Using Spatial Analysis to Assess Bottlenose Dolphins as an Indicator of Healthy Fish Habitat in Florida Bay

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Abstract

Florida Bay is the terminus of the nation's largest ever ecosystem restoration project, a massive effort to improve fresh water flow into the greater everglades ecosystem. In order to sustain a viable ecosystem in this dynamic habitat, managers will need to monitor and predict the biotic and abiotic changes that will take place throughout this heterogeneous environment. This paper examines the hypothesis that bottlenose dolphin foraging behavior in Florida Bay is spatially congruent with healthy and abundant fish populations. Data from the 2002 and 2003 summers collected on the presence/absence of dolphins and their behavior states, fish catch from bottom trawls, and various measured environmental variables were analyzed in a spatial framework (Geographic Information Systems, Mantel tests, and Classification and Regression Trees) to capture fine scale habitat use preferences of the fish and dolphin populations. No single environmental variable was identified as a clear predictor of either fish habitat or dolphin foraging habitat. However, patterns of habitat preference by fish and foraging dolphins were modeled and spatially mapped to assess overlap between foraging dolphins and healthy fish habitats. The comparison of predicted habitats by the models revealed good spatial overlap leading to conclusion that mangers can use foraging dolphins as an indictor of abundant fish habitats in Florida Bay.

Introduction

Florida Bay, which lies at the southern tip of the Florida peninsula (Figure 1), is the terminus of the nation's largest ever ecosystem restoration project. The Comprehensive Everglades Restoration Project (CERP), with the ambitious goal to improve the quality, quantity, and timing of freshwater inputs into the South Florida ecosystem, covers over 18,000 square miles and will require 30 years to complete (1999 – 2029). Quantifying the spatial and temporal changes in species distributions, abundance and diversity in Florida Bay is essential to gauge the success of this ambitious restoration project. This task will require developing tangible quantitative metrics to assess the abiotic and biotic changes taking place in response to the CERP management.

Seabirds and cetaceans are ideal focal organisms for the study of ecosystem-level changes in marine systems because they are numerous and conspicuous predators, with large energetic requirements (Croxall, 1989; Moore and DeMaster, 1998; Baumgartner et al., 2000; D'Amico, 2003). Furthermore, because they forage on fish and squid, prey that are often difficult to sample by conventional means, these predators can be used to monitor ecosystem structure (Furness and Camphuysen, 1997; Griffin, 1999; Moore et al., 2002). Bottlenose dolphins (*Tursiops truncatus*) are prominent in Florida Bay and, like the spotted owl in old growth forests of the Pacific Northwest (Simberloff, 1987; Lamberson et al., 1992; Caro and O'Doherty, 1999), their distribution may be indicative of important habitats. Aerial surveys for dolphins in Florida Bay are a relatively efficient management tool, both financially and logistically; they can be completed in less than one day and require little man power. Dolphin foraging habitat can quickly be identified as productive fish communities, allowing managers an easy tool to spatially and temporally quantify habitat quality and, through long-term observational data collection, monitor spatial migration of productive fish habitats. This approach will help managers mitigate the effects of human development on the Florida Bay ecosystem by identifying and protecting important habitat.

As CERP continues, and the ecosystem of Florida Bay begins to change, resource managers will need to identify habitat alterations, determine the cause, predict the impact, and, in some cases, mitigate anthropogenic activities to conserve ecosystem viability. The working hypothesis underlying this work is that the spatially heterogeneous biotic and physical attributes of Florida Bay influence the distribution and composition of the fish community and, subsequently, determine the distribution and habitat use of dolphins throughout the bay. In other words, top predators map their prey distributions, which in turn map biotic (e.g., chlorophyll) and abiotic (e.g., substrate type, water salinity) properties. The two objectives are: (i) to determine which environmental variables, or combination of variables, influence fish community distribution and composition throughout Florida Bay, and (ii) quantify the links between productive fish habitats and dolphin distributions and habitat use. The immediate research hypothesis asked in this study is “Can bottlenose dolphin distribution in Florida Bay be used to predict the distribution and structure of fish communities?”

In addition to documenting the biophysical linkages supporting upper trophic predators in this heterogeneous environment, our research examines the suitability of the bottlenose dolphin as an indicator species in Florida Bay. [A Management Indicator Species (MIS) is defined as any species, group of species, or species habitat elements selected to focus management attention for the purposes of resource production, population recovery or maintenance of population viability or ecosystem diversity (U.S. Forest Service, 2000).] More specifically, we determined the response of dolphin distributions to spatial and temporal variation in water quality, prey density, and habitat type. Therefore, establishing a link between the various habitat variables, prey distributions and dolphin habitat use patterns, in order to evaluate the feasibility of using bottlenose dolphins as an indicator of important fish habitats in Florida Bay.

Background

Historically, Florida Bay was an extremely productive ecosystem supporting high densities of fish, birds, sea turtles and marine mammals in a complex biological and physical oceanographic environment (Sogard et al., 1989). Since 1881 the watershed of Florida Bay has been highly managed to support agriculture, control floods, and provide water to the growing population of South Florida (McPherson and Halley, 1996; Light and Dineen, 1994). Currently, up to 70% of the freshwater flow through the Everglades is diverted for human consumption (Smith et al., 1989), causing salinity levels in Florida Bay to increase over 50 ppt during drought conditions (Schmidt, 1979; Fourqurean et al., 1992; McIvor et al., 1994). In addition to the drastic decrease in freshwater discharge into Florida Bay, water quality has also deteriorated as a result of high phosphates and dissolved and particulate matter inputs from run-off due to agricultural practices within the watershed (Rudnick et al. 1999). Increased salinity and elevated nutrient levels from anthropogenic sources have stimulated algal blooms, resulting in large-scale dieoffs of seagrasses, sponges and mangroves (Robblee et al., 1991; Boesch et al., 1993; Butler et al., 1995). In turn, this habitat degradation has resulted in reductions in the standing stocks and changes in the composition of fish communities (Matheson et al., 1999). In short, as a result of these anthropogenic disturbances, fish diversity in Florida Bay has greatly diminished (Tilmant, 1989). However, little is known about the way these broad habitat changes have impacted the upper trophic predators.

