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Development of Mission Avoidance Zones in the Eglin Gulf Test and Training Range

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Development of Mission Avoidance Zones in the Eglin Gulf Test and Training Range

Eglin Air Force Base, Florida

January 2006

Final Report

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Legacy Project Number 05-270

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ACRONYMS, SYMBOLS, AND ABBREVIATIONS

AFB	Air Force Base
ANOVA	Analysis of Variance
C	Celsius
CART	Classification and Regression Tree
cm	Centimeters
DoD	Department of Defense
EGTTR	Eglin Gulf Test and Training Range
ESA	Endangered Species Act
F	Fahrenheit
GAM	Generalized Additive Model
GIS	Geographic Information System
GLM	Generalized Linear Model
HSM	Habitat Suitability Modeling
m	Meters
MAZ	Mission Avoidance Zone
MMPA	Marine Mammal Protection Act
MR	Model Run
SST	Sea Surface Temperature

1. INTRODUCTION

This report discusses development of a preliminary computer model to help establish mission avoidance zones in the Eglin Gulf Test and Training Range (EGTTR), an overwater range of Eglin Air Force Base (AFB). These zones are being developed to protect marine mammals from impacts resulting from military activities.

Eglin AFB seeks to avoid areas of high marine mammal concentration; these areas are called "mission avoidance zones" (MAZs). The ability to identify MAZs on a near real-time basis, and to direct missions to other areas accordingly, is a powerful mitigation tool that can expedite the regulatory consultation process and decrease costs and mission delays.

Department of Defense (DoD) water ranges, such as EGTTR, are critical assets in support of weapons systems testing and training. However, efforts to comply with environmental regulations can lead to increased costs of military and training activities, as well as delays. DoD has been facing increased environmental scrutiny and compliance challenges, particularly regarding activities in the marine environment. For example, all Air Force Special Operations Command gunnery test missions in the EGTTR were suspended for three years (1996–1998) due to underwater noise concerns.

Marine mammals are among the species of primary concern for military operations conducted in the EGTTR (as well as other DoD water ranges), due to their susceptibility to impacts from underwater noise. (Marine mammals are mammals that depend on the sea for all or the majority of their life needs.) Up to 29 marine mammal species occur in the Gulf, including whales, dolphins, and the Florida manatee. All species are protected under the Marine Mammal Protection Act of 1972 (MMPA), and some are afforded additional protection under the Endangered Species Act of 1973 (ESA). Under these acts, the "take" of any marine mammal is prohibited without a permit from a federal regulatory agency. "Take" is defined as harass, hunt, capture, or kill. "Harassment" is defined as an activity that could injure or disturb a marine mammal, including underwater noise.

Potential impacts to marine species are usually assessed based on a presumed random and uniform distribution of animals throughout the range. However, recent evidence suggests that marine species are not uniformly distributed but are often associated with specific oceanographic features such as ocean current confluence zones, areas of upwelling, and seafloor topographic features. Such features may provide conditions conducive to the formation of a food web, which results in the concentration of marine species. Many ocean features that are critical for predicting marine mammal presence are readily identifiable on satellite images.

1.1 HABITAT SUITABILITY MODELING AND GEOGRAPHIC INFORMATION SYSTEMS

Habitat suitability modeling (HSM) is a useful technique for developing MAZs, as well as for other habitat-related analyses. HSM is a mapping tool that can be used to estimate the suitability of an area for a given species at a specific point in time. Habitat suitability maps are generated based on a species' habitat requirements and the area's environmental characteristics. The maps can be used to characterize the degree of association (or lack thereof) a species or population is likely to have with a set of environmental features. Marine habitat mapping can be used to assess habitat changes due to natural and anthropogenic impacts, monitor and protect important marine habitats/species, design and locate marine reserves and aquaculture projects, and determine species distributions and stock assessments (Baxter and Shortis, 2002). Environmental managers can use modeling for endangered species management, reintroduction of species, population viability analysis, and ecosystem restoration (Hirzel et al., 2001).

Habitat characteristics and environmental factors generally considered pertinent to marine mammal occurrence, and that have been used in previous models, include water depth, substrate type, sea surface temperature, sea surface height, sea floor depth, prey availability, salinity, chlorophyll *a*, currents, exposure, relief, surface roughness, sediment type, and turbidity. These determinants can be sampled either directly or remotely by a variety of methods. Remote methods include aerial photography, satellite imagery, acoustic imagery, transects, and video. These factors can then be incorporated into models that define habitat suitability and predict species distributions (Baxter and Shortis, 2002).

A geographic information system (GIS) is another tool useful for distribution and habitat modeling. GIS is a computer application that allows users to collect, manage, and analyze large volumes of spatially referenced information and associated attribute data. Outputs are often in the form of maps. Areas in which GIS is particularly useful include data management, data processing, dynamic mapping, data exploration and visualization, hypothesis testing, and modeling predictions.

1.2 MODELING APPROACHES

Marine habitat modeling can be accomplished through nonstatistical, statistical, or behavioral modeling approaches. *Nonstatistical* modeling approaches identify habitat and distributions based on observation and literature reviews. *Statistical* modeling, which is the most common approach, employs models that test the statistical association between animal distribution and surrounding environmental variables. Individual *behavioral* modeling approaches examine the characteristics/behaviors of individuals and their movement across the environment, and can also explore and test ecological relationships. Quantification of species-habitat relationships is the primary goal of predictive modeling (Guisan and Zimmermann, 2000). Statistical modeling is usually the approach most suited to accomplish this goal. Statistical models apply mathematical equations to determine if measured predictor variables adequately explain responses, if the predictor-response relationship is significant, and define the utility and relative contributions of the variables.

1.3 COMMONLY USED MODELS

Redfern et al. (in press) provide an overview of the types of marine habitat modeling available, as well as the associated benefits and disadvantages of each. There are three general types of models used most often in cetacean habitat suitability analysis. The first, environmental envelope models, are typically used to address issues that deal with large-scale distribution questions. The second type is regression models, which are among the most commonly used types. Finally, classification and regression trees are anticipated to be widely used for cetacean habitat suitability modeling in the future. They can be used to make discrete predictions of relationships between species and their habitat characteristics. These three modeling types are described further in the following subsections.

1.3.1 Environmental Envelope Models

Environmental envelope modeling is a technique used to quantify large-scale relationships between species distribution and habitat variables using the concept of ecological niche (Redfern et al., in press; Hirzel and Arlettaz, 2003). This method is based on defining an environmental space, or envelope, delineated by minimum and maximum habitat values that allow a species to exist (Redfern et al., in press; Hirzel and Arlettaz, 2003; Guisan and Zimmermann, 2000). The envelope may encompass all or a portion of the individuals of a species, depending on research needs. The underlying premise is that locations where species occur represent favorable combinations of habitat variables that directly correlate with species densities (Hirzel and Arlettaz, 2003).

