SUMMER HABITAT PREFERENCE OF BELUGA WHALES (*DELPHINAPTERUS LEUCAS*) IN COOK INLET, ALASKA

by

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Date: May 2, 2005

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Masters project submitted in partial fulfillment of the
requirements for the Master of Environmental Management degree in
the Nicholas School of the Environment and Earth Sciences of
Duke University

2005

ABSTRACT

The Cook Inlet beluga whale (*Delphinapterus leucas*) lives in a confined body of water and therefore is susceptible to physical, ecological, and anthropogenic stresses. With approximately 360 animals remaining in the population and ongoing efforts to increase development in the area, it is important to identify habitat preferences of these whales. Advances in technology and statistical methods allow the integration of Geographic Information Systems (GIS) and environmental science to understand species distribution and habitat preferences. The present study aims to identify summer habitat areas using GIS applications. In predicting beluga habitat, twelve years of on-effort survey data were analyzed using logistic regression and Classification and Regression Tree (CART) to determine the importance of 1) bathymetry, 2) mudflats, and 3) flow accumulation values. Results suggest that mudflats are a significant predictor of beluga whale distribution during the summer months. While the importance of flow accumulation varied between the two models, belugas preferred higher flow accumulation inlets overall. The logistic regression and CART models produced similar habitat regions in terms of calculated area and relative location to beluga sightings. The habitat models developed in this study will aid biologists and wildlife managers in meeting conservation goals and making future legislative decisions to prevent the further decline of Cook Inlet belugas.

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INTRODUCTION

A circumpolar species, belugas (*Delphinapterus leucas*) live primarily in waters off northwestern United States, Canada, Russia, Norway, and Greenland (Smith et al. 1990). In Alaskan waters alone are five known summer populations of beluga whales: Cook Inlet, Beaufort Sea, Bristol Bay, Eastern Bering Sea, and Eastern Chukchi Sea (Hazard 1988; Seaman et al. 1988; Frost & Lowry 1990; O'Corry-Crowe et al. 1997). Variation in mitochondrial DNA suggests that the Cook Inlet population is the most genetically distinct (O'Corry-Crowe et al. 1997). Cook Inlet belugas are also geographically isolated from the other four populations by the Alaskan Peninsula (Laider et al. 2000). Due to their small population size, in combination with genetic and geographic segregation, these animals are exceptionally vulnerable to natural and anthropogenic environmental degradation (Moore et al. 2000).

The tendency of belugas to return to shallow, estuarine locations during summer months has contributed to their overexploitation by hunting. The Cook Inlet beluga population declined from the 1970's to the mid 1990's (Rugh et al. 2000) and decreased approximately 50% from 1994-1998 (Hobbs et al. 2000). The annual mean harvest during this period was 21% of the estimated 1998 abundance (Hobbs et al. 2000). As a result, subsistence hunting was regulated in 1998 and an official moratorium was enacted on May 21, 1999 (Pub. L No. 106-31, section 3022, 113 Stat. 57, 100). Exceptions to the moratorium were permitted only through a co-management agreement between the National Marine Fisheries Service (NMFS) and the Alaskan Native Organization (ANO). Now, with only 366 individuals remaining in the Cook Inlet population (Rugh et al. 2005), the stock is listed as "depleted" under the MMPA (65 FR 34590-3497).

Unlike other beluga populations in Alaska, the Cook Inlet stock is restricted to a confined body of water and, therefore, may be more susceptible to physical, ecological and anthropogenic perturbations (Moore et al. 2000). As a result, it is imperative to understand factors important to beluga habitat to prevent the further decline of this already depleted population. Fortunately, the availability of survey data and accessibility of many environmental parameters create ideal conditions for habitat modeling. Studying the environmental variables significant to beluga habitat at the southernmost extent of its range may help to provide important management strategies for the future recovery of the stock.

Although the underlying mechanism of beluga distribution is not well understood, several studies report their occupancy in coastal mudflat areas and in proximity to river inlets during the summer (Calkins 1989; Withrow et al. 1993; Smith & Martin 1994; Moore et al. 2000; Rugh et al. 2000). Belugas reportedly seek large prey aggregations at these locations, so physical and oceanographic features may indirectly affect their assemblages by influencing prey distributions (Huntington 2000; Moore et al. 2000). Several studies have suggested a variety of factors that could influence the distribution of Cook Inlet beluga whales, but none have quantified the influence of physical, ecological or anthropogenic factors on the distribution of this population.

Accurately describing and understanding what determines the distribution of organisms is a fundamental problem in ecology with important conservation and management implications. Habitat models help to elucidate which environmental variables influence the probability of a species' occurrence. Due to the three-dimensional nature of the marine environment, analysis of the habitat requirements of marine vertebrates has lagged behind that of terrestrial species. Many studies have identified the role of environmental features such as land cover, elevation, ambient temperature, and water locality on the distribution of terrestrial taxa (Sieg & Becker 1990; Stoms et al. 1993; Iverson & Prasad 1998; Carroll et al. 1999; Fleishman et al. 2001; Compton et al. 2002). Only recently, however, have efforts been made to examine these relationships in the marine realm (Moses & Finn 1997; Davis et al. 1998; Waring et al. 2001; Baumgartner et al. 2003; Torres et al. 2003). Advances in geographical information systems (GIS) and statistical analysis now make it possible to predict the geographic distribution of species from environmental features (Guisan & Zimmermann 2000; Pearce & Ferrier 2000; Thuiller et al. 2003; Johnson & Omland 2004; Redfern et al. 2005).

The present study examines the ecological relationships between Cook Inlet beluga whales and several environmental variables. I used data collected during twelve years of aerial surveys (1993-2004) plus logistic regression and Classification and Regression Tree (CART) models to predict beluga habitat. Parameters used in the model were based on the availability of environmental data and previous qualitative research on beluga distribution. Since data on prey availability have not been collected in a manner suitable for beluga research, flow accumulation was used as a mechanism to distinguish among tributaries entering Cook Inlet. Using flow accumulation as a proxy for prey distribution is supported by research in which the distribution of prey species was found to vary according to the rate of river runoff and consequent rate of primary production (Kleinenberg et al. 1964; Roberts et al. 1999). The specific goal of this study is to determine the quantitative relationship between the observed distribution of Cook Inlet beluga whales and (1) bathymetry, (2) mudflats, and (3) flow accumulation values. Results from this analysis will aid resource managers in making important conservation decisions that may affect potential beluga habitat in Cook Inlet.

METHODS

Study Area

Located in south-central Alaska, Cook Inlet is a semi-enclosed tidal estuary stretching approximately 370 km from Kamishak Bay to the northeastern reaches of Turnagain and Knik Arm (Moore et al. 2000). The inlet covers approximately 20,000 km^2 with 1350 km of shoreline (Rugh et al. 2000). The study area includes all waters north of a line stretching from Cape Douglas to Elizabeth Island (Fig. 1). Large tidal ranges and broad tidal flats result in currents up to 6.2 m/s and significant changes in shoreline (Moore et al. 2000). Tidal height variations at Anchorage are the second most extreme in the world; at nine meters they are exceeded only by those that occur in eastern Canada's Bay of Fundy (Mulherin et al. 2001).

The Cook Inlet watershed covers over 121,000 km^2 of south-central Alaska. Melting snow and ice from mount McKinley, the Chugach Mountains, and the Aleutian Range drain into rivers which feed the waters of Cook Inlet (Cook Inlet Keeper 2005). This watershed drains over 101,000 km^2 of land (the approximate size of Virginia) and supports 400,000 residents within its boundaries (Cook Inlet Keeper 2005).

Survey Protocol

Using methods described by Rugh et al. (2004), researchers from the National Marine Mammal Laboratory (NMML) conducted aerial surveys each summer from 1993 to 2004. Survey duration ranged between four and nine days with as many as 16 total flights per year. All surveys were conducted between June 2nd and July 29th. The aircraft used for most surveys was a five-passenger Aero Commander 680 FLP with twin-engines, high wings, and ten-hour flying capability. Each of three observers sat at a designated bubble window–two on the left and one on the right. An intercom system provided communication between visually-isolated observers, the data recorder, and the pilot (Rugh et al. 2004). After 1993, a selective listening control device was installed to aurally isolate observers.