The Florida Everglades drains directly into Florida Bay, which is a large (2200 km ^{2}), shallow ecosystem that lies within the boundaries of the Everglades National Park and the Florida Keys National Marine Sanctuary. Mudbanks and mangrove islands divide the Bay into a series of shallow, semi-isolated basins that restrict circulation (Zieman et al., 1989). The watershed of Florida Bay is approximately 12,000 km^2 of wetlands extending south of Lake Okeechobee; the marine influence in the Bay comes primarily from the Gulf of Mexico and, secondarily, through passes to the Atlantic (Fourqurean and Robblee, 1999). A complex gradient between fresh and salt water provides a unique habitat for many protected upper trophic level species including manatees, alligators, crocodiles, sea turtles, and bottlenose dolphins (Holmquist et al., 1989). Additionally, Florida Bay links the mangroves and the coral reef systems in South Florida, acting as an important nursery for many reef and commercial fish (Rutherford et al., 1989; Tabb and Roessler, 1989).

Florida Bay is an ideal field laboratory for assessing the relationship between habitat variability, and the distribution of upper trophic predators and their prey. Florida Bay is a complex mosaic of heterogeneous habitats characterized by striking physical and biotic gradients, patchy bottom substrate types, and variable water quality. On the basis of similar physical characteristics (e.g., salinity, temperature, turbidity) and distributions of flora and fauna (e.g., bottom substrate, seagrass coverage, fish assemblage composition), researchers have identified five distinct zones within Florida Bay: Eastern Zone, Central Zone, Western Zone, Gulf Transition Zone and Atlantic Transition Zone (Figure 1) (Sogard et al., 1989; Thayer and Chester, 1989; Zieman et al., 1989; Matheson et al., 1999; Thayer et al., 1999). It is our contention that the physical and biological variability of Florida Bay structures fish distribution and consequently influences dolphin habitat use.

Methods

Previous research focused on studying dolphin habitat use patterns have used behavioral sampling techniques (Allen and Read, 2000; Waples, 1995). However, these studies did not fully assess habitat quality, which can be inferred by physical attributes, including temperature, salinity, dissolved oxygen concentration, current velocity, water depth, and bottom substrate (Gibson, 1994; Raven et al., 1998; Fraser et al., 1999), and biological parameters, such as the density of predators, prey and competitors (Gibson, 1994). These indirect metrics were employed in this study in order to assess spatially and temporally variable habitat quality.

Data collection / Field Methods

The field methods used to collect the data in Florida Bay during the summers of 2002 and 2003 included boat-based surveys, and randomly stratified trawls and gillnet sets. During each summer season, Florida Bay was surveyed twice for the presence / absence of bottlenose dolphins. Surveys were conducted in a small, outboard-powered vessel using standardized techniques (Buckland et al., 1993). To ensure standardized “sightability” across areas and days, surveys were limited to sea state conditions of Beaufort 2 or less and conducted with a minimum of three observers. GPS waypoints were downloaded every two minutes to record the survey route. Habitat variables, water temperature, salinity, depth, clarity (using a secchi depth measurement), sea state condition and habitat type were measured at 30-minute intervals during surveys. At each dolphin sighting, these same environmental variables were measured, in addition to recording relevant survey (GPS location, the perpendicular distance to the sighting), and ecological (group size, behavior, composition) attributes. The standardized behavioral state categories, adapted from the Sarasota Dolphin Research Program (Urian and Wells, 1996), are travel, social, rest, forage, unknown, play and with boat.

Fish distributions in Florida Bay were sampled with pre-selected stations using (a) 3-minute bottom trawls and (b) 30-minute gillnet sets using a 50m long 3-inch mesh in 2002 and, in 2003, a 100m long gillnet with two 50m panels of 3-inch and 3¼-inch mesh. The locations of bottom trawls and gillnet sets were randomly stratified using Geographic Information System (GIS) software (ArcGIS) to adequately sample the different habitat types within each zone of the Bay. Although both trawls and gillnet sets catch potential dolphin prey, the trawl catches were often of a smaller size than the dolphin prey size class. To obtain a more representative picture of dolphin prey availability, gillnet sets were used to size select the catch. Despite the limits of dolphin-prey catchability of trawls, abundance, species richness and diversity are indicative of habitat quality. Thus, both trawling and gillnetting samples were useful to describe the fish community and dolphin prey availability throughout the bay. Using these fishing techniques, prey distributions was related to dolphin behavior, by comparing fish community composition at sites where dolphins were observed feeding, where dolphins were present but not feeding, and at locations where dolphins were absent.

All captured fish were placed into an aerated bucket of water and removed for identification and measurement before being released alive. During this fieldwork in Florida Bay, 98% of fish caught were released alive. The standardized abundance (catch per unit effort, CPUE), Margalef's richness index ($(S-1) / \log N$), Simpson's diversity index ($\sum p_i^2$), and CPUE of dolphin prey (based on fish species and size) were calculated for each trawl and gillnet set.

