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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 through Habitat Suitability Modeling in the Eglin Gulf Test and Training Range

A Review of the Literature and Results of Interviews with Active Researchers

Introduction

Department of Defense (DoD) Water Ranges, such as the Eglin Gulf Test and Training Range (EGTTR), are critical assets in support of weapons systems testing and training. The EGTTR encompasses more than 124,000 square miles in the Gulf of Mexico and supports thousands of Air Force test and training flights annually. In addition, many Navy and Marine Corps activities occur in waters encompassed by the EGTTR. DoD activities in the marine environment are increasingly confronted with environmental scrutiny and compliance challenges. Regulatory agencies and environmental organizations have generally advocated a more stringent interpretation of environmental laws in recent years, and have placed an emphasis on the effects of underwater sounds produced by human activities. This has led to impacts on military test and training activities in terms of increased cost and delays. For example, AFSOC gunnery test missions in the EGTTR were suspended for 3 years (1996 - 1998) due to underwater noise concerns, and consultation with NOAA Fisheries is still ongoing regarding these missions. Often, potential impacts to marine species are assessed based on a presumed random and uniform distribution throughout the range. However, a growing body of evidence points to the fact 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. Pertinent ocean surface features are readily observed through satellite images.

Eglin AFB proposes to develop the capability to identify mission avoidance zones (MAZ) in the EGTTR based on real-time ocean conditions and features that are likely indicators of marine species presence. The first phase will be collaboration with marine species researchers to identify such indicators. The proposed indicators will then be validated by combining existing animal sighting data with historic ocean satellite data in order to statistically test for correlation. A positive correlation between a species and particular environmental conditions, with an appropriate level of statistical confidence, would allow species presence to be predicted. This report represents the first phase of the project, which entails a review of the pertinent literature and collaboration with researchers.

Review of the Literature

Habitat suitability modeling (HSM) is a technique that began as a tool for exploring terrestrial species-habitat interactions. However, this technique is being more widely used and further developed to identify habitat types and test hypotheses for marine species. HSM has been recently used to predict potential distributions of marine species. Modeling can determine areas where a species is most likely to occur, through evaluation of the physical conditions of the marine environment used by that species. An important element of conservation biology includes mapping and analyzing marine habitats in order to predict marine mammal distribution. Marine habitat mapping can be used to assess habitat changes due to natural and anthropogenic impacts, to monitor and protect important marine habitats, to design and locate marine reserves and aquaculture projects, and to determine species distributions and stock assessments (Baxter and Shortis, 2002). Environmental managers can use modeling for endangered species management, re-introduction of species, population viability analysis, and for ecosystem restoration (Hirzel *et al.*, 2004).

Habitat characteristics and environmental factors that have been used in models include depth, substrate type, sea surface temperature, 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. Data collected on habitats can then be used in multivariate models to define habitat suitability and to predict species distributions (Baxter and Shortis, 2002).

Modeling Approaches

Non-statistical, statistical, and individual behavioral modeling approaches can be used in marine habitat modeling. Non-statistical modeling approaches identify habitat and distributions based on observation and literature reviews. This method is simple, quick, and intuitive; however, results may be biased due to the method of data collection. The most common approach employs models that test the statistical association between distribution and surrounding environmental variables. This modeling approach shows gradients within potential habitat and distribution ranges. Additionally, this method can explore and test hypotheses on ecological relationships that occur between marine mammals and their environment. However, data input and computations are intensive, and the data often violate statistical assumptions. Individual behavioral modeling approaches examine the characteristics/behaviors of individuals and their movement across the environment. This method is beneficial because it can simulate movement patterns of marine mammals. Individual behavioral modeling can also explore and test ecological relationships. Challenges associated with this technique include intensive data input/computations and philosophical difficulties (i.e. simplifying complex organisms' behaviors) (Hamazaki, 2004).