The recorder used the aircraft's global positioning system (GPS), interfaced with a laptop computer, to record the location of each sighting. Additional data entries included: location (at least once per minute), group size, cloud cover, sea-state (Beaufort scale), glare (left and right), visibility (left and right), and effort status (on or off). The observers categorized visibility into five subjective classes (excellent, good, fair, poor, useless) based on sea-state, glare, available light, and weather conditions. Regardless of group size, the location of each sighting functioned as the response variable in later statistical analysis.

In most years, researchers conducted both coastal surveys and off-shore transects. Coastal surveys were conducted approximately 1.4 km offshore and 244 m above sea level (Moore & DeMaster 2000). This standard altitude and coastal search area maximized opportunities for finding belugas in shallow, near-shore waters while causing minimal disturbance to the whales.

Offshore transects were flown in a sawtooth pattern about 30 m apart from Anchorage to the southern limits of Cook Inlet between Cape Douglas and Elizabeth Island. As in the coastal surveys, observers searched primarily 1.4 km on either side of the aircraft, although good viewing conditions permitted searches well beyond that distance (Moore & DeMaster 2000).

GIS Analysis

TRACKLINES AND SIGHTINGS DATA

All data classified "off-effort" (i.e. time segments not solely dedicated to the searching of beluga groups) or coincident with "poor" or "useless" weather were excluded from the analyses. Using the animal movement extension in Hawth's Analysis tools (Beyer 2004), I created individual tracklines from the GPS point locations recorded during the aerial surveys. All tracklines were buffered 1.4 km on each side (the maximum sighting distance) and the then merged to create a single polygon layer assuming a World Geodetic System 1984 (WGS84) horizontal datum.

Off-effort sighting data and observations made outside the study area boundaries were not included in analyses. Each of the 226 sightings considered in this study represented the "best" estimated location for a group of animals. An additional 226 random positions were generated within the buffered on-effort polygon layer using Hawth's random point generator tool for Arc 8.3 (Buyer 2004). The 452 points (sightings and random point locations) were used in statistical analyses to distinguish potential beluga habitat from non-habitat.

BATHYMETRY

A GIS bathymetry coverage was not available for the Cook Inlet area, so I obtained soundings data from two sources: (1) NOAA Electronic Navigation Charts (ENC 2004) and (2) the National Ocean Service (NOS) hydrographic data base (NOSHDB) (USGS 2005). Because each dataset contained soundings excluded from the other, the two datasets were combined; latitude, longitude and depth values were extracted and appended in an ACCESS 2002 database. The tidal datum for all soundings were referenced in Mean Lower Low Water (MLLW). I imported the combined file into Arc/Info (version 8.3) and used the Inverse Distance Weighted (IDW) method to interpolate bathymetry for the study area. Complete gridded bathymetry was in 100 x 100 m cell resolution, with depth measured in meters. To compensate for values greater than 0 (above water), we added 9 m to the entire grid to achieve depths at maximum tidal height. North American Datum 1983 (NAD83) was used to define the bathymetry coverage.

MUDFLATS

A polygon shapefile depicting areas less than < 10 m deep and mudflat regions was obtained from NOAA, Alaska Fisheries Science Center (AFSC). Mudflat areas were extracted and the resulting layer was defined using a NAD83 horizontal datum. I used the spatial analyst extension in Arc/Info (version 8.3) to create a distance to mudflat grid with a 100 x 100 m cell resolution.

INLET LOCATIONS AND FLOW ACCUMMULATION

I obtained hydrographic Arc/Info coverages for the Cook Inlet watershed from two sources: (1) the United States Geological Survey (USGS 2004) seamless data distribution system and (2) the Alaskan Department of Fish and Game Fish Distribution Database (FDD 2005). Next, I used a 2-arcsecond (1:63,360) Digital Elevation Model (DEM) (USGS 2004) for Alaska, in combination with the spatial hydrographic data, to create a point coverage depicting the locations where each river and stream entered Cook Inlet. Before continuing with the analysis, all data from the USGS were converted from a NAD27 to a NAD83 horizontal datum to maintain consistency across spatial data layers.

Keeping the original cell size of the Alaska DEM, I used the FLOWDIRECTION grid command in Arc/Info (version 8.3) to create a grid of flow direction from each cell to its steepest down-slope neighbor. Accumulated flow to each cell was then calculated by summing the weight for all cells that flow into each down-slope cell using the FLOWACCUMULATION grid function. To compensate for spatial inaccuracies between the flow accumulation grid and hydrographic coverages, I buffered all inlet points 150 m and used the REGIONGROUP grid command to create a unique identity for each inlet buffer. I then used the ZONALMAX grid command to assign the highest flow accumulation value within the 150 m buffer to each inlet. Based on the spread of flow accumulation values, I classified inlet points as high, medium, or low flow inlets (Appendix 1). Inlets with flow accumulation values less than the first quartile were categorized as low flow accumulation inlets; values between the first and third quartiles were classified as medium flow accumulation inlets; and those streams with values greater than the third quartile were classified as high flow accumulation inlets (Appendix 2). Using the spatial analyst extension, I created three 100 x 100 m cell resolution distance grids: distance, in meters, from high flow accumulation, medium flow accumulation, and low flow accumulation inlets.

SPATIAL SAMPLING

Once all environmental variables were prepared and projected into Universal Transverse Mercator (UTM), I used the SAMPLE grid command to determine the five corresponding environmental values (BATHY, DISTMUD, DISTLOW, DISTMED, DISTHIGH) for each beluga sighting and random point location. The resulting database table was imported into S-plus (version 6.2) for statistical analysis.

Statistical Analysis

MULTIPLE LOGISTIC REGRESSION

Due to the binary nature (presence = 1; absence = 0) of the response variable, I first used multiple logistic regression as a method of statistical analysis. This type of regression analysis describes the presence or absence of belugas as a function of several other environmental or explanatory variables. The predictions of logistic regression are in terms of probability of beluga presence in a cell, given the cell's independence from other environmental variables. The form of the equation is

$$p = e^{(f)}/(1 + e^{(f)})$$

where $f = a_0+a_1x_1+a_2x_2 \ldots a_ix_i$, $x_1 \ldots x_i$ are the independent variables, $a_0 \ldots a_i$ are the regression coefficients and p is the probability of a beluga sighting within a cell. To assess the significance of several GIS-derived habitat variables (Table 1), I used automated stepwise model fitting with both backward and forward selection. Models were evaluated with the Akaike Information Criterion (AIC) which seeks to minimize variance and optimize the number of model parameters. The AIC procedure eliminates problems typically associated with multicollinearity despite the strength of environmental correlations (Thuller et al. 2003). In addition to AIC values, I used the Likelihood Ratio Test (LRT) to evaluate the adequacy of nested models. Variables included in the final equation were those that significantly improved prediction ($p < 0.05$) and fit of the logistic regression model.

I used the Receiver Operating Characteristic (ROC) curve to evaluate the predicting accuracy of the final model. ROC analysis originated from signal detection theory as a model of how well a receiver is able to detect a signal in the presence of noise. The ROC curve is a graphical method that represents the relation between the false positive fraction (1-specificity) and the true positive fraction (sensivity) for a range of thresholds. The dependent variable is either presence or absence, and the model predicts the threshold of a given variable at which a species is present (Legendre & Legendre 1998). The optimal threshold optimizes errors of omission verses errors of commission. Good model performance is characterized by a curve that maximizes sensitivity for low values of (1-specificity). The ROC library (Atkinson & Mahoney 2001) for S-plus (version 6.2) was used for ROC and AUC analysis of the model.

The area between the 45 degree line and the curve measures the ability of the model to correctly classify a species as present or absent (area under the curve: AUC) (Thuiller et al. 2003). The AUC value ranges from a value of .5, indicating no discrimination ability, to 1 for models with perfect discrimination capability (Pearce &

Ferrier 2000). Models with greater AUC values than .9 are considered very good because the sensitivity is high relative to the false positive rate (Swets 1988).