Data Analysis

The central theme of the analysis was to quantify the spatial structure of Florida Bay and its effect on habitat quality and fish and dolphin distributions. Because inherent correlations exist between environmental variables and space, as well as among environmental variables themselves, the objective of this work was to tease apart the relative influence of each individual variable on fish and dolphin distribution. These patterns were analyzed using geo-statistical techniques specially suited to integrate disparate types of auto-correlated data, including the Mantel test and Classification and Regression Trees (CARTs), and then visualized with a Geographic Information System (GIS). Mantel tests (1967) are multivariate statistics that can explicitly include space as an explanatory variable. Moreover, Mantel tests account for the effects of spatial autocorrelation on dependent and independent variables, thus allowing for the rigorous testing of spatially explicit relationships between dolphin and fish distribution, and environmental variables. Subsequently, fish and dolphin foraging habitats were modeled using Classification and Regression Trees (CARTs) (Venables and Ripley, 1997). CARTs recursively partition data using an algorithm that splits observations into groups based on a single best predictor variable, until all points are classified. Essentially, CARTs are a set of nested "if" statements that are used to define the relationship of each response variable to predictor variables. Categorical data cannot be included in a Mantel test. Therefore, habitat type and zone were addressed only with the CART analysis. Figure 2 depicts the generalized model tested in this paper.

The Mantel tests were used to relate the four indices (CPUE, species richness, species diversity, and dolphin prey) of each data set (2002 and 2003 trawls, and 2002 and 2003 gillnet sets) to the following environmental variables for the 2002 data: temperature, salinity, depth, water clarity, habitat type, zone, chlorophyll, percent saturated dissolved oxygen, turbidity, distance from land and distance from mudbanks. [Chlorophyll, percent saturated dissolved oxygen, and turbidity data provided by the SERC-FIU water quality monitoring network which is supported by SFWMD/SERC cooperative agreements #C-10244 and #C-13178 as well as EPA Agreement #X994621-94-0. These data points were interpolated in GIS using a guassian kriging technique and sampled for each trawl and gillnet location.] Chlorophyll, percent saturated dissolved oxygen, and turbidity data were not available for 2003, so trawl and gillnet catch from 2003 were not tested against these variables.

CART models of CPUE from 2002 and 2003 trawls were built for each of the five zones, using the same environmental data, with the addition of habitat type. The resulting five "zonal" CART models predicting abundant fish habitats in Florida Bay were spatially mapped out in GIS. Additionally, a CART model was preformed to classify the habitat of foraging versus non-foraging dolphins during the 2002 and 2003 summer field seasons. The predicted dolphin foraging habitat from these CART models were also mapped out spatially using GIS and overlaid on the predicted fish habitats for comparison.

Results

Dolphins were sighted throughout the bay, with foraging behavior observed, during both the 2002 and 2003 summer field seasons (Table 1). Additionally, 99 randomly stratified trawls were conducted in 2002, and 94 randomly stratified trawls were performed in 2003. In 2002, 24 gillnet sets were conducted using a 50m long 3-inch mesh. A 50m panel of 3¼-inch mesh was added to the gillnet in 2003, and 50 randomly stratified gillnet sets were conducted.

Mantel Tests

A multitude of Mantel tests were performed to determine the significance of each variable on each of the four catch indices from the two fish sampling methods. For all tests, space was highly correlated with environmental variables ($p = 0.001$). Moreover, the global Mantel tests revealed that fish catch was related to space, even when the effect of the environmental variables on space was removed ($p < 0.034$ or less). This was true for each index, for each fish catch data set, except gillnet sets from 2003. This result suggested that zone could be an important factor influencing the Florida Bay fish community.

Additionally, the Mantel tests determined that when the effect of spatial autocorrelation is removed, no single tested environmental variable had a consistent significant effect on any of the fish catch indices. Various pure partial Mantel tests were conducted in order to test the individual effect of each variable, on each index, for the four fish catch data sets. However, only secchi depth (water clarity), depth and chlorophyll were occasionally significant (Table 2).

Five environmental variables were strongly correlated with space in every test except with the 2003 gillnet data set: depth ($p < 0.05$), salinity ($p < 0.001$), secchi depth ($p < 0.004$), distance from land and mudbanks ($p < 0.04$), and distance from mudbanks ($p < 0.005$). A correlation matrix was also preformed for all environmental variables for each fish catch data set to determine relationships among variables. The environmental data from the 2002 trawl and gillnet data sets showed very strong relationships between chlorophyll and turbidity (trawl = 0.80; gillnet = 0.78). Additionally, secchi depth had a relatively strong inverse relationship to chlorophyll (-0.41) and turbidity (-0.43). Percent-saturated dissolved oxygen had a fairly strong inverse relationship to salinity (-0.54).

Classification and Regression Trees (CARTs)

A benefit of CARTs is the ability to incorporate both continuous and categorical data into the model. Therefore, CART models were run with all the environmental variables, including habitat type and zone, for each index of each fish catch data set. While each resulting tree looked different, one consistent trend was evident: habitat type and zone were always primary explanatory variables used to split the response data, with secchi depth often used further down the tree. However, the divisions created by these variables were not consistent. For instance, habitat type was not always partitioned so that dense seagrass had a greater fish catch; nor was higher water clarity always indicative of better fish habitat. Figure 2, based on dolphin prey subset from 2003 trawls, is an example of a typical CART result from this analysis. The combination of this result and the result from the Mantel tests indicating the significance of space regardless of environmental variables, suggested that the effect of zone is significant. Therefore, individual CARTs were performed for each zone on CPUE from the 2002 and 2003 trawl data. The residual mean deviance (a measure of misclassification by the CART) of these models ranged from 0.001 to 0.464 in 2002, and between 0.001 and 0.230 in 2003 (Table 3). A higher deviance value indicates that it was more difficult for the model to split the response variable (level of CPUE) into homogeneous groups based on the available predictor variables.