1.3.2 Regression Models

Regression is a technique commonly used to model the relationship between two or more variables. The response of the dependent variable may be determined by one (simple regression) or a combination (multiple regression) of other variables (typically called the independent variables). In the case of habitat modeling, the independent variables are environmental predictors. Traditional regression models are based on site observations that determine the relationships between species-communities and the environment; these models have proven to be especially useful in modeling the spatial distribution of species and communities (Guisan et al., in press; Gauisan and Zimmerman, 2000). The use of regression analysis assumes that equilibrium exists between species and their environments (Guisan et al., in press). Regression models must incorporate a wide range of data in order to describe ecological relationships and may, therefore, be limited by data availability (Redfern et al., in press).

A disadvantage of traditional regression techniques is that models become unreliable when dimensionality becomes high. Generalized linear models (GLMs) and generalized additive models (GAMs) were developed to address this problem. GLMs and GAMs have been used extensively because of their compatibility with traditional linear modeling practices and capabilities to manage large amounts of data (Guisan et al., in press).

Linear regression is a statistical technique that attempts to make predictions about one variable based on knowledge of another variable. It involves use of a straight line that most nearly fits a set of graphed data points. Using the slope of the line, the value of a dependent variable, usually graphed on the ordinate (y) axis, can be approximated from the value of the independent value on the abscissa (x). A calculated value, called r^2, is a measure of the "goodness of fit" of the line to the actual data and is expressed as a value between 0 and 1. Values closer to 1 indicate a better fit.

GLMs are mathematical extensions of the linear regression technique that accommodate noncontinuous or nonlinear data. This approach provides more flexibility in the modeling of dependent variable responses such as species richness, abundance, and presence/absence data (Guisan et al., in press; Lehmann et al., 2002). GLMs allow the mean of a population to depend on a linear predictor, via a link function.

GAMs are extensions of GLMs that allow the introduction of nonlinear responses to predictor variables. This method is appropriate when the relationship between the variables is expected to be of a complex form, not easily fitted by standard linear or nonlinear models. Like GLMs, the GAM uses a link function between the mean of the response variable and a smoothed function of the explanatory variables. Therefore, a major assumption of GAMs is that the effects of predictor variables are smooth (Gausin et al., in press; Lehmann et al., 2002). Smoothing functions that replace linear function include moving averages, running median, smoothing splines, and kernel smoothers (Redfern et al., in press). Unlike GLMs, the GAM can also be modeled nonparametrically.

1.3.3 Classification and Regression Trees

Classification and regression tree (CART) is an analytical, rule-based classification (qualitative response) and regression (quantitative response) modeling technique used to predict the values of a categorical or numeric response variable from categorical or numeric environmental predictors (Redfern et al., in press; Guisan and Zimmermann, 2000). The structures created by these methods are termed "classification trees" if the dependent response variable is categorical or "regression trees" if the response variable is numeric. Tree-based modeling provides a nonparametric alternative to GLMs and GAMs. The purpose is to generate classifiers (binary trees) that resolve relationships within complex datasets (Redfern et al., in press). Classifier rules can be defined by integrating knowledge from literature reviews, laboratory analysis, and professional experience. CARTs generate successive divisions of an entire dataset into increasingly homogenous binary tree branch and node structures (Redfern et al., in press). One advantage of tree-based models over regression analysis is their capability to evaluate species-habitat relationships and patterns by capturing nonadditive interactions among predictor variables. However, in predicting discrete species-habitat relationships, CARTs may be less adapted to capture smooth gradients of species-habitat variables (Redfern et al., in press).

2. METHODS

2.1 STUDY SITE

Eglin AFB, a 465,408-acre military installation, is situated in the northwest panhandle region of Florida and is adjacent to the Gulf of Mexico. The installation includes overland airspace directly connected to overwater airspace The EGTTR encompasses more than 124,000 square miles, which is approximately one-third of the eastern Gulf. The area is divided into five main Warning Areas and six Eglin Water Test Areas. This overwater range supports thousands of Air Force test and training flights annually. Additionally, Navy and Marine Corps activities occur in waters encompassed by the EGTTR. Eglin schedules all DoD use of the EGTTR airspace except for Warning Area W-155, which is controlled by the Navy.

2.2 STUDY SPECIES

Testing and training events that occur in the EGTTR have the potential to impact protected marine species, including marine mammals. For example, missions have the potential to directly strike animals and harass protected species through projections of underwater noise. Two marine mammal species were selected for modeling, based on resource limitations (time and funding). The bottlenose dolphin and the sperm whale were selected because 1) they have been extensively studied, 2) scientists have documented general habitat preferences, and 3) sighting data from the eastern Gulf are available. Additionally, these species reside in areas where human activities, including the introduction of underwater noise, are prevalent. The following subsections provide background information on the marine mammals selected.

2.2.1 Bottlenose Dolphin (*Tursiops truncatus*)

The bottlenose dolphin (*Tursiops truncatus*) has a worldwide distribution. This species occurs in a variety of habitats in tropical and temperate latitudes, in waters ranging from 50 to 90° Fahrenheit (F), or 10 to 32° Celsius (C) (Wells and Scott, 2002). Two types of bottlenose have been identified: the coastal bottlenose dolphin and the offshore bottlenose dolphin. The coastal bottlenose is found in bays, estuaries, sounds, and coastal waters of the Atlantic and Gulf of Mexico, while the offshore bottlenose is found in deeper pelagic habitats. Some populations of bottlenose dolphins stay in one area for their entire lives while others migrate to many different areas. Migratory patterns from inshore to offshore are likely associated with the movements of their prey (Ridgway, 1972; Irving, 1973; Jefferson et al., 1992).

2.2.2 Sperm Whale (*Physeter macrocephalus*)

The sperm whale (*Physeter macrocephalus*) is the largest toothed whale; it dives deeper and longer than any other whale. Although endangered in U.S. waters, the sperm whale is probably the most abundant cetacean in the world's oceans. Sperm whales are found from the equator to polar waters devoid of ice and are perhaps most common along the equator and in deep offshore waters. The sperm whale prefers areas with high productivity, generally where upwelling occurs. The sperm whale relies on acoustics—passive listening and echolocation—to navigate and find prey. Due to their long time period to sexual maturity, the sperm whale has been unable to recover quickly from decades of overexploitation.