Results from the final logistic regression were mapped into geographic space using ArcGIS (version 8.3). I used the raster calculator tool embedded within the spatial analyst extension for ArcGIS (version 8.3) to enter the algebraic expression from the final regression model. All explanatory variables in the model were represented by GIS grids and were multiplied with the appropriate calculated parameter coefficient to form a visual representation of habitat suitability. Based on the calculated threshold value from the ROC curve analysis, I classified habitat probability as either beluga habitat or non-habitat areas. The continuity in grid cell size (100 x 100 m) allowed for simple habitat area calculations.

CLASSIFICATION AND REGRESSION TREE

Classification and Regression Tree (CART) analysis can be used to decipher the relationship between species distribution and environmental parameters (Iverson & Prasad 1998). In this case, I developed a CART model to describe beluga habitat from point observations. CART makes none of the assumptions of linearity, normality, homogeneity of variance or independence of the data (Venables & Ripley 1997). In addition, CART accounts for spatial autocorrelation among predictors and produces robust results in terms of how species are related to the environment. An algorithm based on a single best predictor variable is used to resolve relationships within a complex dataset (Torres 2003). As a result, a binary tree is produced from the recursive partitioning of data into increasingly homogenous subgroups. Each split in the tree is based on the maximum deviance in the response variable (Redfern et al. 2005). The tree ends with a set of terminal nodes representing final classifications. Without a rule to determine when to stop the binary partitioning, splitting will continue until terminal nodes contain only one data point. Therefore, I used a cross-validation technique to determine an appropriate stopping point–the highest prediction accuracy for an independent data set. The tree function in S-plus (version 6.2) was used to run the following model: beluga presence/absence as a function of BATHDEPTH, DISTMUD, DISTLOW, DISTMED, DISTHIGH (Table 1). Habitat area resulting from classification rules were mapped using the DOCELL grid command in Arc/Info (version 8.3) (Appendix 3).

RESULTS

Multiple Logistic Regression Model

As a first step in the model selection process I examined the full model including all measured environmental variables (Table 2). All interaction terms were also examined, but they were both insignificant and, due to the addition of unnecessary model complexity, excluded from the remainder of the analysis. Of the five environmental variables considered, neither BATHDEPTH ($p = 0.084$) nor DISTLOW ($p = 0.818$) contributed significantly to the fitted model. AIC values from automated stepwise model fitting were ranked for five models including the full model (Table 3). The model with parameters BATHDEPTH, DISTMUD, DISTMED, and DISTHIGH was the most parsimonious model. However, using the likelihood ratio test, I found weak evidence for an association between BATHDEPTH and beluga presence, after accounting for DISTMUD, DISTMED, and DISTHIGH ($p = 0.079$). These results suggest that the model selected as "best" by AIC is too rich for reliable parameter estimates, given the same sample size. Therefore, BATHDEPTH was dropped from the model, resulting in the following final model (ranked second by AIC):

$$\text{logit}(p) = 3.92 - 8.14\text{E-}04\text{DISTMUD} - 1.14\text{E-}04\text{DISTMED} - 3.82\text{E-}05\text{DISTHIGH}$$

where p is the probability of beluga detection. Model coefficients, standard errors, and significance values are reported in Table 4. Once mapped into geographic space, the final model provided a visual representation of habitat probability (Fig. 2). The median odds ratios (Table 4) indicate that every 100 meters of additional distance from mudflats results in an 8% decrease in the probability of finding a beluga; every 500 meters of additional distance from medium flow accumulation inlets results in a 6% decrease in the probability of finding a beluga; and that every 1000 meters of additional distance from high flow accumulation inlets results in a 4% decrease in the probability of finding a beluga. In other words, the probability of finding a beluga is significantly greater closer to mudflats, and medium and high flow accumulation inlets (Fig. 3).

The ROC curve (Fig. 4) indicates the proportion of sites correctly predicted to be a beluga site (sensitivity or true positive rate) and the proportion of sites incorrectly predicted to be a beluga site (1-specificity or false positive rate). There was a 0.69 probability threshold for the final model in which threshold values ≥ 0.69 were considered habitat and values < 0.69, non-habitat. Habitat area was mapped and calculated in Arc/Info (version 8.3) using the final model. For the Cook Inlet study area, there were approximately 232 km^2 of beluga habitat (Fig. 5).

I determined the model's ability to discriminate between beluga absence and presence by calculating the area under the ROC curve (AUC). A 0.92 AUC value indicated that the model correctly discriminated between beluga presence and absence based on the three selected environmental variables 92% of the time. In other words, if a pair of evaluation sites (beluga present vs. absent) is chosen at random, there is a 0.92 probability that the model will predict a higher likelihood of occurrence for the beluga present site than absent site.

Classification and Regression Tree Model

The CART input function (clade as a function of BATHDEPTH, DISTMUD, DISTLOW, DISTMED, and DISTHIGH) returned a tree with thirty terminal nodes. Using the cross-validation method, I pruned the tree to three nodes to avoid over-fitting the data. Using only DISTMUD and DISTMED, the CART correctly classified 88% of the samples as beluga sightings or random points (misclassification error = .12).

Terminal node 1, farther than 2.7 km from mudflats, was the only node to contain unmixed results. This node classified 162 non-beluga sites as random points. The remaining two terminal nodes contained mixed data (Table 5). Terminal node two, within 2.7 km of mudflats and less than 11.5 km form medium flow accumulation inlets, contained mixed results; of the 243 beluga sightings considered, 36 were misclassed as random points (misclassification error = .15). Within 2.7 km of mudflats and further than 11.5 km from medium flow accumulation inlets, terminal node three also contained mixed results. This node had the highest level of uncertainty with a misclassification error of 0.40.

Figure 6 displays the distribution of points in relation to the CART partitioning of the data and further supports the conclusion that both DISTMUD and DISTMED can be used to distinguish between beluga sighting and non-sighting locations. In fact, belugas were most commonly found within 2.7 km of mudflat areas and 11.5 km of medium flow accumulation inlets. Once mapped into GIS, the CART results translated into approximately 298 square kilometers of habitat area (Fig. 7).

DISCUSSION

The logistic regression and CART models both predicted a similar size and location of beluga habitat in Cook Inlet. Both models suggest that mudflats and flow accumulation are important environmental features in the distribution of this population. Belugas tend to prefer medium and high flow accumulation inlets, indicating a preference for larger river basins.

In contrast, low flow accumulation inlets and bathymetry were not significant predictors of beluga habitat in either of the two models. Due to the confined area of Cook Inlet, bathymetry may not have been variable enough to affect beluga distribution after accounting for distance from mudflats, and distance from medium and high flow accumulation inlets. However, bathymetry may be more important to beluga populations inhabiting open waters (i.e. Beaufort Sea, Eastern Chukchi Sea).

These conclusions agree with previous qualitative studies that report belugas near coastal mudflats and river inlets during the summer (Calkins 1989; Withrow et al. 1993; Smith & Martin 1994; Moore et al. 2000; Rugh et al. 2000). However, the occurrence of Cook Inlet belugas near mudflats, and medium and high flow accumulation inlets may be more directly related to biological parameters rather than physical environmental variables. For example, other studies suggest that belugas may be attracted to near-shore environments for reasons such as prey availability (Calkins 1989; Woodley & Gaskin 1996; Huntington 2000; Moore et al. 2000), breeding (Calkins 1989), calving (Sergeant & Brodie 1975; Calkins 1989) and molting (Calkins 1989; Smith et al. 1990, St. Aubin et al. 1990).

Even though the habitat predicted by logistic and CART modeling includes coastal areas extending the entire length of Cook Inlet, only 3% of the sightings were recorded south of the East and West Forelands (Fig. 1). Historically, belugas inhabited the northern and southern reaches of the inlet (Rugh et al. 2000). However, since NMFS began conducting aerial surveys in 1993, belugas have been primarily sighted along the northern perimeter (Rugh 2001). Past hunting pressures in combination with beluga preference for estuarine waters may explain the current distribution of whales in the core areas of their range.

While this study examined several environmental parameters, it would be useful to incorporate other physical variables such as sea surface temperature, precipitation, turbidity, tidal cycles and salinity into habitat models. Unfortunately, sea surface temperature, turbidity, and salinity data were not available for Cook Inlet. In the case of sea surface temperature, satellites were unable to register near-shore data during low tide due to the extensive tidal range and, therefore, could not be incorporated into the logistic regression or CART model.