Dolphin foraging habitat was also modeled using CARTs. Environmental data from dolphin sightings for each year were used as predictor variables of behavior state (foraging or non-foraging) during the sighting. Figures 4 and 5 depict the resulting trees for 2002 and 2003, respectively. In 2002, the CART model used zone, habitat type and secchi depth as the predictor variables of dolphin foraging habitat. In 2003, only habitat type and secchi depth were used by the CART model as explanatory variables.

Abundant fish habitats of each zone were mapped using GIS for both 2002 and 2003 based on the “zonal” CART models. Additionally, the predicted dolphin foraging habitats for 2002 and 2003 were mapped. These maps were overlaid, by year, to spatially compare the areas predicted (Figures 6 and 7).

There is generally a good spatial overlap between those areas predicted as abundant fish habitats and the locations where dolphins forage. In 2002 (Figure 6), no area of the Eastern or Western zones was modeled as dolphin foraging habitat because no dolphins were observed foraging in these zones during this summer. In the other zones of Florida Bay, overlap between models in 2002 is good, especially the Gulf transition zone and the northern and southern portions of the Central zone. There were only three sightings of foraging dolphins in the Atlantic transition zone in 2002. This small sample size made trend analysis and extrapolation of habitat preference to the entire zone difficult. However, both the fish and dolphin foraging CARTs correctly modeled the locations of these three foraging sightings.

In 2003 (Figure 7), the CART model of fish habitat for the Western zone did not find any significant predictor variable. Therefore, the entire Western zone is classified as abundant fish habitat because all trawls had a high CPUE. Hence, all observations of foraging animals in the Western zone overlapped with predicted abundant fish habitat. Although more area was predicted as dolphin foraging habitat in the Eastern zone in 2003 than in 2002, fewer habitats were modeled as fish habitat. However, the two sightings of foraging dolphins did overlap with small areas predicted as abundant fish habitat. In the Central zone, less area was predicted as abundant fish habitat in 2003 than in 2002, but much of the same area in the northern portion of the zone was identified in both years. Only one observation of foraging dolphins occurred in this area in 2003 and did not overlap with predicted fish habitat. Conversely, essentially opposite habitats were predicted as abundant fish habitat in the Gulf transition zone between 2002 and 2003. But, in 2003, two sightings of foraging dolphins did overlap, or closely overlap, with predicted fish habitat. In the Atlantic transition zone, two large areas of predicted habitat overlapped, but no location of foraging dolphins were captured by both models.

Discussion

This research addressed two critical research priorities: (1) “What is the relationship between environmental and habitat change and the upper trophic levels in Florida Bay?” Population declines of some species, such as wading birds, indicate that the system’s carrying capacity has diminished and/or that important habitats have been degraded (Deegan et al., 1998). (2) As identified by The Florida Bay Integrated Science Plan, we examined the hypothesis that bottlenose dolphins are good indicators of the distribution of forage fish and quality of fish habitat in Florida Bay (Dynamic Higher Trophic Levels Science Plan, 2001). Despite considerable prior efforts to understand the ecosystem dynamics of Florida Bay, very little research has focused on a dominant upper trophic level predator, the bottlenose dolphin. Bottlenose dolphins range throughout Florida Bay and their patterns of distribution reflect oceanographic variability, changes in marine food webs and anthropogenic impacts (Woodley and Gaskin, 1996; Baumgartner, 1997; Kasamatsu et al., 2000). Understanding dolphin distributions, foraging ecology, and habitat use can help resource managers to monitor ecosystem-level changes and to enhance the understanding of biogeographic and ecological processes in this heterogeneous and dynamic ecosystem.

The CART models, and subsequent GIS mapping, of both fish and dolphin foraging habitats, were able to spatially capture the patchy quality of the Bay in a realistic manner. In particular, in 2002 and 2003, both models impressively mapped habitats around locations of foraging dolphin sightings, showing fine scale accuracy and overlap of predicted habitats (denoted by arrows in Figures 6 and 7). While some areas of predicted habitat in 2002 and 2003 do not coincide, these models can be fine-tuned using additional habitat variables, an improved bottom habitat types map (in progress), and a larger data set. Based on these preliminary results, however, it appears that dolphins can be used to predict the distribution and structure of fish communities throughout Florida Bay. This connection can be very useful for mitigation purposes because as the restoration project continues managers can use this link between foraging dolphins and fish to identify healthy habitats supporting upper trophic level species. Moreover, an understanding of which habitat parameters are important to the health of bottlenose dolphin and fish populations within Florida Bay will allow managers to concentrate restoration efforts on degraded habitats while simultaneously protecting habitats that continue to support a healthy ecosystem.

For simplicity sake, the “zonal” CART analysis and spatial modeling was done only with the CPUE index from 2002 and 2003 trawls, but these models could have been based on species diversity, species richness or the dolphin prey subset. The index chosen to determine “healthy fish habitats” is a management question. Management based on CPUE will identify areas of abundant fish, regardless of size or species. However, using species diversity or species richness as the management metric can lead to management of marginal habitats. This is due to the fact that areas of high species diversity or richness may be intermediate or marginal habitats, supporting a variety of species but not providing optimal habitat for any of the organisms.