Statistical modeling approaches can be further divided into the following categories: density, habitat, hypothesis testing, and Bayesian stochastic. Density modeling uses environmental variables to model spatial/temporal distributions. Techniques include generalized linear models (GLMs), generalized additive models (GAMs), and logistic models. Less emphasis is placed on ecological interpretations, and no definition of the habitat is needed in these models. Habitat modeling examines ecological organization units/habitat in association with marine mammal distributions. This approach requires an understanding of the ecological relationship between marine mammals and features of their habitat. The hypothesis testing approach examines the cause-and-effect of ecological relationships between the environment and marine mammals. This approach requires that researchers formulate a testable hypothesis by collecting data. Additionally, less emphasis is placed on model prediction using this approach. Bayesian modeling uses Bayesian statistics to model distributions based on current and/or historical data observations and environmental conditions. Bayesian statistics can be used in any of the other modeling approaches. This approach requires intensive data input and computations and has philosophical difficulties associated with it (Hamazaki, 2004).

Geographic Information Systems (GIS) provides many capabilities that are useful for distribution and habitat modeling. Areas that GIS proves to be useful include data management, data processing, dynamic mapping, data exploration and visualization, hypothesis testing, and modeling predictions. GIS can be used to process spatially referenced two-dimensional (2-D) data such as slope, distance and area. However, it does not have handling capabilities for three-dimensional (3-D) and four- dimensional (4-D) data sets that are typically associated with oceanographic features, such as latitude, longitude, depth, and time. These 3-D and 4-D data sets can be reduce to conform to the 2-D capabilities of GIS, but the reduction must be based on oceanographic or ecological grounds because habitat studies require an understanding of the variability of spatial and temporal scales in the environment. Biased survey data is often a challenge in using GIS to analyze survey data. This challenge is typically overcome by using raster grids, which requires survey effort to ensure a reasonable representation of relative abundance. Although GIS provides some statistical tools for analysis, alternative tools can be incorporated to improve GIS analysis capabilities. For example, Matlab, ID, PV-Wave and NetCDF, can be used in all phases of research to replicate GIS functionality (Baumgartner, 2001).

Past Modeling Projects

A recent project conducted in the Faroe-Shetland Channel analyzed dolphin distributions and environmental variables (Hastie et al, 2005). A GAM was applied to passive acoustic survey data to determine the relationship. Data collected in 2001 was used to create models. Then, the data was cross-validated to test the predictive power. During each stage of the model building, predictions were calculated and tested against 2002 data. Results of the models suggested that the most significant influences on the probability of acoustically detecting dolphins during 2001 were the level of noise, and the time of day as well as the month, the water depth, and the surface temperature. Models were also successful in predicting dolphin distribution in 2002. However, some variables that explained within-year patterns of dolphin distribution in 2001 resulted in poor predictions of distributions between years. Overall, water depth seemed to have the greatest influence on dolphin occurrence in the region (Hastie *et al*., 2005).

The models provided important new information on the relationship between environmental determinants and oceanic dolphin habitat in the northeast Atlantic. The models also provide a valuable tool in addressing concerns about potential impacts from anthropogenic activities. The results of the modeling suggest that the relationships between environmental factors and dolphin distributions are non-linear. GAMs provide a flexible framework to identify predictive variables in habitat models without the constraints of using assumptions about underlying relationships. Therefore, using other methods of analysis that rely on those assumptions may not detect or may misinterpret the relationships between environmental determinants and dolphin distribution (Hastie *et al*., 2005).

Another study investigated whether environmental factors can explain/predict the presence and seasonal distribution of dolphins along the Dorset coast (Sykes, 2002). Researchers collected data on salinity, turbidity, sea surface temperature, and chlorophyll *a*. Additionally, the researchers obtained historical datasets to supplement the collected data. These datasets included salinity, sea surface temperature, chlorophyll *a*, and fish catch. The frequency of dolphin sightings was significantly correlated with seasonal and yearly catches of certain types of prey. The presence and seasonal distribution of bottlenose dolphins along the Dorset coast was most significantly influenced by prey availability. Sykes (2002) concluded that conservation and management efforts can be greatly improved by understanding the use(s) of dolphins' preferred habitats, and the motivation(s) for using such habitats.