In addition to environmental factors, accounting for biological and anthropogenic variables would further aid researchers in explaining the distribution of beluga whales.

Biological factors, such as prey distribution and availability would be helpful in determining whether beluga preferences for medium and high flow accumulation inlets are indeed a function of food availability. The specific diet of the Cook Inlet beluga is largely unknown, but fish are the dominant prey items in the stomachs of Bering and Chuckchi sea beluga populations during the summer (Seaman et al. 1982). It is likely that Cook Inlet belugas prey on fish species as well. The fish fauna in upper Cook Inlet include the spring-to-fall availability of eulachon (*Thaleichthys pacificus*), plus immigrating smolt and emigrating adults of five Pacific salmon species: Chinook (*Oncorhyncus ishawytscha*), Pink (*O. gorbuscha*), Coho (*O. kisutch*), Sockeye (*O. nerka*), and Chum (*O. keta*) (Moulton 1997; Moore et al. 2000). During the months of June and July, when the surveys were conducted, many of these anadromous fish species were present and often at their peak availability (Moore et al. 2000).

Incorporating measures of prey distribution, in general, and anadromous fish runs in particular, could offer greater predictive accuracy about the distribution of belugas. However, descriptions of fish abundance and distribution for the Cook Inlet area is generally lacking (D. Westerman, personal communication). Fish run data are currently biased toward commercial valuable fish stocks such as sockeye, while escapement data for other fish species are recorded only on an opportunistic basis. This trend of monitoring economically important fish species as well as the assorted, inconsistant data collection methods used to monitor fish runs (i.e. weir counts, sonar counts, ground surveys and aerial surveys) have led to unreliable data within and across years. To date, data on prey distribution have not been collected for the purpose of beluga or other marine mammal research.

Finally, the predictive power of these habitat models could be further increased by accounting for anthropogenic factors such as fishing, illegal harvest, oil and gas activity, military action, and transportation. Using variables as these can be difficult because of the amount of information needed to accurately model the effect of such anthropogenic factors. For example, in order to incorporate oil and gas activity in habitat models, researchers must account for the location and activities of individual oil rigs. Data on anthropogenic factors potentially influencing beluga distribution in Cook Inlet were not readily available, and consequently, were not included in this study.

When constructing habitat models, it is important to choose habitat measures based on what is known about the biology and behavior of the species. Models for other marine mammal populations have included variables such as sea surface temperature, tidal cycles, proximity to shore, distance from continental shelf, bathymetric slope, and temperature fronts (Davis et al. 1998; Hooker et al. 1999; Gregr & Trites 2001; Waring et al. 2001; Hamazaki 2002; Mendes et al. 2002; Baumgartner et al. 2003; Torres et al. 2003). The parameters included in any particular model are context specific; clearly many of these parameters would not be appropriate for modeling Cook Inlet beluga habitat.

The results from this study and others suggest that it is possible to use statistical modeling to predict cetacean habitat based on environmental parameters. Nevertheless, as with most modeling approaches, there are constraints. To predict cetacean habitat, predictor variables must be available for surveyed and unsurveyed regions. As found in this study, the lack of available data, such as prey distribution, hinders the power of habitat modeling.

The accuracy of sighting location poses another limitation to habitat modeling. Because belugas and other cetaceans commonly travel in large groups, it is difficult to determine the exact sighting location. Sightings recorded only a few meters from the actual location of the belugas may cause inaccurate associations with environmental variables and increase model error. Also, the effect of water depth on sighing probability was not taken into consideration because of the extreme tidal range in Cook Inlet. Likewise, the white coloration of adults and the grey appearance of juvenile belugas make sightings difficult in rough or highly turbid waters.

In addition to sighting uncertainty, it is important to acknowledge the limitations associated with creating and describing environmental variables using spatial software packages such as ArcGIS. Care needs to be taken in selecting the appropriate spatial resolution in order to accurately detect fine-scale differences in environmental parameters. The present study used a 100 m^2 gridded cell size to study the relationship between Cook Inlet belugas and their environment, but a wide range of spatial scales have been used in other studies. For example, Moses and Finn (1997) used 356 km^2 and 64 km^2 to predict right whale habitat based on environmental variables. Torres (2003) used a 500 m^2 cell size in the geospatial analysis of bottlenose dolphin distribution. Scale should be assessed on a study-by-study basis and chosen according to the question of interest. Inverse distance weighted and kriging are examples of several interpolation techniques available to refine spatial resolution in cases when only course scale data exist (Bolstad 2002).

Researchers should consider not only spatial scale but also the suite of statistical models available. In addition to the logistic regression and the CART model used in this study, several other mathematical approaches exist for habitat modeling. Similar studies have used clustering (Hamazaki 2002), canonical correspondence analysis (CCA) (Reilly & Fiedler 1994), non-metric multidimensional scaling analysis (NMDS) (Palacios 2003), generalized additive models (GAMs) (Forney 2000), and Mantel tests (Schick & Urban 2000) to determine the relationship between marine mammal species and environmental parameters. Each of the statistical approaches relies on different assumptions and is useful in different contexts. Therefore, the data should be examined thoroughly before choosing a model to predict species habitat.

This present study provides an example of how the interdisciplinary integration of geographic information systems, biology, physical earth sciences, and statistical modeling can reveal important aspects of the habitat requirements and of a cetacean species. The results of this project help to describe the present distribution of Cook Inlet belugas and will enable managing agencies to identify and protect areas of beluga whale habitat more effectively.

Table 1. Definitions of variables used in the development of habitat models.

Variable	*Definition*	*Abbreviation*
Bathymetric depth	Measurement of water depth in meters	BATHDEPTH
Distance from mudflats	Distance from mudflats, measured in meters	DISTMUD
Distance from river inlet	Distance from river inlets, measured in meters	DISTINLET
Distance from low flow accumulation rivers	Distance from low flow accumulation river inlets, measured in meters	DISTLOW
Distance from medium flow accumulation rivers	Distance from medium flow accumulation river inlets, measured in meters	DISTMED
Distance from high flow accumulation rivers	Distance from high flow accumulation river inlets, measured in meters	DISTHIGH

Table 2. Logistic regression for full model.

Variable	*Coefficient*	*SE*	*p*
Intercept	3.97	5.69E-01	<0.001
BATHDEPTH	4.50E-02	2.60E-02	0.084
DISTMUD	-6.03E-04	1.86E-04	0.001
DISTLOW	-4.19E-06	1.81E-05	0.818
DISTMED	-1.11E-04	3.29E-05	<0.001
DISTHIGH	-4.27E-05	1.63E-05	0.009

Table 3. Logistic regression models supported by AIC (n=452).

Model	*AIC*	*Intercept*	*BATHDEPTH*	*DISTMUD*	*DISTLOW*	*DISTMED*	*DISTHIGH*
DEPTH + DISTMUD + DISTMED + DISTHIGH	272.7	3.92	4.60E-02	-6.08E-04		-1.11E-04	-4.20E-05
DISTMUD + DISTMED + DISTHIGH	273.8	3.29		-8.14E-04		-1.15E-04	-3.82E-05
DEPTH + DISTMUD + DISTLOW + DISTMED + DISTHIGH	274.7	3.97	4.50E-02	-6.03E-04	-4.16E-04	-1.11E-04	-4.27E-05
DISTMUD + DISTLOW + DISTMED + DISTHIGH	275.7	3.38		-8.03E-04	-6.30E-06	-1.14E-04	-3.92E-05
DISTMUD + DISTMED	277.7	2.99		-8.37E-04		-1.47E-04	

Table 4. Logistic regression for final model.