2.3 MODELING APPROACH

ArcView Spatial Analyst Model Builder (Environmental Systems Research Institute, Redlands, California), a GIS tool, was used to develop a preliminary model to predict areas to be avoided during military operations in the Gulf. The Spatial Analyst Model Builder was selected because it has demonstrated capabilities for similar functions in terrestrial habitat models. For example, the tool has been successfully employed in the analysis of foraging habitat for red-cockaded woodpeckers by Eglin AFB. Furthermore, the program is easy to use and readily available.

The model was refined for use in the marine environment to allow staff at Eglin AFB to direct missions away from MAZs, thereby reducing potential impacts. The tool would allow planners to choose alternate locations or different times for planned missions, so that disruption to test and training events due to environmental compliance is minimized.

The model development required first identifying and ranking key parameters that influence the distribution of bottlenose dolphins and sperm whales in the Gulf. Then, the model was run to produce site rankings, based on habitat suitability for the two focal species.

2.4 IDENTIFICATION OF KEY PARAMETERS

The available literature on bottlenose dolphins and sperm whales was reviewed to determine the parameters to be used in the preliminary model. The review focused on those habitat preferences identified from surveys conducted in the Gulf. Based on the surveys, four parameters were identified for the dolphin species and three parameters were identified for the whale species (Table 2-1).

Table 2-1. Parameters Used for Preliminary Habitat Model of the Bottlenose Dolphin and the Sperm Whale in the EGTTR

PARAMETERS FOR BOTTLENOSE DOLPHIN MODEL	PARAMETERS FOR SPERM WHALE MODEL
BATHYMETRY	BATHYMETRY
TEMPERATURE	REFLECTANCE
REFLECTANCE	SEA SURFACE HEIGHT
SLOPE	

Once the parameters were identified, sources for the required data were identified. The bathymetry data, with a resolution of 1.3 kilometers, was obtained from GIS coverages available from NOAA. The temperature and reflectance data was obtained from the Applied Physics Laboratory at Johns Hopkins University, which processes information from Advanced High Resolution Radiometer (AVHRR) satellite (Johns Hopkins University APL, 2006). Reflectance is considered to be an indicator of chlorophyll presence. The resolution of the temperature data is 0.5 ^{o}C, while the resolution of the reflectance is unknown. Precision where no clouds are present is 0.003 (or 0.3 percent). Sea surface height is available through the Colorado Center for

Astrodynamics Research (CCAR) at the University of Colorado (CCAR, 2006). Finally, the slope coverage was generated using the spatial analysis tool to look at the differences in water depth by 1-nautical-mile (NM) grids.

The model and subsequent statistical analysis and validation incorporated only oceanographic data for the spring months. Sighting data from the GulfCet II survey were used (Davis et al., 2000); this survey was conducted by Texas A&M University through the Minerals Management Service. Aerial and ship-based surveys were conducted in various spring, summer, and fall months. The data for a particular month were included only if data were collected for that month in more than one year of the survey, which happened only during the spring season (March through May).

2.5 RANKING CRITERIA AND VALUE SCORING

A weighting system was applied to the criteria based on the available literature. The sum of the model influences in the ArcView Spatial Analyst Model Builder was required to equal 100 percent. This process created a hierarchical system of a parameter's importance relative to the other criteria. Then, each value within the criterion was weighted according to how it should influence the habitat suitability model for the respective species. For example, the overall influence of water depth was estimated at 35 percent. However, each value, which for this example was divided into 50 feet increments, did not carry equal weight within the parameter. Therefore, a water depth of, for instance, 51 to 100 feet was given a weighting of 5 while water depths below 900 feet were given a weighted value of 1. This weighting signifies that bottlenose dolphins are more likely to be found in shallower waters than in deeper waters in the EGTTR. Tables 2-2 and 2-3 provide the overall weighting system used for each parameter for the bottlenose dolphin and for the sperm whale, respectively.

Table 2-2. Model Inputs for Bottlenose Dolphin Habitat Suitability

PARAMETER	OVERALL MODEL INFLUENCE (PERCENT)	VALUE	INFLUENCE
WATER DEPTH	35	0 – 100 M	5
		100 – 200 M	5
		200 – 300 M	5
		300 – 400 M	5
		400 – 500 M	5
		500 – 600 M	5
		600 – 700 M	5
		700 – 800 M	4
		800 – 900 M	3
		900 +	1
TEMPERATURE	10	0 ^{O}C	1
		1 ^{O}C	1
		2 ^{O}C	1
		3 ^{O}C	1
		4 ^{O}C	1
		5 ^{O}C	1
		6 ^{O}C	2
		7 ^{O}C	3
		8 ^{O}C	3

Table 2-2. Model Inputs for Bottlenose Dolphin Habitat Suitability Cont'd

PARAMETER	OVERALL MODEL INFLUENCE (PERCENT)	VALUE	INFLUENCE
		9 ^{O}C	4
		10 ^{O}C	5
		11 ^{O}C	5
		12 ^{O}C	5
		13 ^{O}C	5
		14 ^{O}C	5
		15 ^{O}C	5
		16 ^{O}C	5
		17 ^{O}C	5
		18 ^{O}C	5
		19 ^{O}C	5
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		28 ^{O}C	5
		29 ^{O}C	5
		30 ^{O}C	5
		31 ^{O}C	5
		32 ^{O}C	5
		33 ^{O}C	4
		34 ^{O}C	3
		35 ^{O}C	3
		36 ^{O}C	2
		37 ^{O}C +	1
REFLECTANCE	40	0	1
		1	1
		2	1
		3	1
		4	1
		5	2
		6	3
		7	4
		8	5
		12	5
SLOPE	15	0 – 5	1
		5 –10	2
		10 –15	3
		15 – 20	4
		20 +	5

Table 2-3. Factors for the Habitat Suitability Model for Sperm Whales

PARAMETER	RANKING (IN PERCENT)	VALUE	INFLUENCE
WATER DEPTH	33	0 – 100 M	3
		100 – 200 M	4
		200 – 300 M	4
		300 – 400 M	4
		400 – 500 M	4
		500 – 600 M	4
		600 – 700 M	4
		700 – 800 M	5
		800 – 900 M	5
		900 – 1000 M	5
		1,000 – 1,100 M	5
		1,100 – 1,200 M	5
		1,200 – 1,300 M	4
		1,300 – 1,400 M	4
		1,400 – 1,500 M	4
		1,500 – 1,600 M	4
		1,600 – 1,700 M	4
		1,700 – 1,800 M	4
		1,800 – 1,900 M	4
		1,900 – 2,000 M	4
		2,000 – 2,100 M	3
		2,100 – 2,200 M	3
		2,200 – 2,300 M	3
		2,300 – 2,400 M	3
		2,400 – 2,500 M	2
		2,500 – 3,200M	2
SEA SURFACE HEIGHT	34	-50 – -40 CM	5
		-40 – -30 CM	5
		-30 – -20 CM	5
		-20 – -10 CM	4
		-10 – 0 CM	4
		0-10 CM	3
		10 – 20 CM	2
		20 – 30 CM	1
		30 – 40 CM	1
		40 + CM	1
REFLECTANCE	33	0	1
		1	1
		2	1
		3	1
		4	1
		5	2
		6	3
		7	4
		8	5
		12	5

m = meters; cm = centimeters

2.6 STATISTICAL ANALYSIS AND VALIDATION

The structure of the model was statistically examined and validated through analysis of variance (ANOVA). ANOVA provides the researcher with a statistical tool that measures differences in the means among two or more groups. To conduct the statistical analysis, sighting data were used from GulfCet II for March through May.

