	32.49***	26.83***	12.39***	1.027***
	(3.294)	(2.563)	(0.144)	(0.138)	(0.121)	(1.068)	(1.837)	(0.306)	(0.113)	(0.371)	(0.0472)
Observations	822	436	431	431	788	804	802	663	667	635	439
R-squared					0.024	0.007		0.067	0.051	0.066	0.045

Standard errors
in parentheses
*** p<0.01, **
p<0.05, * p<0.1

Guiana Dolphin GLMM Model Selection

10 Best Models for Fitting Regressions using Environmental Variables to estimate Distinct Guiana Dolphin Social Metrics

Unstandardized Best Models

*Note- "Maximum Number of Adults" features only variable in the best model, since only one variable was found to be significant in the previous GLMM analysis. "Number of Calves" was excluded from model selection as no variables were found to be significant in the previous GLMM analyses.

MAXIMUM GROUP SIZE MODELS

Table 3. Max Group Size Best Model AICC-Weight Posterior Inclusion Probabilities

	Group Observation Duration	Wind Speed
r1	1	0.496224

Table 4. Max Total Individuals Best Models

Model Ranking	Δ AICc	Group Observation Duration	Wind Speed	Constant (Intercept Term)
r1	0	0.058707		-0.65032
r2	0.030207	0.057513	-0.03476	-0.49013
r3	233.3316		-0.08976	1.080313
r4	235.6808			0.607094

RANGE OF GROUP SIZE MODELS

Table 5. Range of Group Size Best Model AICC-Weight Posterior Inclusion Probabilities

	Group Observation Duration	Wind Speed
r1	1	0.413329

Table 6. Range of Group Size Best Models

Model Ranking	ΔAICc	Group Observation Duration	Wind Speed	Constant (Intercept Term)
r1	0	0.068295		-2.01597
r2	0.700437	0.067196	-0.04356	-1.7954
r3	178.8867		-0.10021	0.090032
r4	180.924			-0.38226

NUMBER OF RE-SIGHTINGS MODELS

Table 7. Count Number of Re-sightings Best Model AICC-Weight Posterior Inclusion Probabilities

	Group Observation Duration	Salinity
r1	1	0.929562

Table 8. Count Number of Re-sightings Best Models

Model Ranking	ΔAICc	Group Observation Duration	Salinity	Constant (Intercept Term)
r1	0	0.076387	-0.0302	-1.42142
r2	5.159955	0.074856		-2.31114
r3	127.089			-0.12396
r4	129.0212		-0.0047	0.025569

MAXIMUM GROUP SIZE PER REIGHTING MODELS

Table 9. Max Group Size per Re-sighting Best Model AICC-Weight PIP

	Group Observation Duration	Salinity
r1	1	0.965053

Table 10. Max Group Size per Re-sighting- Best Models

Model Ranking	ΔAICc	Group Observation Duration	Salinity	Constant (Intercept Term)
r1	0	0.069398	- 0.03492	-0.89076
r2	6.636709	0.068327		-1.91478
r3	92.46875			-0.12103
r4	92.94118		- 0.01701	0.406786

MAXIMUM NUMBER OF ADULTS PER RE-SIGHTING MODELS

Table 11. Max Number of Adults in Re-sighting Groups Best Model AICC-Weight PIP

	Group Observation Duration	Salinity
r1	1	0.970134

Table 12. Maximum Number of Adults in Re-sighting Groups Best Models

Model Ranking	ΔAICc	Group Observation Duration	Salinity	Constant (Intercept Term)
r1	0	0.068855	- 0.03512	-0.90526
r2	6.961448	0.068267		-1.94489
r3	95.20061			-0.1447
r4	95.60459		- 0.01727	0.390829