					95% Confidence Interval	
Variable	*Coefficient*	*Odds ratio (median)*	*SE*	*p*	*Upper*	*Lower*
Intercept	3.92	-	3.50E-01	<0.001	4.60	3.23
DISTMUD	-8.14E-04	.92 (100 m)	1.57E-04	<0.001	-5.06E-04	-1.12E-03
DISTMED	-1.14E-04	.94 (500 m)	3.26E-05	<0.001	-5.01E-05	-1.78E-04
DISTHIGH	-3.82E-05	.96 (1000 m)	1.57E-05	0.015	-7.43E-06	-6.90E-05

Table 5. Classification of 452 sample location within the three terminal nodes created from CART analysis

	Terminal node 1	Terminal node 2	Terminal node 3
	Farther than 2.7 km from mudflats	Within 2.7 km from mudflats and less than 11.5 km from medium flow accumulation inlets	Within 2.7 km from mudflats and greater than 11.5 km from medium flow accumulation inlets
Number of beluga sightings	0	207	19
Number of random sightings	162	36	28
Total	162	243	47

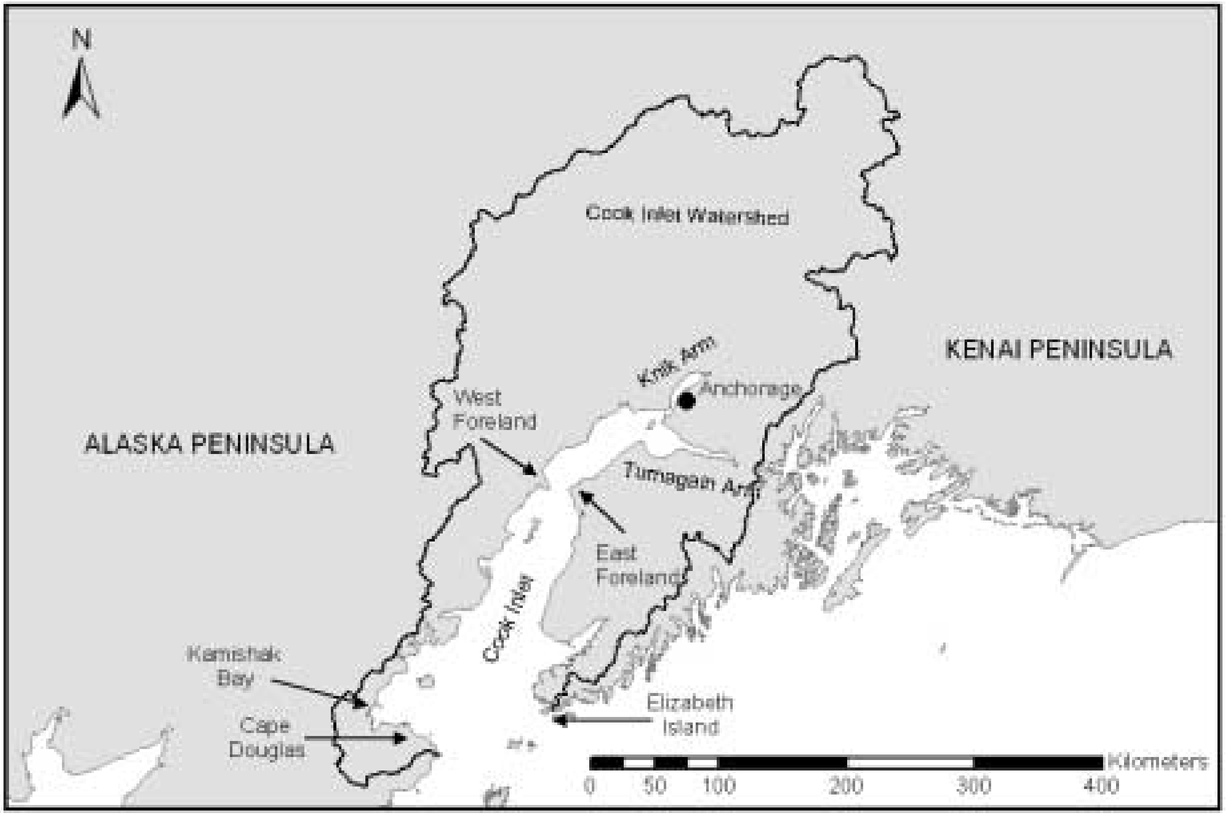

Figure 1: Cook Inlet study area.

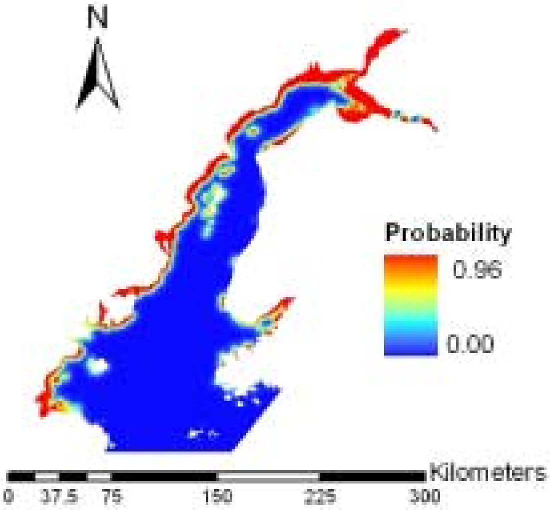

Figure 2: Habitat probability of the Cook Inlet beluga according to the logistic regression model

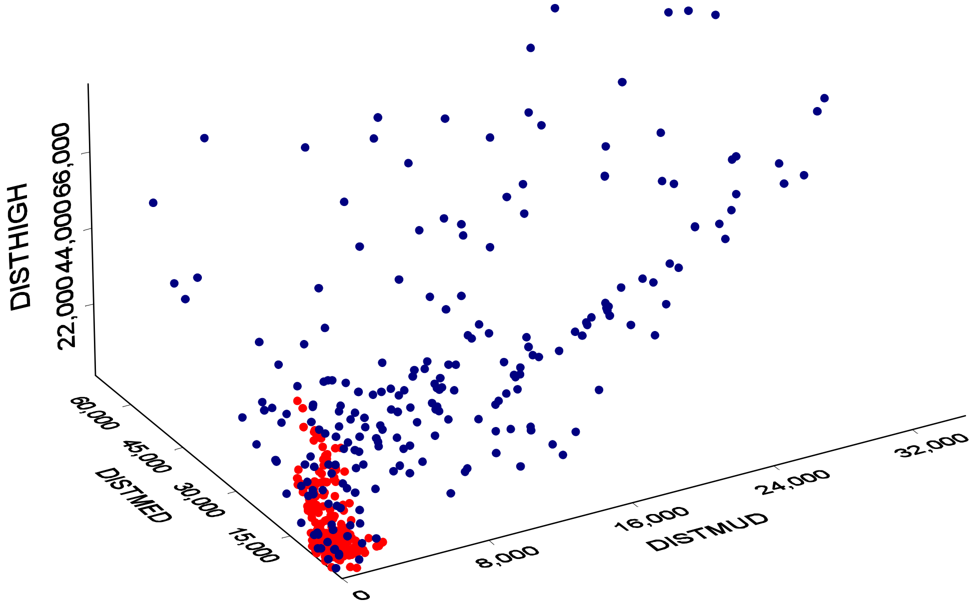

Figure 3. Comparison of beluga sightings (red) and random points (blue) relative to distance from mudflats and distance from medium and high flow accumulation inlets, in meters.

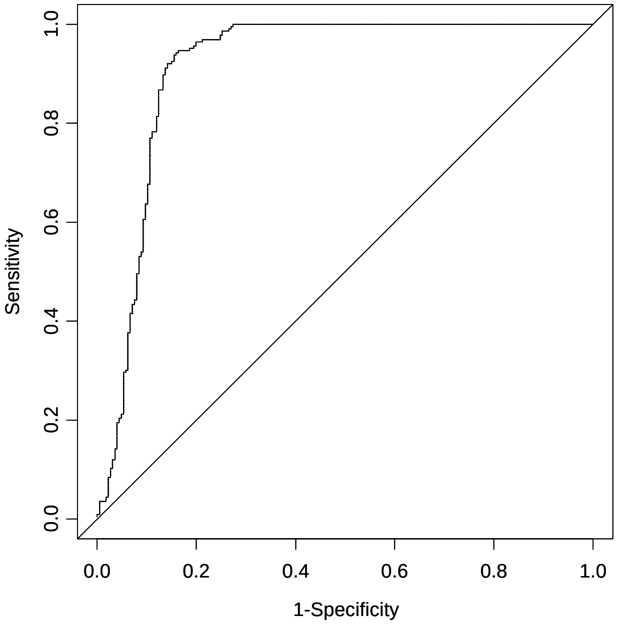

Figure 4. The Receiver Operator Characteristic (ROC) curve produced from the final logistic regression.