The latitude and longitude of the sightings were plotted in GIS and the associated habitat suitability measure—the model run (MR) value—as well as the oceanographic and environmental parameters were obtained for each sighting of a bottlenose dolphin and sperm whale. This test used the combined spring values for the MR output for each sighting. The dependent variable to test the model parameters is the MR. The independent variables include the oceanographic and environmental data used for the bottlenose dolphin and for the sperm whale, respectively (Section 2.4). The alpha level (the predetermined acceptable level of error) was set at 0.05, or 5 percent. The null hypothesis for this ANOVA test is that the differences in the model results and the oceanographic sightings data are equal and that any difference is due to chance. To apply this statement to the test of the model, the null hypothesis would support that the variables used in the model do not need to be refined.

All statistical tests were performed in SAS version 6.1.2. Descriptive statistics were obtained using the Data Analysis Tool in Microsoft Excel 2003.

3. RESULTS

3.1 BOTTLENOSE DOLPHIN MODEL

Table 3-1 provides the descriptive statistics for oceanographic data associated with the sightings of the bottlenose dolphin. The statistics for the spring model are also provided. Boxplots of the model results versus the chlorophyll and sea surface temperature (SST) are also included below (Figures 3-1 and 3-2). Figure 3-3 depicts the range of suitable habitat for bottlenose dolphin in the eastern Gulf on a scale from 1 (low) to 4 (high).

A significant statistical difference exists between the model results and the environmental parameters associated with the sightings data ($F_{4, 69} = 50.093$, $p = 0.0001$). Therefore, the null hypothesis is rejected. That is, the association between animal occurrence and oceanographic features was not due to chance.

The potential exists that the model should be improved. The r^2 value associated with the test of this model versus the environmental data is 0.7438. This value is the relative predictive power of the model and is measured on a scale from zero to one. The closer the r^2 value is to one, the greater the predictive potential. In simpler terms, the r^2 value for this model can be interpreted as: 74 percent of the variation in habitat suitability for bottlenose dolphins can be predicted using this model, which incorporates water depth, slope, chlorophyll, and SST.

Table 3-1. Descriptive Statistics for Oceanographic Data and for the Bottlenose Dolphin Spatial Model

	N	MEAN	MEDIAN	STANDARD DEVIATION	STANDARD ERROR
GROUP SIZE	80	11.76	6.00	20.24	2.26
SEA SURFACE TEMPERATURE (SST)	80	23.34	24.00	7.20	0.80
WATER DEPTH	74	346.82	262.40	332.95	38.70
SLOPE	74	0.49	0.33	0.58	0.07
SPRING PERCENT CHLOROPHYLL	74	0.08	0.00	0.40	0.05
SPRING SST	74	23.49	23.50	0.91	0.11
SPRING MODEL RESULTS	74	2.86	3.00	0.48	0.06

N = number of animals

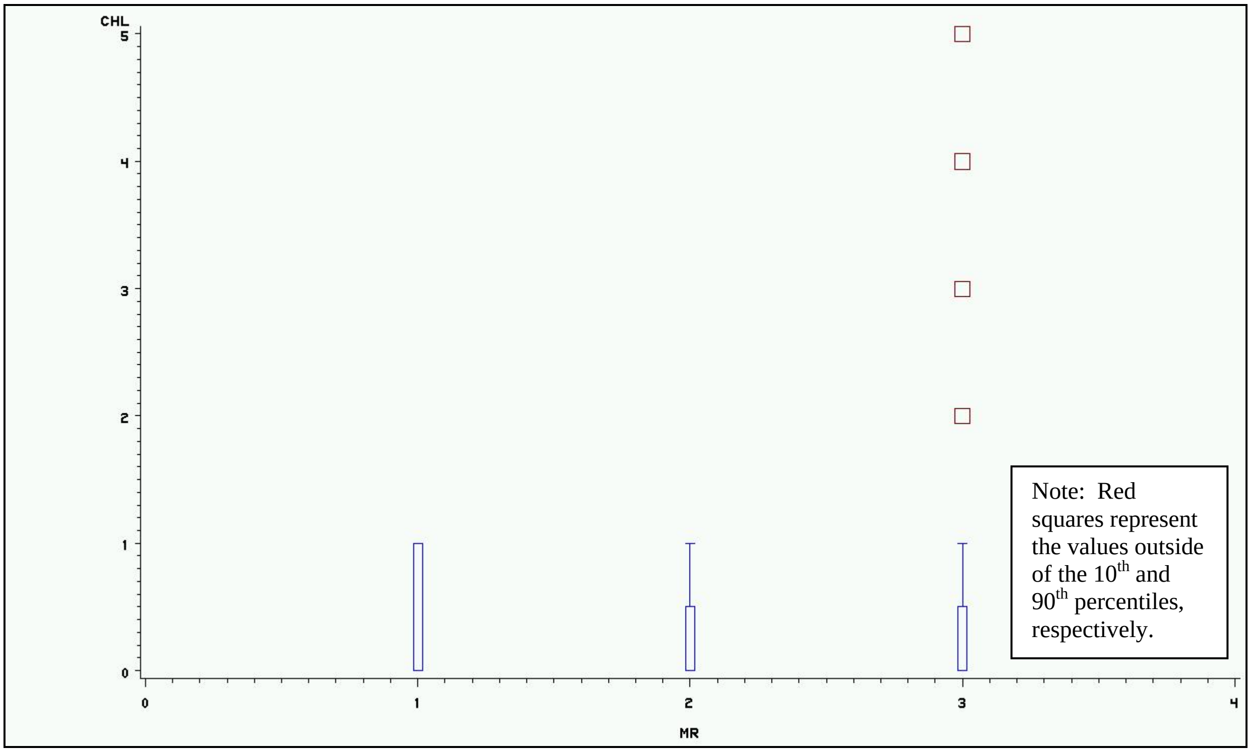

Figure 3-1. Boxplot Representing the Chlorophyll Data Based on Model Results for Bottlenose Dolphins