Results from this analysis underscore the extremely heterogeneous nature of Florida Bay. No single environmental variable was identified as the determining factor of productive fish habitat. Instead, it appears from both the Mantel and CART results, that combinations of variables interact to provide patchy habitats throughout the Bay. Moreover, the correlations between certain environmental variables (chlorophyll, turbidity and secchi depth; percent-saturated dissolved oxygen and salinity) also indicate that the relative effect of each variable is not easily detectable, but rather it is the interplay between variables that creates complexly defined habitat quality. However, certain environmental variables were identified through this analysis as being primary predictor variables of abundant fish communities: zone, habitat type, water clarity, chlorophyll and salinity.

The complexity of Florida Bay is further confounded by the dynamics of habitat quality across the different zones of the Bay. For instance, in the hardbottom communities of the Atlantic transition zone, the fish community is mostly composed of reef dwelling animals dependent of habitats supported by good water clarity. However, less than 25km away, in the central zone of Florida Bay, the fish community is composed more of mullets and snappers, fish that prefer murky water clarity. Therefore, its not just the significance of different variables that changes with spatial location (zone) in the Bay, but also the magnitude or direction of individual variables.

Finally, this exercise showed that Mantel tests and CARTs are applicable and useful tools to incorporate space into the analysis of fish and dolphin habitats. One objective of this on going research is to establish geo-spatial statistics required to detect physical and biological changes in this highly heterogeneous habitat, where habitat parameters interact to predict habitat use patterns. Here, data was integrated into a predictive habitat-modeling “tool-box” that can help resource managers and stakeholders quantify changes in the unique South Florida ecosystem.

Further field research and analysis, including step-wise generalized linear models, logistic regressions and discriminant functions, will improve the models described above. Our goals are to quantify fine scale (on the order of 10s of meters) habitat quality variation spatially and to relate this variability to upper trophic level predator use. Greater sample sizes and multiple years of data will provide the stronger statistical power needed to elucidate inter-annual variation. These methods will allow local spatial structure of habitat quality in Florida Bay to be teased out by discriminating between suitable and non-suitable habitat for the various upper trophic level users considered in this study.

The South Florida population continues to grow at an astounding rate, adding pressure to the already stressed water management system of the greater everglades region. These intensive pressures of human development have changed the structure and function of coastal systems throughout South Florida (U.S. Army Corps of Engineers, 1999). In light of the current habitat restoration efforts, research that leads to appropriate management decisions and practices is essential to enhance the preservation of the biological diversity of Florida Bay. This research took an ecosystem-level approach to resource management by synthesizing studies of water quality, habitat heterogeneity, fish distribution, and dolphin behavior to give managers a reliable mitigation tool: the distribution of bottlenose dolphins as a management indicator species of fish habitats. In summary, this research characterized the spatially variable habitat quality supporting abundant fish populations in Florida Bay and demonstrated a link to dolphin foraging behavior, enabling mangers to better understand, conserve, and restore this heterogeneous ecosystem.

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Tables

Table 1. Number of dolphin sightings and foraging observations from survey effort in Florida Bay during the summers of 2002 and 2003.

2002	Sightings	Dolphins
Sightings	57	356
Foraging	26 (46%)	190 (53%)
Non-Foraging	31 (54%)	166 (47%)

2003	Sightings	Dolphins
Sightings	68	520
Foraging	24 (35%)	194 (37%)
Non-Foraging	44 (65%)	326 (63%)

Table 2. P-values from the pure partial Mantel tests that produced significant or marginally insignificant results. A pure partial Mantel test removes the confounding effect of all other variables, including space, from the test. NS = not significant.

Data Set and Index	**Secchi depth**	**Depth**	**CHLA**
Trawls 2002	0.113	0.055	NS
CPUE			
Dolphin Prey	0.047	0.051	NS
Simpson	0.005	NS	NS
Richness	NS	0.114	
Trawls 2003			
Richness	0.054	NS	NS
Gillnet Sets 2002	NS	0.102	0.097
CPUE			
Dolphin Prey	0.131	0.116	0.095
Simpson	NS	NS	0.056
Richness	NS	NS	0.122
Gillnet Sets 2003			
Simpson	0.048	NS	NS
Richness	0.02	NS	NS

Table 3. Residual mean deviance from CART models for each zone of fish CPUE from 2002 and 2003 trawls. A higher deviance value indicates that it was more difficult for the model to split the response variable (level of CPUE) into homogeneous groups based on the available predictor variables. No value is associated with the 2003 Western zone because the CART model found no significant predictor variable for the response data.

	Eastern	**Central**	**Western**	**Atlantic transition**	**Gulf transition**
2002	0.001	0.002	0.464	0.003	0.05
2003	0.230	0.001	NA	0.013	0.026

List of Figures:

Figure 1. The location and description of the Florida Bay study area: Benthic habitat types and zones. Note patchiness of habitat types throughout the Bay. Benthic habitat type map provided by Robert Halley and Ellen Prager, 1997, Florida Bay Bottom Types map: USGS Open-File Reports OFR 97-526, U.S. Geological Survey, Reston VA.

Figure 2. The general tested model of this paper: effect of environmental variables on space and the subsequent effect on fish catch and dolphin habitat use; effect of space on environmental variables and the subsequent effect on fish catch and dolphin habitat use; the direct effect of space on fish catch and habitat use; the direct effect of environmental variables on fish catch and dolphin habitat use.

Figure 3. CART of dolphin prey subset of CPUE from 2003 trawls. Circles denote terminal nodes. Numbers in parentheses are mean CPUE for the specified group. Residual mean deviance = 0.0044. Note that the first three breaks are habitat type and zone.