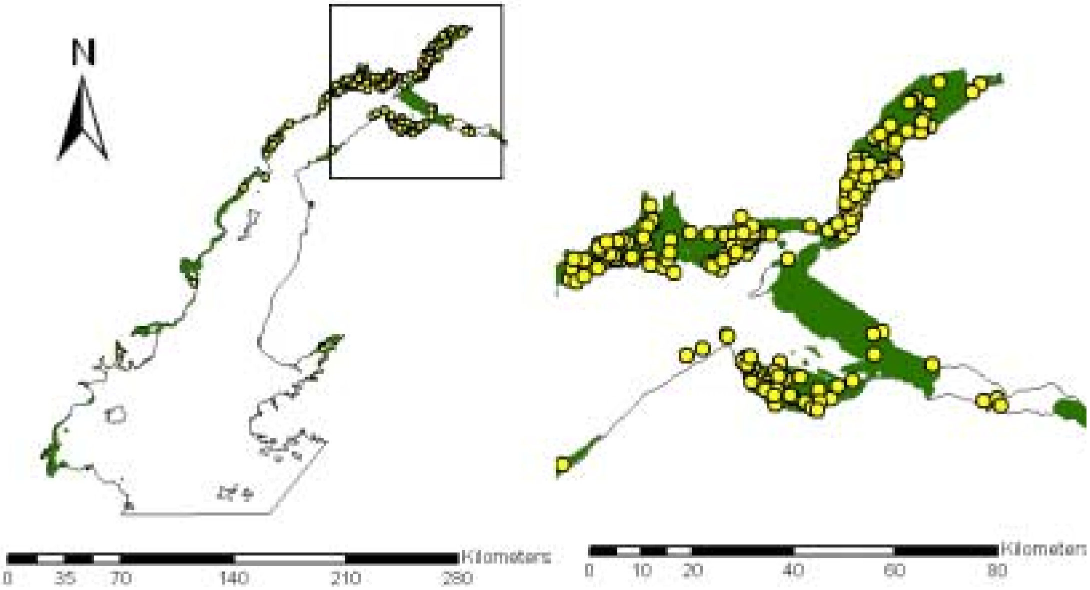

Figure 5. Habitat (green) predicted by the logistic regression model with beluga sightings shown in yellow.

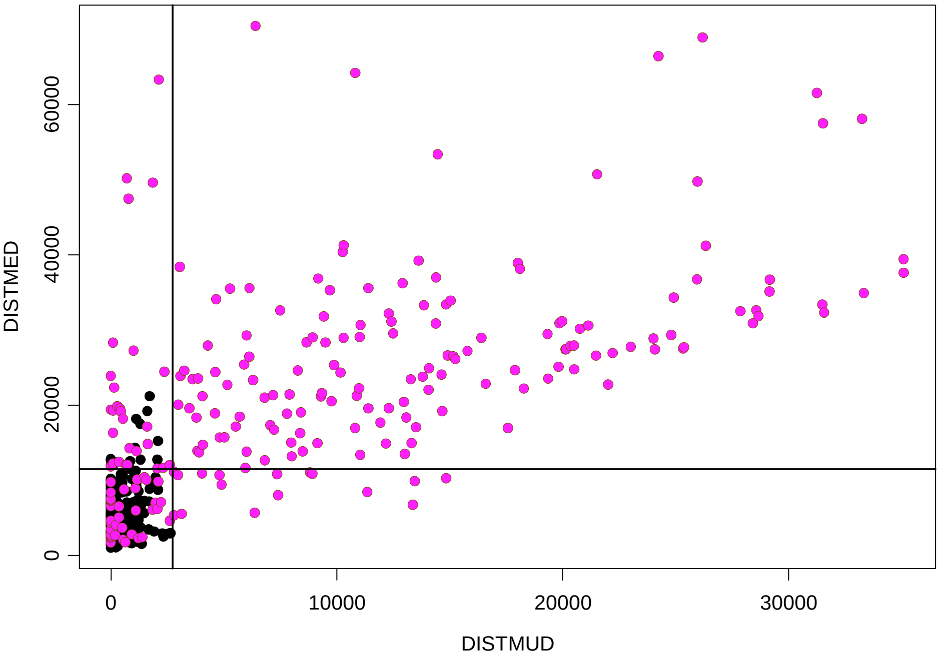

Figure 6. Distribution of beluga sighting (black) and non-sighting locations (magenta) relative to distance from mudflats and distance from medium flow accumulation inlets, in meters.

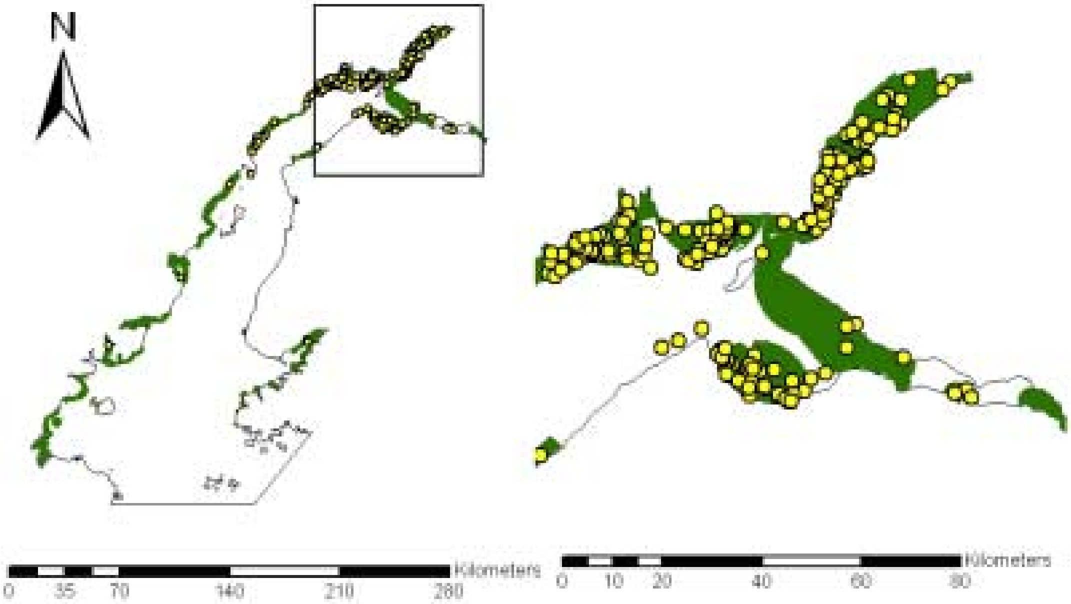

Figure 7. Habitat (green) predicted by the CART model with beluga sightings shown in yellow.

ACKNOWLEDGEMENTS

I would like to thank the numerous people that contributed to this project. First, I would like to thank my advisor, Dr. Andy Read for all his suggestions and advise on improving this project. Also, I would like to thank Jennifer Maresh and Joan Carris for reviewing and commenting on earlier drafts. I am grateful to Dr. Pat Halpin, Ben Best, and Eric Treml from Duke University and Janet Benson from the National Marine Mammal Laboratory (NMML) for their technical assistance and help with data interpretation. Bob Shavelson from Cook Inlet Keeper generously provided spatial data and always kept me up to date on current legislative developments.

I express my sincerest thanks to Rod Hobbs and Dave Rugh from NMML, for allowing me to use the data for my analyses. I am particularly indebted to Dave Rugh for his good humor and invaluable assistance in editing the survey data. Kim Shelden and Kristin Laidre provided constant support and enthusiasm along the way. Finally, I would like to send my appreciation to all those who made this study possible by assisting in the data collection during the 1993-2004 aerial surveys.

REFERENCES

Atkinson, B., and D. Mahoney. Mayo Foundation for Medical Education and Research. 2001. Roc library for Splus. Available from http://mayoresearch.mayo.edu/mayo/research/biostat/splusfunctions.cfm (accessed February 2005).