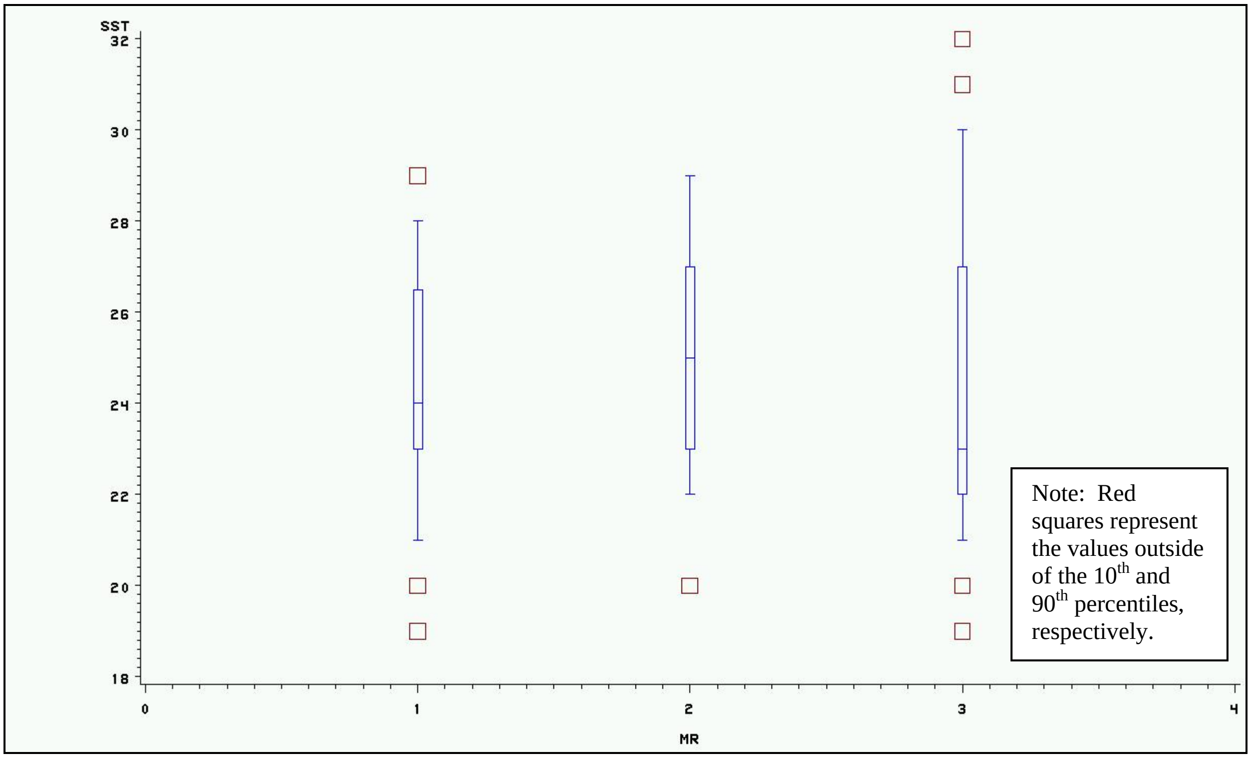

Figure 3-2. Boxplots for SST Based on Bottlenose Dolphin Model Results

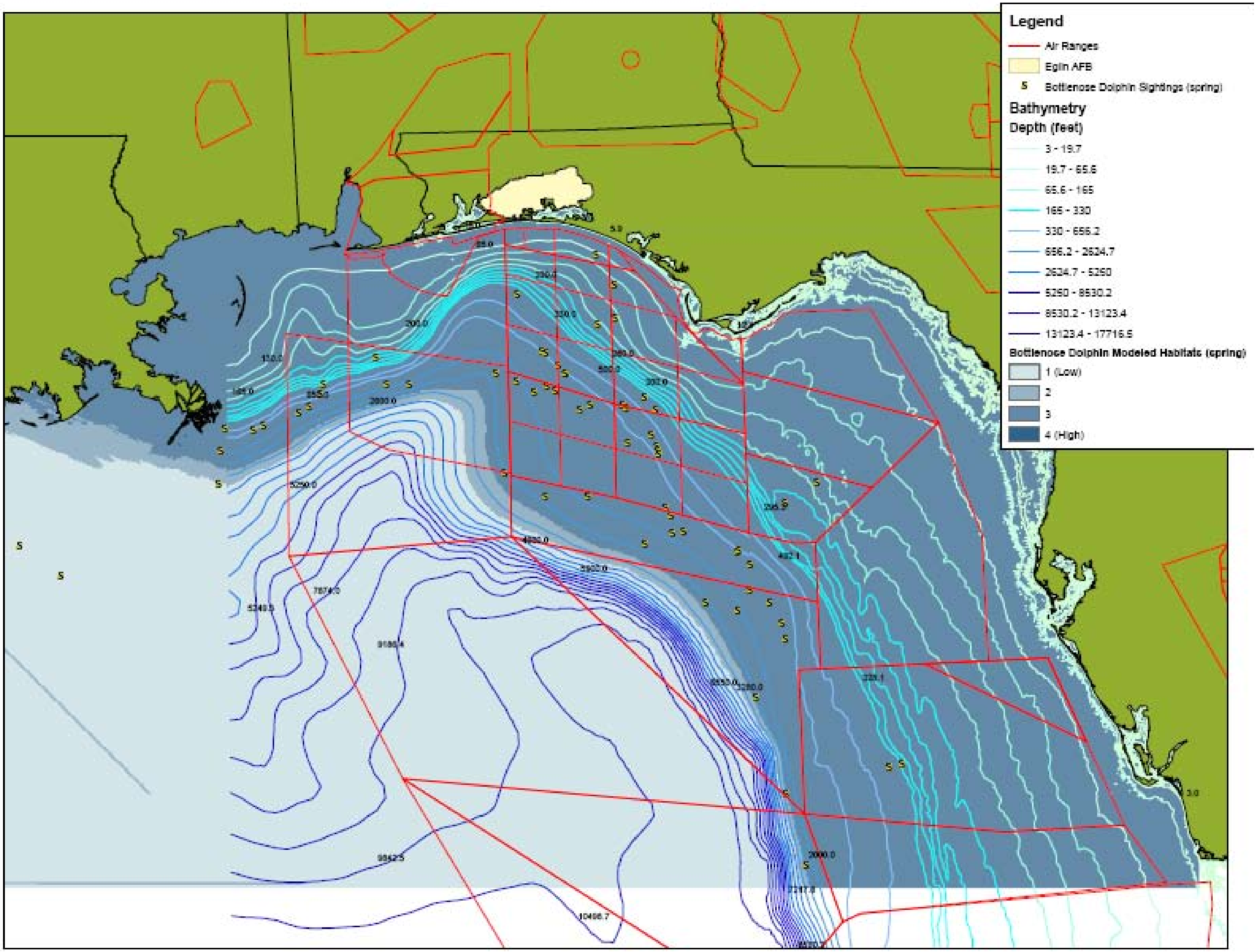

Figure 3-3. Habitat Suitability Model Results for Bottlenose Dolphins in the Eastern Gulf

3.2 SPERM WHALE MODEL

Table 3-2 provides the descriptive statistics for model parameters based on sightings data from GulfCet II as well as for the model of sperm whales. Boxplots of the model results versus the chlorophyll and SST are provided in Figures 3-4 and 3-5. Figure 3-6 shows the range of suitable habitat, with 1 at low suitability and 3 at high suitability, for sperm whales in the Gulf.