Tynan *et al*. (2005) conducted a study in the North California Current System which examined the associations between cetacean distribution, oceanographic features, and bioacoustics backscatter. The researchers conducted line-transect surveys of cetaceans, coupled with multidisciplinary surveys of ocean and ecosystem structures. Hydrographic and ecological variables were compared with cetacean presence/absence patterns. These variables included sea surface salinity, sea surface temperature, thermocline depth, halocline depth, chlorophyll maximum, and acoustic backscatter. In addition to these variables, the group also collected information on the distance to the center of the equatorward jet and the distance to the shoreward edge of the upwelling front. Measured oceanographic data explained approximately 94 percent of the variation in cetacean distribution. Upwelling and circulation correlated well with the cetacean survey data. Cetacean distributions were shown to be most strongly influenced by flow-topography interaction (Tynan *et al*., 2005).

Ongoing Modeling Projects

The Strategic Environmental Research and Development Program (SERDP) is currently funding researchers to develop models that the Navy will use to predict marine mammal habitat and distribution along the U.S. Atlantic coast. The models use static and dynamic environmental variables. These variables include sea floor depth, sea surface temperature, and chlorophyll concentration as well as distance to shore, distance to shelf, distance to sea surface temperature front, and distance to chlorophyll concentration fronts. The project uses spatially explicit statistical techniques and modeling approaches to determine how physical habitat features influence the distribution of marine mammals. These approaches include GLMs, GAMs, classification trees, environmental envelope models, canonical correspondence, and Bayesian models. The goals of the project are to allow the Navy to 1) implement improved mitigation procedures to protect marine mammals without compromising training exercises, 2) access archived oceanographic and cetacean distribution data, 3) update climate data sets with real-time information, and 4) analyze marine mammal distribution across multiple forecasting time and space scales. This project was initiated in May 2004 and is expected to be completed in 2007. (Read, ND; Read, 2004; and Read *et al*., 2004)

Other researchers on a partner SERDP project are developing a tool that the Navy will use to estimate seasonal cetacean density. These researchers will build spatially explicit models to predict cetacean density in the North Pacific with the use of a geospatial habitat model. The model will be built using survey and environmental data from 1986 to 2002, which are based on geographically fixed factors and environmental variables. The objective of this project is to better guide the location of Navy activities by improving the ability to estimate cetacean density in smaller geographic areas. The habitat modeling will use GAMs to define cetacean-habitat relationships based on past surveys. Habitat modeling can be used to interpolate cetacean density between transect lines and sightings of each species. The predictive power of the models across seasons will be tested using aerial surveys. The Navy will make more accurate estimations of cetacean abundance within operational areas from the results of this project. The tool will also help to improve the quality of environmental assessments in the analysis of potential impacts to cetaceans from military activities. The anticipated completion date for this project is 2008 (Barlow, 2004).

Gulf of Mexico Cetacean Habitat Studies

The distribution, abundance, and habitat preferences of five species of cetaceans in the northern Gulf of Mexico were determined from surveys conducted during the spring seasons from 1992 to 1994 (Baumgartner *et al*., 2001). Cetacean habitat distributions were investigated using oceanic variables including depth (digital bathymetry), depth gradient (digital bathymetry), surface temperature (thermosalinograph), surface temperature standard deviation (infrared satellite imagery), surface chlorophyll concentration (surface samples), and epipelagic zooplankton biomass (oblique bongo tows). Additionally, researchers used the depth of the 15°C isotherm (CTD and XBT casts). These variables were chosen for the study either because they represent specific oceanographic and/or physiographic features or conditions, or because some cetacean distributions have been previously associated with these features in the Gulf of Mexico.