Baumgartner, M. F., T. V. N. Cole, P. J. Clapham, and B. R. Mate. 2003. North Atlantic right whale habitat in the lower Bay of Fundy and on the SW Scotian Shelf during 1999-2001. Marine Ecology Progress Series 264:137-154.

Beyer, H. L. 2004. Hawth's Analysis Tools for ArcGIS. Available from http://www.spatialecology.com/htools (accessed September 2004)

Bolstad, P. V. 2002. GIS Fundamentals: A first text on Geographic Information Systems. Eider Press, White Bear Lake.

Calkins, D. G. 1989. Status of belukha whales in Cook Inlet. Pages 109-112 in L. E. Jarvela and L. K. Thorsteinson, editors. Gulf of Alaska, Cook Inlet, and North Aleutian Basin information update meeting. Anchorage, AK, Feb. 7-8, 1989. Anchorage, AK: USDOC, NOAA, OCSEAP.

Carroll, C., W. J. Zielinski, and R. F. Noss. 1999. Using presence-absence data to build and test spatial habitat models for the fisher in the Klamath region, U.S.A. Conservation Biology 13:1344-1359.

Compton, B. W., J. M. Rhymer, and M. McCollough. 2002. Habitat selection by wood turtles (*Clemmys insculpta*): An application of paired logistic regression. Ecology 83:833-843.

Cook Inlet Keeper. 2005. About the Cook Inlet Watershed. Available from http://www.inletkeeper.org/abtwatershed.htm (accessed March 2005).

Davis, R. W., G. S. Fargion, N. May, T. D. Leming, M. Baumgartner, W. E. Evans, L. J. Hansen, and K. Mullin. 1998. Physical habitat of cetaceans along the continental slope in the north-central and western Gulf of Mexico. Marine Mammal Science 14:490-507.

Fleishman, E., R. Mac Nally, J. P. Fay, and D. D. Murphy. 2001. Modeling and predicting species occurrence using broad-scale environmental variables: an example with butterflies on the Great Basin. Conservation Biology 15:1674-1685.

Forney, K. A. 2000. Environmental models of cetacean abundance: reducing uncertainty in population trends. Conservation Biology 14:1271-1286.

Frost, K. J., and L. F. Lowry. 1990. Distribution, abundance and movements of beluga whales, *Delphinapterus leucas*, in coastal waters of western Alaska. Canadian Bulletin of Fisheries and Aquatic Sciences 224:39-57.

Gregr, E. J. and A. W. Trites. 2001. Predictions of critical habitat for five whale speceis in the waters if coastal British Columbia. Canadian Journal of Fisheries and Aquatic Sciences 58:1265-1285.

Guisan, A., and N. E. Zimmermann. 2000. Predictive habitat distribution models in ecology. Ecological Modelling 135:147-186.

Iverson, L. R., and A. M. Prasad. 1998. Predicting abundance of 80 tree species following climate change in the eastern United States. Ecological Monographs 68:465-485.

Hamazaki, T. 2002. Spatiotemporal prediction models of cetacean habitats in the mid-western north Atlantic Ocean (from Cape Hatteras, North Carolina, U.S.A. to Nova Scotia, Canada). Marine Mammal Science 18:920-939.

Hazard. K. 1988. Beluga whale, *Delphinapterus leucas*. Pages 195-235 in J. W. Lentfer, editor. Selected marine mammals of Alaska: species accounts with research and management recommendations. Marine Mammal Commission, Washington, D.C.

Hobbs, R. C., D. J. Rugh, and D. P. DeMaster. 2000. Abundance of belugas, *Delphinapterus luecas,* in Cook Inlet, Alaska, 1994-2000. Marine Fisheries Review 62:37-45.

Hooker, S. K., H. Whitehead, and S. Gowans. 1999. Marine protected area design and the spatial and temporal distribution of cetaceans in a submarine canyon. Conservation Biology 13:592-602.

Johnson, J. B., and K. S. Omland. 2004. Model selection in ecology and evolution. Trends in ecology and evolution 19:101-108.

Kleinenberg, S.E., A. V. Yablokov, B. M. Belkovich, and M. N. Tarasevich. 1964. Beluga (*Delphinapterus leucas*): Investigation of the species. Moscow: Akademii Nauk SSSR. (Translation from original Russian by Israel Program for Scientific Translations, Jerusalem, 1969.)

Laidre, K. L., K. E. W. Shelden, D. J. Rugh, and B. A. Mahoney. 2000. Beluga, *Delphinapterus leucas*, distribution and survey effort in the Gulf of Alaska. Marine Fisheries Review 62:27-36.

Legendre, P., and L. Legendre. 1998. Numerical Ecology. 2nd English edition. Elsevier, Amsterdam, The Netherlands.

Mendes, S., W. Turrell, T. Lütkebohle, and P. Thompson. 2002. Influence of the tidal cycle and a tidal intrusion front on the spatio-temporal distribution of coastal bottlenose dolphins. Marine Ecology Progress Series 239:221-229.

Moore, S. E. and D. P. DeMaster. 2000. Cook Inlet Belugas, *Delphinapterus leucas*: status and overview. Marine Fisheries Review 62:1-21.

Moore, S. E., K. E. W. Shelden, L. K. Litzky, B. A. Mahoney, and D. J. Rugh. 2000. Beluga, *Delphinapterus leucas*, habitat associations in Cook Inlet, Alaska. Marine Fisheries Review 62:60-80.

Moses E., and J. T. Finn. 1997. Using geographic information systems to predict north Atlantic right whale (*Eubalaena glacialis*) habaitat. Journal of Northwest Atlantic Fisheries Science 22:37-46.

Moulton, L. L. 1997. Early marine residence, growth, and feeding by juvenile salmon in northern Cook Inlet, Alaska. Alaska Fishery Research Bulletin 4:154-177.

Mulherin, N. D., W. B. Tucker III, O. P. Smith, and W. J. Lee. 2001. Marine ice atlas for Cook Inlet, Alaska. ERDC/CRREL TR-01-10, Cold Regions Research and Engineering Laboratory, Hanover, NH, for National Oceanic and Atmospheric Administration, Office of Response and Restoration, Seattle.

National Oceanic and Atmospheric Administration (NOAA) Electronic Navigation Charts (ENC). 2004. Office of coast survey, NOAA, ENC direct to GIS. Available from http://nauticalcharts.noaa.gov/csdl/ctp/encdirect_new.htm (accessed October 2004)

O'Corry-Crowe, G. M., R. S. Suydam, A. Rosenberg, K. J. Frost, and A. E. Dizon. 1997. Phylogeography, population structure and dispersal patterns of the beluga whale *Delphinapterus leucas* in the western Nearctic revealed by mitochondrial DNA. Molecular Ecology 6:955-970.

Palacios, D. M. 2003. Oceanographic conditions around the Galápagos Archipelago and their influence on cetacean community structure. Ph.D. Thesis, Oregon State University, Corvallis, Oregon.

Pearce J., and S. Ferrier. 2000. An evaluation of alternative algorithms for fitting species distribution models using logistic regression. Ecological Modelling 128:127-147.

Redfern, J. V., E. A. Becker, M. C. Ferguson, K. D. Hyrenbach, C. Good, K. Kaschner, K. A. Forney, L. T. Ballance, J. Barlow, M. Baumgartner, P. Fauchald, P. Halpin, T. Hamazaki, A. J. Pershing, S. Qian, A. Read, S. Reilly, L. Torres, and C. Werner. 2005 in review. Techniques for cetacean-habitat modeling: a review. Marine Ecology Progress Series.

Reilly, S. B., and P. C. Fiedler. 1994. Interannual variability of dolphin habitats in the eastern tropical Pacific. I: Research vessel surveys, 1986-1990. U.S. Fishery Bulletin 92:434-450.

Rugh, D. J., K. E. W. Shelden, and B. A. Mahoney. 2000. Distribution of belugas, *Delphinapterus leucas*, in Cook Inlet, Alaska, during June/July 1993-2000. Marine Fisheries Review 62:6-21.

Rugh, D. J., K. L. Laidre, K. E. W. Shelden, and B. A. Mahoney. 2001. Distributional changes in a declining beluga population. Abstract in the Fourteenth Biennial Conference on the Biology of Marine Mammals. Vancouver, B.C., Canada, Nov.28-Dec.3, 2001. Poster.