Table 3-2. Descriptive Statistics for Oceanographic Data and for the Sperm Whale Model

	N	**MEAN**	**MEDIAN**	**STANDARD DEVIATION**	**STANDARD ERROR**
GROUP SIZE	36	1.97	1.00	1.50	0.25
SEA SURFACE TEMPERATURE (SST)	36	24.53	27.00	7.72	1.29
WATER DEPTH	33	1,671.80	1,359.30	742.09	129.18
SPRING PERCENT CHLOROPHYLL	33	0.00	0.00	0.00	0.00
SPRING SEA SURFACE HEIGHT	36	3.47	3.46	5.16	0.86
SPRING MODEL RESULTS	33	2.70	3.00	0.47	0.08

N = number of animals

A significant statistical variation existed between the model results and the environmental parameters associated with the sightings data ($F_{3, 29}$ = 23.32; p = 0.0001). Therefore, the null hypothesis is rejected. The r^2 value for the model of sperm whale habitat versus the three parameters is 0.7070. Thus, 70 percent of the variation in the habitat suitability for sperm whales can be predicted using this model.

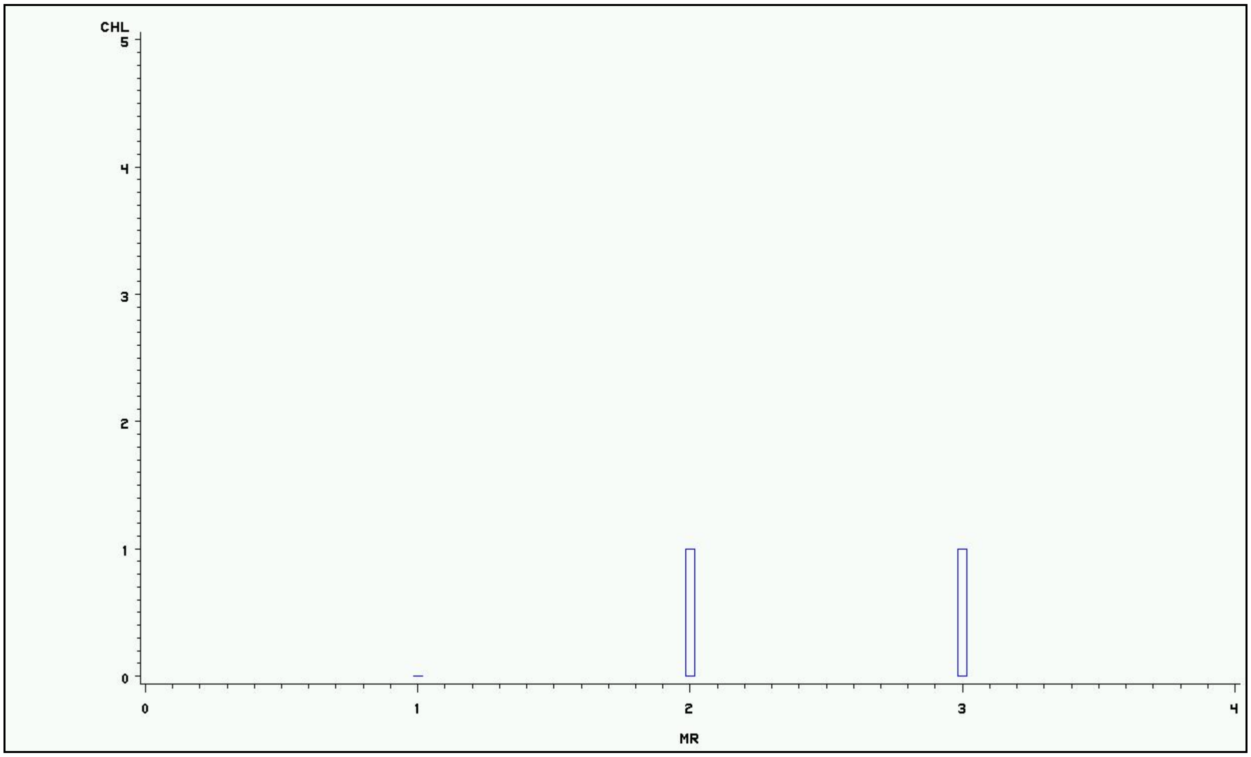

Figure 3-4. Boxplots for Chlorophyll Data Based on Sperm Whale Habitat Modeling

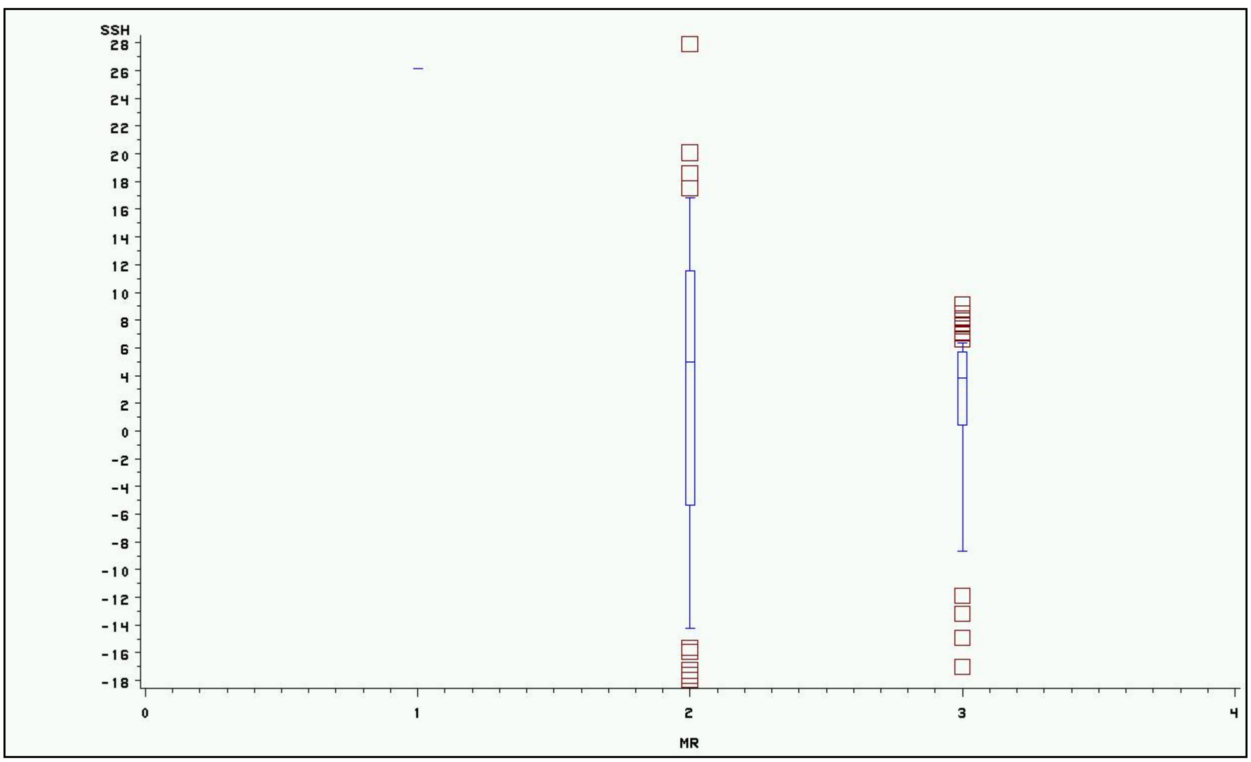