Results showed that bottlenose dolphins occurred most frequently in two regions - the shallow continental shelf and the area just seaward of the shelf break. Furthermore, more frequent sightings were made in areas with high surface temperature variability within these regions. This occurrence suggests that an association exists between bottlenose dolphins and ocean fronts. Risso’s dolphins occurred more frequently in steeper sections of the upper continental shelf. Pygmy sperm whales and dwarf sperm whales occurred in the same region as Risso’s dolphins, but in areas with higher zooplankton biomass. Finally, the pantropical spotted dolphin and sperm whale occurred over the lower continental slope and deep Gulf. However, the occurrence of sperm whales was much less frequent in regions with a deep 15°C isotherm, indicating avoidance of anticyclonic oceanographic features.

Another study that defined cetacean habitats in the northern oceanic Gulf of Mexico used visual surveys and hydrographic collections from ships (Davis *et al.*, 2002). Data on cetacean distribution, zooplankton biomass, and hydrographic features were collected simultaneously during the study. Hydrographic data collection included features such as dynamic sea surface height anomaly, mixed layer depth, 15°C depth, sea surface temperature, ocean depth, and salinity. Zooplankton biomass was estimated using net and acoustic sampling. Results show cetaceans were abundant along the continental slope in areas of cyclonic circulation and high chlorophyll levels. Additionally, a significant correlation was found between high plankton biomass and cetacean distribution. However, this correlation may vary seasonally and inter-annually.

Challenges in Habitat Modeling

Habitat suitability modeling is in the early stages of development for marine applications. Therefore, challenges and uncertainties exist in both the data used and in the models themselves. Challenges in data availability include the sufficiency of marine mammal and environmental predictor data (i.e. availability versus ecological relationships, indirect versus direct data sources, and scales between species and environmental data). Biased survey data presents another challenge in data source uncertainties. Surveys most often take place in areas where marine mammals are known to occur, and statistical models and relationships are limited to the range of sampled data. Species identification must also be correct. Modeling challenges include under-fitting and over-fitting, scaling, and prediction uncertainties, as well as differences among various modeling techniques and approaches (Hamazaki, 2004).

Uncertainties may arise in predictor variables, which make models imprecise and difficult to interpret. Variables such as sea surface temperature, fronts, chlorophyll, depth, slope, salinity, and currents are easily obtained, but they relate indirectly to distribution and they are unable to explain or predict the nature of the relationship. Other variables, such as prey abundance, prey type, and interspecific and intraspecific interactions, are direct and able to show ecological and theoretical relationships. However, these data are usually more difficult to obtain (Hamazaki, 2004).

Literature Review Summary

Several modeling approaches exist that can be utilized to model marine mammal habitats and distributions. Each approach has advantages and disadvantages. Therefore, approaches should be chosen based on the objectives of the project and the available data. Non-statistical approaches are better suited for studies that lack sufficient data. Either way, uncertainties associated with the data and with the model should be considered (Hamazaki, 2004). Environmental models have predictive abilities more often when using simple variables. Creating more accurate models requires the collection of more extensive data sets and the use of cross-validation methods. School size models, higher trophic level environmental data, and examination of scale issues are some ways in which models can be improved (Forney, 2004).

Interviews with Habitat Suitability Modeling Researchers

Personal communication with Dr. Andrew J. Read, Duke University Nicholas School of the Environmental and Earth Sciences' Marine Laboratory, revealed that a group of nineteen authors (Redfern *et al*., in press) have conducted a comprehensive literature review on cetacean habitat modeling. Dr. Read, in a telephone interview, explained that the paper provides an overview of the approaches and foundations for modeling, as well as the associated benefits and disadvantages to each. A summary of the findings of this paper, along with discussion of the development of HSM and MAZs for the EGTTR, is given in the following paragraphs.