Figure 4. CART of dolphin foraging habitat for 2002 based on zone, habitat type and secchi depth (water clarity). Circles denote terminal nodes. Misclassification error rate: 0.1175 = 39/332

Figure 5. CART of dolphin foraging habitat for 2003 based on habitat type and zone. Circles denote terminal nodes. Misclassification error rate: 0.069 = 33/475

Figure 6. Overlap of predicted abundant fish habitat (based on zonal CARTs of CPUE from 2002 trawls) and predicted dolphin foraging habitat (based on CART of sightings from 2002) during the summer of 2002. Arrows point to observations of foraging dolphins that both models identified as habitat; these areas are discussed in the text.

Figure 7. Overlap of predicted abundant fish habitat (based on zonal CARTs of CPUE from 2003 trawls) and predicted dolphin foraging habitat (based on CART of sightings from 2003) during the summer of 2003. Arrows point to observations of foraging dolphins that both models identified as habitat; these areas are discussed in the text.

Figures:

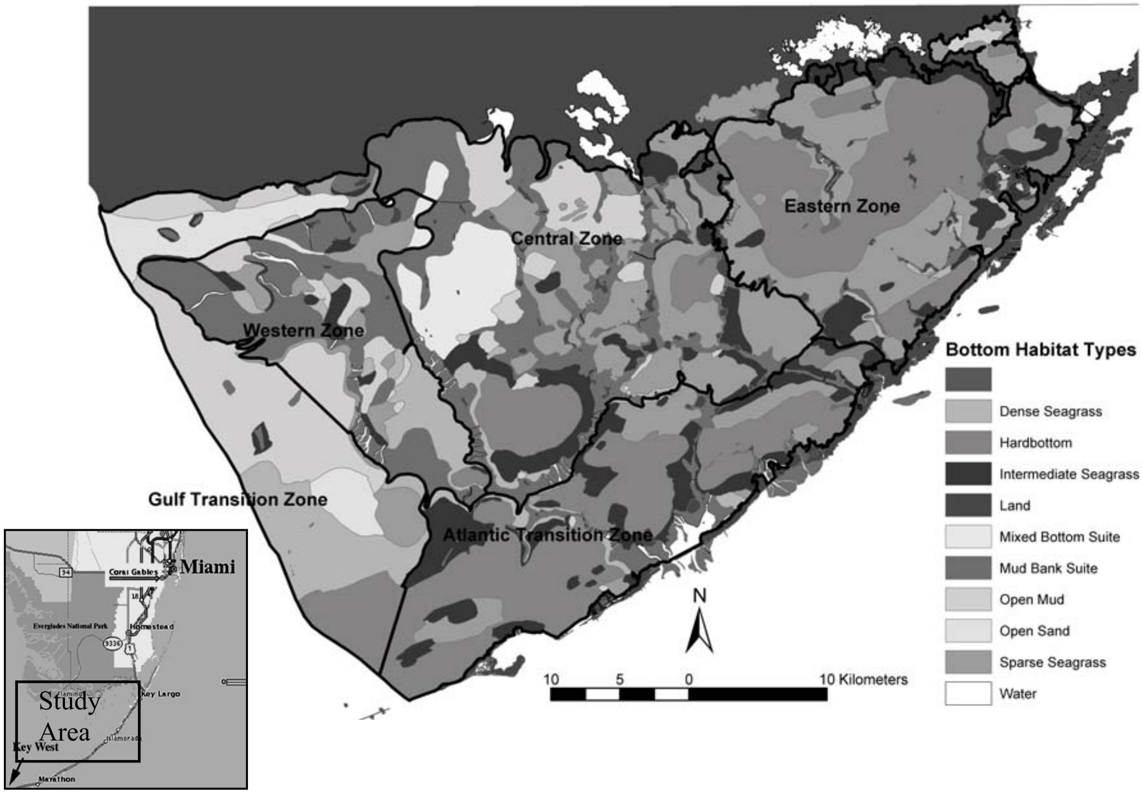
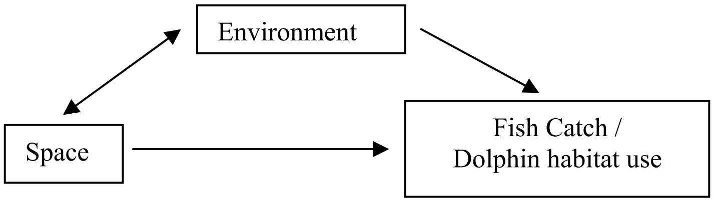


Figure 1.



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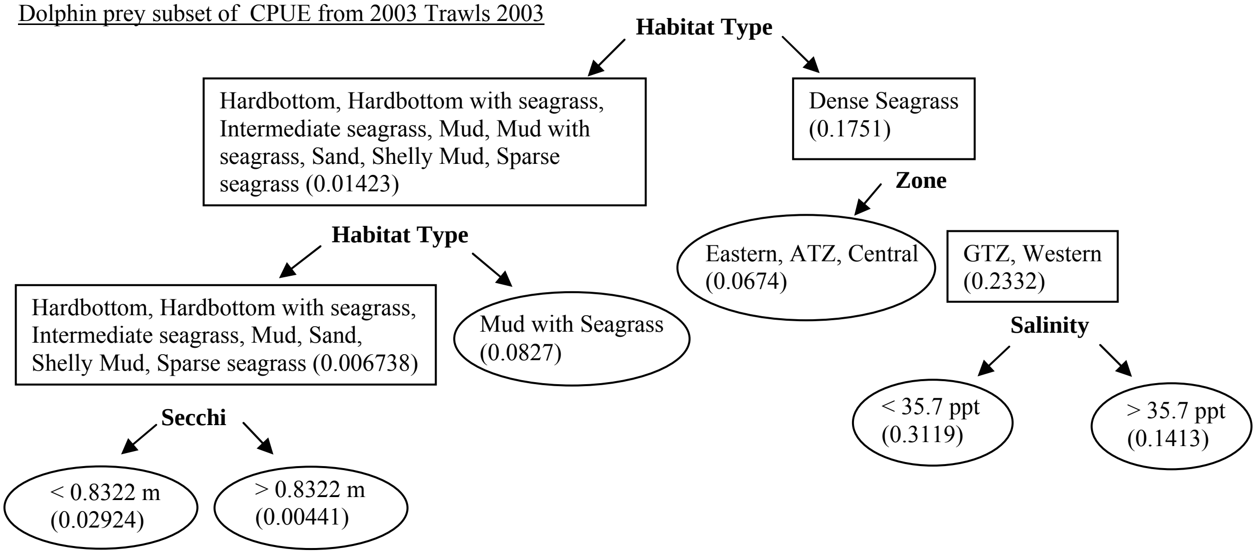