Figure 3-5. Boxplots for SST Based on Bottlenose Dolphin Model Results

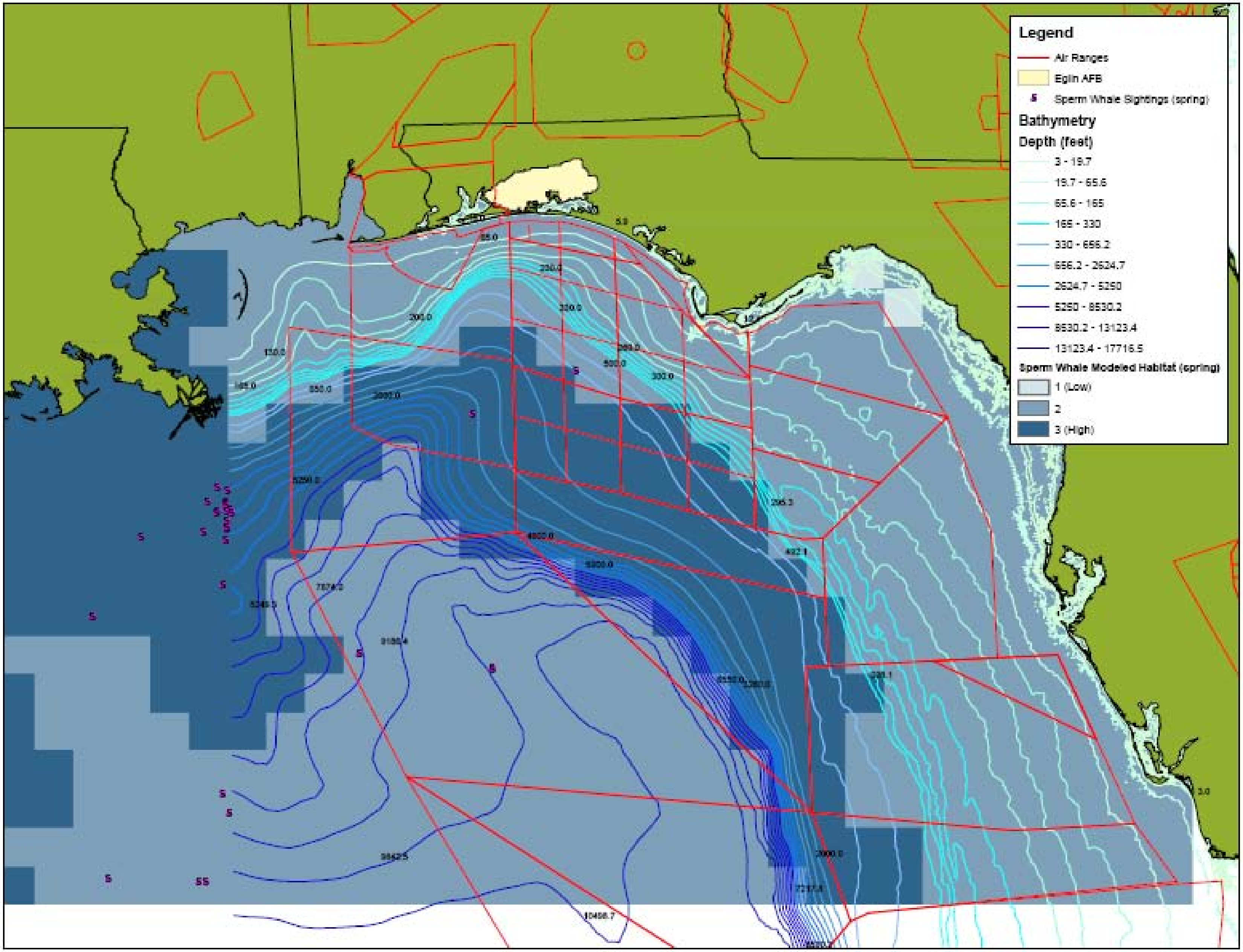

Figure 3-6. Suitability of Habitat in the Eastern Gulf for Sperm Whales Based on Model Results

4. CONCLUSIONS AND RECOMMENDATIONS

4.1 CONCLUSIONS

Spatially, the model shows that in spring, bottlenose dolphin occurrence is strongly related to water depth. Sightings are most likely to occur in waters from the coastline to beyond the 2,000-foot isobath line. Of the 86 sightings recorded by during the GulfCet II spring cruise, only three animals were observed in the low (1) area (Figure 3-3) when sightings were plotted over model results. All other spring sightings were made in the medium-high to high (3 to 4) areas.

This same trend, although not as pronounced, was also observed for sperm whales. Only six sightings correspond with the modeled low (1) suitable habitat (Figure 3-6); all other sightings occurred in the high (3) suitable habitat. The trends are within the range that would be expected based on the current knowledge of the biology and ecology of these species.