The purpose of this HSM project is to develop a predictive model that Department of Defense mission planners can use to avoid or minimize potential impacts to marine mammals in the EGTTR. This purpose will lay the foundation for selection of appropriate techniques and of the use of the model in general. Predictive models require a greater amount of certainty on the variables influencing cetacean distribution as compared with other modeling purposes. Additionally, larger data sets are needed to build and validate the models with which planners will rely on their predictive capabilities. These characteristics will likely drive the initial selection of species to be analyzed. Species such as bottlenose dolphin, Atlantic spotted dolphin, sperm whales, and other commonly studied species in the Gulf may be best suited for preliminary predictive analysis.

Redfern *et al*. (in press) conclude that the distribution of dolphins and whales correlates to their role as predators in the food web. Therefore, predictive cetacean assessments and models should take into account the variables that influence prey of the cetaceans that they model. Frequently, modeling is conducted on cetaceans at the mesoscale level. This level examines the interaction of cetaceans with a variety of habitat and water column features. Overall, variables chosen should be based on the established understanding of factors that influence cetacean distribution.

Cetacean and Habitat Data

Data on cetaceans and their environment can be obtained using a variety of methods. This team will likely rely on the most readily available type for cetaceans in the Gulf, which is shipboard and aerial survey data. However, data from these surveys are just one of the many types of collection methods. Other techniques include tagging, acoustics, focal follows and photo-identification, and opportunistic collections. Furthermore, habitat data may be obtained from *in situ* collections (typically from vessels), from satellite derived data, and from numerical circulation models. It is anticipated that satellite data will be used, which would allow decisions to be made using "real-time" data. The time resolution will need to be investigated in relation to the time lag associated with satellite data, which is typically constrained to daily updates (Redfern et al, in press).

Models

Redfern *et al*. (in press) address three general types of models used 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 some of the most commonly used types. GAMs are probably the most commonly used type of regression model. Finally, classification and regression trees are anticipated to be widely used for cetacean habitat suitability modeling in the future. Although no papers that use these trees have yet been published, they can be used to make discrete predictions of relationships between species and their habitat characteristics.

The choice of statistical test will be the primary driver for the type of model used. Typical methods include least squares, maximum likelihood, and Bayesian statistics. To determine the best fit, researchers have used *t*-tests to keep only the significant variables, have used separate tests to assess, fit, and estimate parameter values, and have conducted sequential selection (Redfern *et al*., in press).

Deviance, Akaike's Information Criterion (AIC), Bayes factor, and Bayesian Information Criterion (BIC) can be used to evaluate the models (Redfern *et al*., in press). Each has their own constraints. For example, AIC and Bayes factor can only be used to compare among models. BIC selects simpler models. Penalties increase with an increasing number of variables. All models contain some type of uncertainty, which arises from inherent errors with sampling design and data collection, ecological processes, and model selection. Therefore, uncertainty should be assessed. Four primary methods are used to examine uncertainty in cetacean modeling. They include the use of confidence intervals, bootstrapping and jackknifing techniques, and model averaging. Bootstrapping and jackknifing requires the power and time to conduct iterations of data. Model averaging is generally used to determine best estimates of parameters or model predictions common to all models (Redfern *et al*., in press).

Finally, the model must be evaluated to assess its predictive accuracy and to determine whether the selected model can be used to answer particular questions with respect to ecology or management goals. Statistical tests can be used to evaluate the predictive accuracy and include goodness of fit tests, correlation tests, and probabilities. In the assessment of the latter, the researchers acknowledge that less quantitative information and more qualitative information may be used. Additionally, it is important to evaluate the inherent model error and assess the costs that it creates (Redfern *et al*., in press).

Conclusion

Each of the aforementioned steps and components of model design are critical areas for the HSM team to explore. The Redfern *et al*. summary paper provides the group with a foundation to evaluate and formulate the most appropriate techniques and steps required to provide a MAZ modeling tool to mission planners conducting tests in the EGTTR.

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