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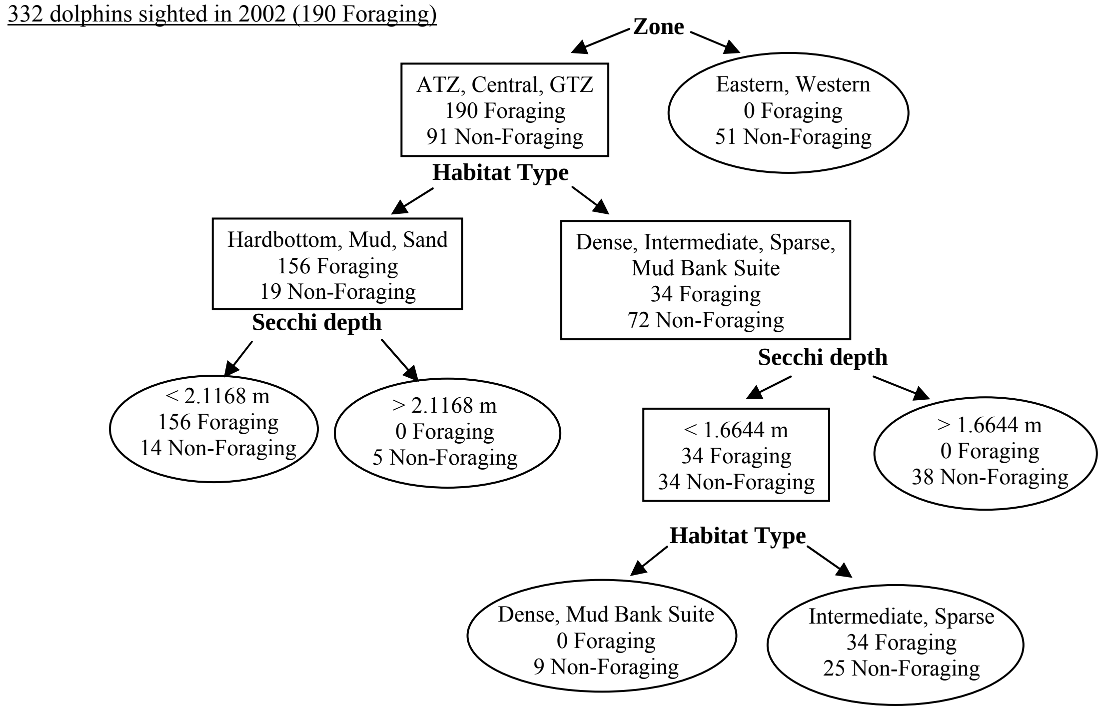

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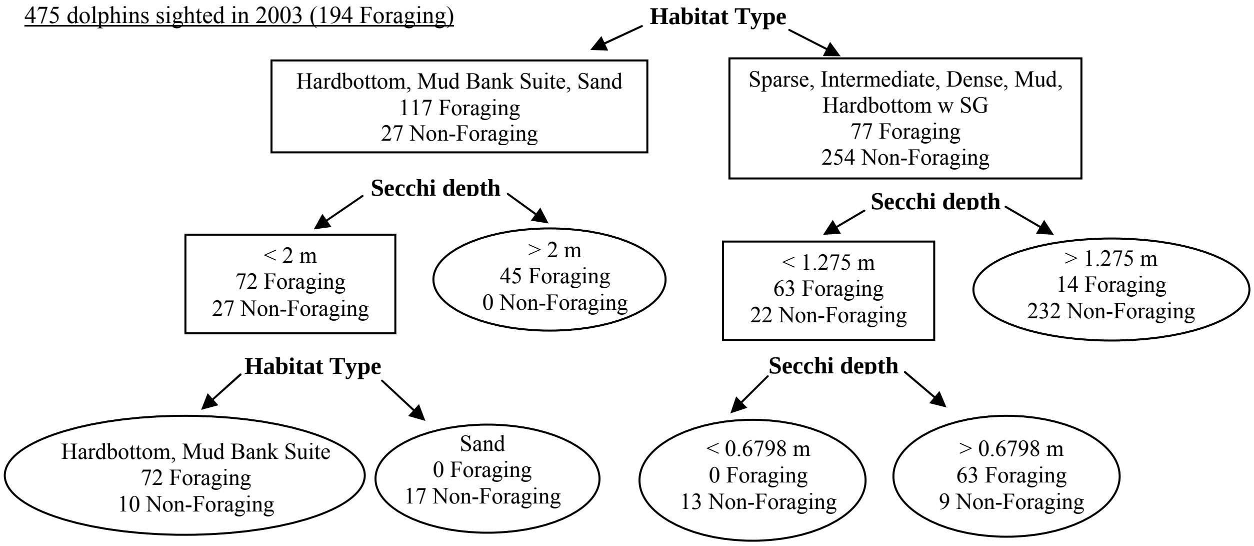