The conclusion can be drawn that more than 70 percent of the variability in habitat suitability can be explained by the model developed for bottlenose dolphins and sperm whales. However, although the r^2 value may approach an acceptable level, limitations inherent to the analysis exist that restrict the predictive power of the model. The statistical tests were conducted for an entire season based on resource limitations including time and available data. This analysis, therefore, grouped all seasons from March through May together. The distribution of marine mammals is dependent on prey species. It has been suggested that prey, and in turn marine mammal, distribution is dynamic and driven by changing environmental conditions. Researchers have recommended that models be conducted on a weekly, if not daily, time frame (Redfern et al., in press). Thus, the grouping of all data into one season reduces the predictive power of the habitat indices and also impacts the subsequent statistical tests. In addition, the data set used to analyze the model is limited to about 80 bottlenose dolphin and 40 sperm whale sightings. Compared with the amount of oceanographic and environmental data available to build the model, the amount of sighting data to validate the spatial tools are limited.

The results of the statistical tests performed on this model indicate that, while the spatial tools can explain a high percentage of the variability in habitat suitability, the model would benefit from refinement. Generally, an r^2 value at 0.90 or less may benefit from either a refinement in technique or the inclusion of additional explanatory variables (Ramsey and Shafer, 1997). An r^2 value of 0.75 or higher may in some situations be acceptable for field biology (Davis, 2001). Taking the r^2 value and this latter threshold into consideration, the bottlenose dolphin model would require minimal to no changes, while the sperm whale model would require modifications. However, limitations exist in the sole use of r^2 values to examine the fit of a model. Although the r^2 statistic can be used to determine the predictive capacity of a model, some statisticians recommend that additional statistics be used to test models. The other recommended analysis tools include goodness-of-fit and correlation tests, as well as probabilities.

4.2 RECOMMENDATIONS AND FUTURE RESEARCH

The results of this pilot program have successfully demonstrated that the methods we have formulated to date to develop MAZs in the Gulf for two species can effectively predict areas of high concentrations of particular marine mammals over a broad region. The initial effort, completed within less than six months from start to finish, has provided results equivalent to, perhaps even higher than, the level that we anticipated. Where acceptable limits for r-squared values range anywhere between 50 percent (social science) and 90 percent (laboratory), the r-squared values of our tests based on the environmental parameters that we used in the spatial model fell at the mid-point of this range. In fact, the models came to within 1 percent and 5 percent of a biometrically acceptable limit (or r-squared = 0.75). Furthermore, the r-squared values were only between 16 and 20 percentage points below the level set by statisticians. These statistician-based thresholds are generally only conducive to laboratory (ideal or perfect-world) settings.

The statistics on which we have reported from this project are based on the outcome of the first models developed for bottlenose dolphins and sperm whales in the Gulf. Our spatial analyst tools were never upgraded nor fine-tuned prior to this report of these initial findings. Thus, we provide evidence that our cooperative interdisciplinary approach was successfully planned to achieve success in this preliminary portion of the program.

We must now take additional steps forward to compel the Department of Defense, Eglin AFB in particular, towards the development and implementation of this effective mitigation tool. These models, once complete, would improve the military's ability to plan and execute realistic training and testing more quickly by identifying in near real-time appropriate areas in which to conduct military missions. First and foremost, the models that we have developed to date need to be refined through the re-examination of the parameters used within the spatial analysis tools. The weighting and valuation process used the best available science that we could identify and obtain within the time frame of this study. Realizing that the models, although close to acceptable limits, could be refined, we should conduct a longer and more thorough search of the available literature on habitat modeling and oceanographic influence on marine mammals in the Gulf. This additional investigation would allow us to scrutinize and refine, as needed, the system that we used. Additional variables should be investigated and the variables that we used re-evaluated to ensure: 1) that other important oceanographic features were not omitted from the bottlenose dolphin and sperm whale models and 2) that the weighting and valuation process was applied in the most effective manner and that this strategy does not need to be updated.

Second, we need to examine additional statistical tests to validate the models that we populated in this pilot program. As we alluded to earlier in the report, methods beyond r-squared values should be incorporated to assess the predictive capability of the models. Goodness-of-fit, correlation, and probability tests would help us to more extensively explore the validity of the habitat suitability models. These statistical methods would also demonstrate additional support for the tools.

Thirdly, our work would benefit from the incorporation of a new field study or a partnership with other research on marine protected species. Limited data were available in the Gulf to validate the results of the bottlenose dolphin and sperm whale models; the dataset that we used was restricted to spring, based on our assumptions and requirements. Therefore, the sightings data could not be divided into weeks or even into months. Currently, if we separated our data on a monthly basis, we would not have the statistical power to conduct the tests. The collection of additional information would help us to examine and execute the modeling process not only on a seasonal basis but also on a monthly and, perhaps in the future, even a weekly capability. For example, through new and/or additional data collection, the GulfCet II data would be supplemented with information that would increase the statistical power of our tests and that would allow for greater confidence in the models. Furthermore, collection of additional data would also allow the team to validate the model on a monthly basis initially and, hopefully in the future, down to a weekly basis. We would examine the capability to partner with researchers conducting federally funded marine projects in the Gulf to supplement our data. Such a partnership would allow us to collect the data that we need and to work cooperatively with other organizations and agencies to reduce any inherent duplicative processes within the research field. We recognize that the greater the amount of data gathered in a uniform, systematic manner, the greater our capability to validate and, where needed, to refine the results from our preliminary work.

Finally, we find it imperative that we extend our modeling effort to other species that have the potential to be impacted by military operations in the eastern Gulf. Eighteen marine mammal species and five sea turtle species regularly occur in the Gulf. Ten more marine mammal species have been recorded here. Of the marine mammal species, eight are protected by the ESA. The number of species coupled with the increasing number of military missions in the Gulf heightens the probability for interactions to occur between protected species and DoD activities. The increasing public interest in and regulatory agency concern towards potential underwater impacts to marine species has recently played a significant role in the consultation process. As described previously, these consultations are required of federal agencies conducting activities that potentially affect protected species. Military missions have recently faced scheduling problems in upwards of two years based on this process as a result of these concerns. The models that we created, which to date can explain up to 74 percent of the variability in habitat suitability, could be applied to direct missions seasonally and geographically away from high concentrations of protected species. Therefore, these spatial tools, once refined and implemented, would allow for near real-time planning that has the potential to expedite missions and to enhance the aforementioned consultation processes. The implementation of these models to the EGTTR benefits not only the U.S. Air Force but also the other branches that test and train in and above these waters, including the U.S. Navy and the U.S. Marine Corps. Additionally, new methods and technologies that mitigate impacts to marine species are embraced by the federal agencies charged with their protection. Therefore, because mitigation techniques are a key component to consultation processes and because these measures would enhance conservation requirements in near-real time assessments, these spatial tools would expedite the work of the resource agencies evaluating military activities. Ultimately, we foresee that these tools would result in faster compliance processes that would allow all branches of the U.S. military to efficiently and adequately prepare troops to fight and win wars.

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