Rugh, D. J., B. A. Mahoney, and B. K. Smith. 2004. Aerial surveys of beluga whales in Cook Inlet, Alaska, between June 2001 and June 2002. NOAA Technical Memorandum NMFS-AFSC-145.

Rugh, D. J., K. E. W. Shelden, C. L. Sims, B. A. Mahoney, B. K. Smith, L. K. Litzky, and R. C. Hobbs. 2005. Aerial surveys of belugas in Cook Inlet, Alaska, June 2001, 2002, 2003, and 2004. NOAA Technical Memorandum NMFS-AFSC-149.

Schick, R. S. and D. L. Urban. 2000. Spatial components of bowhead whale (*Balaena mysticetus*) distribution in the Alaskan Beaufort Sea. Canadian Journal of Aquatic Fisheries Science 57:2193-2200.

Seaman, G. A., L. F. Lowry, and K. J. Frost. 1982. Foods of Belukha (*Delphinapterus Leucas*) in Western Alaska. Cetology 44:1-19.

Seaman, G. A., K. J. Frost, and L. F. Lowry. 1988. Investigations of belukha whales in coastal waters of western and northern Alaska. Part I. Distribution and abundance. U.S. Department of Commerce, NOAA, OCSEAP Final Report 56:153-220.

Sergeant, D. E., and P. F. Brodie. 1975. Identity, abundance, and present status of populations of white whales, *Delphinapterus leucas*, in North America. Journal of the Fisheries Research Board of Canada 32:1047-1054.

Sieg, C. H., and D. M. Becker. 1990. Nest-site selected by Merlins in southeastern Montana. The Condor 92:688-649.

Smith, T. G., D. J. St. Aubin, and J. R. Geraci. 1990. Research on beluga whales, *Delphinapterus leucas*: Introduction and overview. Pages 1-6 in T. G. Smith, D. J. St. Aubin, and J. R. Geraci editors. A Canadian Bulletin of Fisheries and Aquatic Sciences 224.

Smith, T. G., and A. R. Martin. 1994. Distribution and movements of belugas, *Delphinapterus leucas*, in the Canadian High Arctic. Canadian Journal of Fisheries and Aquatic Sciences 51:1953-1663.

St. Aubin, D. J., T. G. Smith, and J. R. Geraci. 1990. Seasonal epidermal moult in beluga whales (*Delphinapterus leucas*). Canadian Journal of Zoology 68:359-367.

Stoms, D. M., F. W. Davis, C. B. Cogan, M. O. Painho, B. W. Duncan, J. Scepan, and J. M. Scott. 1993. Geographic analysis of California Condor sighting data. Conservation Biology 7:148-159.

Swets, J. A. 1988. Measuring the accuracy of diagnostic systems. Science 240:1285-1293.

Thuiller, W., M. B. Araujo, and S. Lavorel. 2003. Generalized models vs. classification tree analysis: Predicting spatial distributions of plant species at different scales. Journal of Vegetation Science 14:669-680.

Torres, L. G., P. E. Rosel, C. D'Agrosa. 2003. Improving management of overlapping bottlenose dolphin ecotypes through spatial analysis and genetics. Marine Mammal Science 19(3): 502-514.

United States Geological Survey (USGS). 2004. Seamless data distribution system, national center for earth resources observations and science (EROS), Sioux Falls. Available from http://seamless.usgs.gov/website/Seamless/ (accessed December 2004)

United States Geological Survey (USGS). 2005. National hydrographic dataset (NAD) data availability. Available from http://nhd.usgs.gov/data.html (accessed September 2004)

Venables, W. N., and B. D. Ripley. 1997. Modern applied statistics with S-PLUS. 2nd edition. Springer, New York.

Waring, G. T., T. Hamazaki, D. Sheehan, G. Wood, and S. Baker. 2001. Characterization of beaked whale (*Ziphiidae*) and sperm whale (*Physeter macrocephlus*) summer habitat in shelf-edge and deeper waters off the Northeast U.S. Marine Mammal Science 17:703-717.

Withrow, D.E., K.E.W. Shelden, and D. J. Rugh. Beluga whale (*Delphinapterus leucas*) distribution and abundance in Cook Inlet, summer 1993. Annual report to the MMPA Assessment Program, Office of Protected Resources, NMFS, NOAA.

Woodley, T. H., and D. E. Gaskin. 1996. Environmental characteristics of North Atlantic right and fin whale habitat in the lower Bay of Fundy, Canada. Canadian Journal of Zoology 74:75-84.

Appendix 1. Calculated flow accumulation values for tributaries entering Cook Inlet

River Name	*Flow Accumulation*
Seven Egg Creek	12
Otter Creek	16
Drift River	17
Seldovia Slough	21
Stonehocker Creek	33
Wrong Branch trail Creek	35
Little Indian Creek	72
Little Kamishak River	72
Cottonwood Creek	85
Seal River	86
Theodore River	100
Little Polly Creek	144
Fish Creek	153
Bedlam Creek	184
Middle River	194
Red River	264
Cannery Creek	447
Kustatan River	490
Right Arm Creek	761
Marsh Creek	768
Polly Creek	954
Porcupine Creek	2153
Silver Creek	2598
Big Indian Creek	2674
Douglas River	2674
Indian Creek	2901
Ivavn River	3732
Grewingk Creek	3842
Chickaloon River	3888
Bear Creek	4330
Sheep Creek	4583
Johnson Slough	5047
Sixmile Creek	5080
Maquire Creek	5212
Potter Creek	5427
Virgin Creek	6173
Chakachatna River	8821
Rabbit Slough	8830
Little Jack Slough	8860
Threemile Creek	9246
Chinitna River	9397
Mikfik Creek	9716
Jakolof Creek	9802
Pincher Creek	10669
Portage Creek	11497
Montana Bill Creek	11994
Difficult Creek	13122
Bear Creek	13945
Old Tyonek Creek	14667
Hungryman Creek	15718
Sunday Creek	16143
Bowser Creek	17518
Iniskin River	17556
Tyonek Creek	19335
Rabbit Creek	19536
Indian Creek	21016
Martin Creek	21073
Fritz Creek	22950
Brown Creek	24409
Seattle Creek	24649
Middle Glacier Creek	24945
Clearwater Creek	25238
Fire Creek	25744
Lewis River	27213
Barbara Creek	27224
Open Creek	27481
Halibut Creek	28455
English Bay	28669
Ingram Creek	28735
Susitna River	32847
Seldovia River	34324
Fox Creek	34590
Matanuska River	35455
Campbell Creek	35883
East Glacier Creek	38425
Amakdedori Creek	39212
Bishop Creek	39320
Nikolai Creek	43915
Goose Creek	44553
Battle Creek	55301
Harriet Creek	57457
Humpy Creek	67605
Portage Creek	71204
Stariski Creek	75571
Glacier Creek	77160
Rodoubt Creek	95237
Bird Creek	103919
Chester Creek	112141
Bradley River	118200
Peters Creek	121627
McNeil River	139487
Johnson Creek	142308
Placer River	164625
Ship Creek	172359
West Glacier Creek	208212
Resurrection Creek	217065
Chuitna River	219695
Twentymile River	222049
Fish Creek	223668
Eklutna River	241378
Paint River	244522
Ninilchik River	252079
Anchor River	272212
Deep Creek	279107
Swanson River	280464
Eagle River	333134
Cresent River	347738
Sixmile Creek	363583
Kamishak River	392122
Texedni Creek	411268
Fox River	416798
Big River	488971
Little Susitna	530798
McArthur River	553770
Kasilof River	1066736
Beluga River	1457214
Kenai River	2865271
Knik River	4723468
Susitna River	28411330

Appendix 2. Summary statistics on flow accumulation values.

Minimum	12.0
1st Quartile	5063.5
Mean	404959.7
Median	25238.0
3rd Quartile	140897.5
Maximum	28411330.0
Total N	119.0
Standard Deviation	2642824.0

Appendix 3. DOCELL script used to map logistic regression results

```
if((DISTMUDi<2720.5) and (DISTMED<11500.5)) dl_hab = 1
else dl_hab = 0
end
END
```