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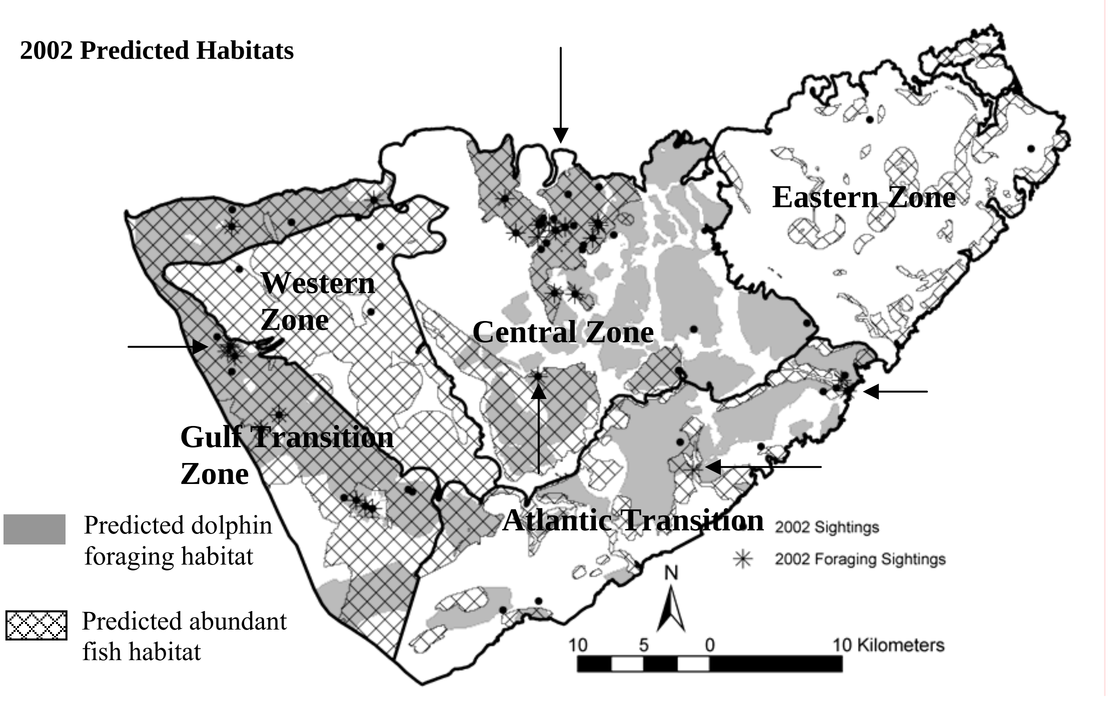

Figure 6.

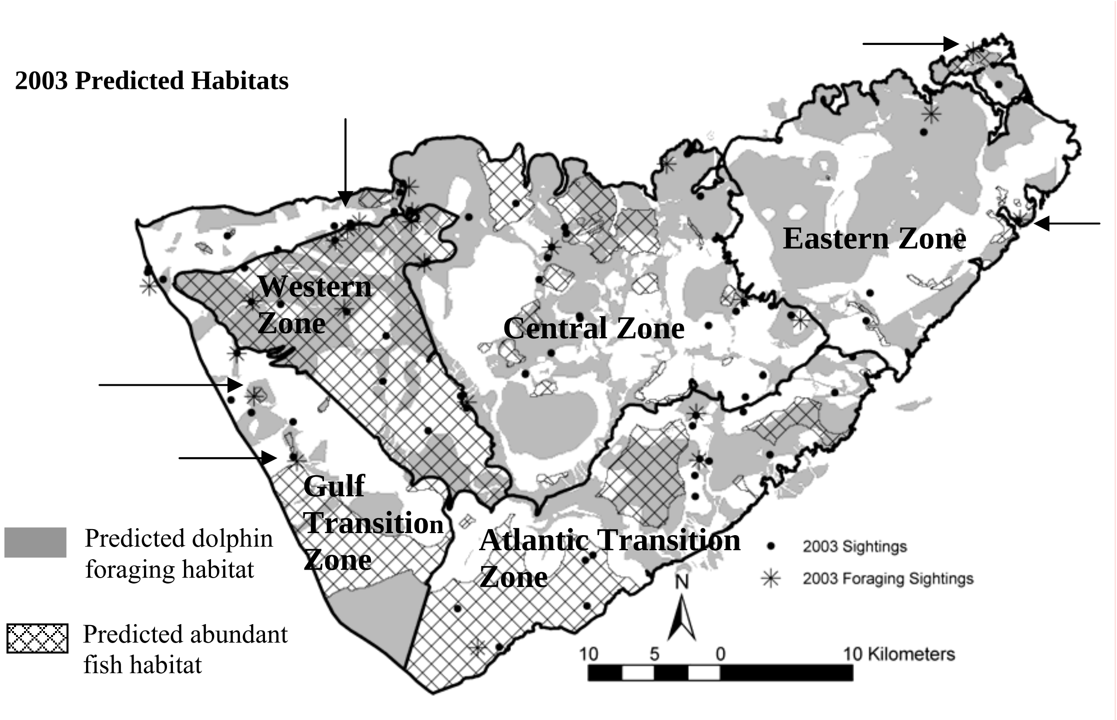
2003 Predicted Habitats
Western Zone
Central Zone
Eastern Zone
Gulf Transition Zone
Atlantic Transition Zone
Predicted dolphin foraging habitat
Predicted abundant fish habitat
2003 Sightings
2003 Foraging Sightings
N
10
5
0
10 Kilometers

Figure 7.